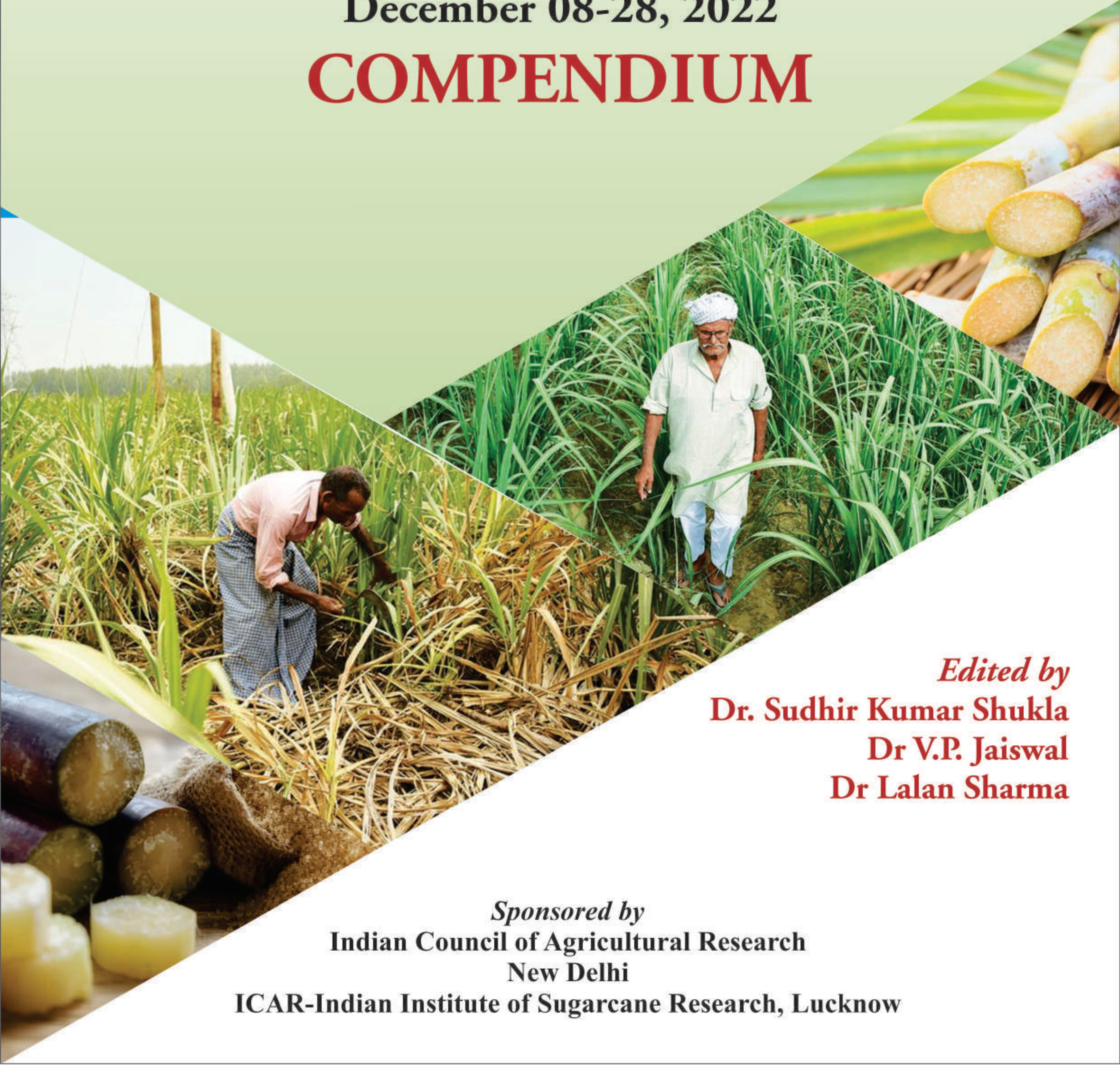
G20
भारत 2023 INDIA
वसुधैव कुटुम्बकम्
ONE EARTH • ONE FAMILY • ONE FUTURE

ISO 9001 : 2015

WINTER SCHOOL
on
Recent Approaches for Doubling Farmers Income in Sugarcane Based Cropping System

December 08-28, 2022

COMPENDIUM



Edited by
Dr. Sudhir Kumar Shukla
Dr V.P. Jaiswal
Dr Lalan Sharma

Sponsored by
Indian Council of Agricultural Research
New Delhi
ICAR-Indian Institute of Sugarcane Research, Lucknow

वसुधैव कुटुम्बकम्
ONE EARTH • ONE FAMILY • ONE FUTURE

WINTER SCHOOL

On

Recent Approaches for Doubling Farmers Income in Sugarcane Based Cropping System

December 08-28, 2022

COMPENDIUM

Edited by
Dr Sudhir Kumar Shukla
Dr V.P. Jaiswal
Dr Lalan Sharma

Sponsored by
Indian Council of Agricultural Research
New Delhi

ICAR-INDIAN INSTITUTE OF SUGARCANE RESEARCH, LUCKNOW

CONTENTS

C. Crop Production Technologies and soil carbon management

Chapter No. 1: Sustainability of Indian Sugar Industry: Product Diversification

S. Solomon
Former Director, Indian Institute of Sugarcane Research, Lucknow
Former Vice Chancellor, CSA University of Agriculture & Technology, Kanpur
Email: presidentssrp@gmail.com

Abstract

Sugarcane is an excellent biomass feed stocks for renewable fuel and green energy, apart from several other main and by-products. The fluctuating sugar markets, the demand for alternative bio-based fuels and increased consumer demands for bio-based products are significant factors that drive the global sugar industry towards diversification for sustainability. With a high biomass and high conversion efficiency, sugarcane has emerged as a very attractive option for diversification to bio-based products.

The Indian sugar industry plays a leading role in global sugar market being the world second largest producer after Brazil, producing nearly15 and 25 per cent of global sugar and sugarcane respectively. The sugar industry is inherently inclusive with the crop occupying around 5.2 million hectares, i.e. 2.57% of the gross cropped area and supporting over 12 million farmers and their families, along with workers and entrepreneurs of over 550 sugar mills. The Indian sugar sector has recorded phenomenal growth in the last two decades with a record production of sugar (35.8 MMT in 2021-22). Sugarcane production reached a peak (>400 MMT), with the highest cane productivity (80.2 t/ha) in 2020-21 and national average sugar recovery touching 11.01% in 2018-19. The per capita white sugar consumption also increased from 4.8 kg/year (1960) to 18.8 kg/ha (2020) recording an almost four-fold increase. The country's vast network of 525 working sugar factories, 400 distilleries, 365 co-gen units and the many open pan jaggery & *khandsari* units is dependent on 340-370 MMT sugarcane produced annually by over 55 million cane farmers. The industry, besides producing 30-32 MMT white sugar, also generates over 4.3 billion liters of alcohol, 7650 MW of power, 6-8 MT *jaggery* and many "green" chemicals and bio-products. India is the second largest exporter of sugar (11.0 MMT in 2021-22). Sugar industry is also contributing to Government of India initiative of E20 Ethanol Blending Program by diverting 3.5 MT sugar equivalent (2021-22) in addition to B & C heavy molasses, syrup and cane juice, for bio-ethanol production. The Indian sugar industry has been capable of meeting the sweetener and energy demand of the nation and to a great extent, has become self-reliant, showing the path to the other countries in building a productive, profitable and sustainable industry. The contemporary sugar sector is in a privileged position where it has the potential to influence several key Sustainable Development Goals (SDGs) through practicing climate resilient green technologies in production and processing and several diversification options such as ethanol, cogeneration of energy using sugarcane bagasse and bio-based products. This sector has also emerged as a significant carbon credit and power producer and support highly ambitious ethanol blending programme of Government of India of E 20 and beyond.

During the last one decade, Indian sugar industry has demonstrated unique potential to produce more than 35 million tonnes of sugar subject to the availability of sugarcane. In the previous crushing season (2020-21) favorable environment for sugar exports and Government of India's proactive policy of Ethanol Blending Program and financial position of the sugar industry was sound. In spite of historic production of 35.5 million tonnes of sugar, more than 9 million tonnes was exported including raw sugar leaving balance of around 27 million tonnes for domestic consumption. In addition, around 3.5 million tonnes of equivalent sugar was diverted for production of ethanol which is likely to go up to 5.0 MT in near future. . All these developments resulted in keeping the sugar price steady and stable in the domestic market. The real task before the sugar industry is how to create a space for India as an exporting nation at global level and this is a formidable task. Therefore, the sugar industry will have to explore the different areas to strengthen financial conditions of all stakeholders in the industry. In this regard, export, and diversification programs are very crucial for economically sustaining the Indian sugar industry. In view of the present status of cane cultivation in the country, future requirement of cane (Vision 2050) and the national commitment to food security and requirement of land for food grains, it is clear that there are limitations to increase the area under sugarcane in near future and the only way forward is to increase the productivity per unit of land (>110 tons/ha/yr)and take steps to enhance the sugar recovery (>11.50 % cane).

Sugarcane products diversification

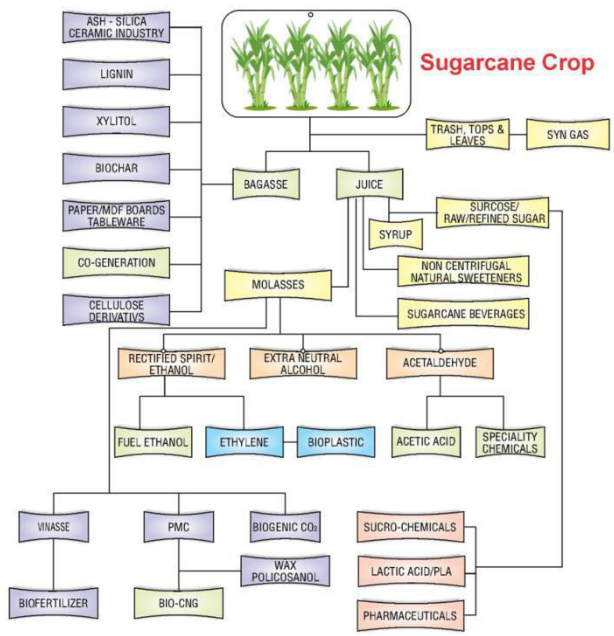
Sugarcane can be considered as the best green crude for a bio-based industry, giving rise to an efficient and sustainable bio-based economy. The C_4 route of photosynthesis taking place in the plant, suitability to the tropical environments, ready-to-use source of soluble carbohydrate, the utilization of the whole crop as source of various products, with a very positive energy balance and the lowest carbon foot print etc., make this crop the best choice for an efficient bio-based economy. Sugarcane provides the raw material for food, fodder, bio-fuel, green energy, bio ethanol, bio-plastics, bio-detergents, bio-molecule coated fabrics etc. The textiles industry also makes use of bagasse based products for manufacturing nature friendly garments.

Co-generation: Co-generation has provided a good and stable platform for generation of income. Moreover, the electricity from co-generation is available when there is high demand for electricity, secondly the project cost of co-gen. is much less than the thermal electricity project. Therefore, the co-gen. projects are economically and environmentally more friendly and sustainable. The largest sugarcane producing countries Brazil and India have well established system of bagasse-based co-generation, that generate energy at a commercial scale. At a global level, the potential for bagasse-based cogeneration has been estimated to be 135029 Gwh per year. India's has around 365 cogeneration units with a cumulative installed exportable capacity of 7650 MW, with modernization of the new and existing sugar mills country has potential to generate surplus power across all sugar factories in India.me. Currently, solar energy is being harnessed on a large scale. It is cheaper and also based on renewable source. The solar energy will prove to be more economic and competitive to co-gen. The sugar industry in future may opt for solar energy project rather than co-gen. project and this will be a welcome change and raw material-bagasse used for co-gen will be used in better ways for other by-products. Gradual introduction of solar energy is a welcome move to strengthen financial health of sugar mill.

Bioethanol: Considering the import of crude in 2021, the Government of India has spent around 55 billion dollars to meet about 77%of the requirement of the crude oil. The Government decided to reduce the import by 10% in the current year. It is also planned that EBP should achieve 20% target. This ethanol blending program is a huge opportunity for the sugar sector to explore a new avenue for financial stability. The Central Government's proactive policy will certainly enable sugar sector to gear-up for a profitable economic pursuit. The present system of using C-Molasses will be no longer relevant for production of ethanol. Now industry has demonstrated that ethanol from B-Heavy is not only profitable but a sizable quantity of sugar can be diverted for ethanol. The Central Government's permission to use syrup for ethanol is an added advantage. Therefore, the Government will have to be persuaded to take a policy decision that the ethanol from C-heavy should be stopped forthwith and ethanol production from B-Heavy and syrup/ sugarcane juice should be encouraged. The most important concern in this program is the capacity of distilleries which is very small. The present capacity of all the distilleries is 7000 million liters of which, around 80% is used for production of ethanol. In order to produce 12,000 million liters alcohol in 2025, the distillery production capacity should be around 15,000 million liters.India will have to follow Brazilian model where capacity of distilleries is much more and diversification of sugar production to ethanol production is very easy. The Central Government is very positive in ethanol production and blending program. At this hour, oil producing companies and banks should also be positive. The banks should give sufficient credit and oil producing companies need 60 to enter into a long term agreements to bring about the stability in production. The success of ethanol blending program will ensure diversification of sugar to ethanol, reduce undesirable sugar stock, reduce the inventory and help ensure payment to cane growers. The use of 20% ethanol blended petrol will save sizable foreign exchange. Based on 3 pillars of sustainability, namely economic, environment, and social aspects, waste generated from sugarcane and processing, can be put back into the economy through options of reuse, recycling or remanufacturing.

Paper, packaging material: These are already being manufactured from bagasse at a commercial level. Newsprint, ordinary writing paper, packing material, and cardboard are made, making use of varying process technologies. This assumes importance especially in the present context of shortage of other raw materials like wood and bamboo. In India Tamil Nadu News Prints Ltd (TNPL), in Tamil Nadu state produces eco-friendly papers from sugarcane-bagasse at a commercial scale. Different grades of papers, paper boards etc., are being manufactured. Other paper manufacturing firms are also producing bagasse based paper and boards and other related products at a commercial scale.

Chemical derivatives from bagasse & molasses: Bagasse forms the source of several chemicals and pharmaceuticals. Lignin, an important constituent of bagasse has a high binding capacity to nitrates, bile salts, mineral salts, carcinogenic substances and also to some pathogenic microorganisms. This binding capacity has been exploited in developing many useful chemical derivatives. LIGAMED –A therapeutic for treating digestive disorders, Furfural a selective solvent in refining oils, Furan-based chemicals and furfuryl alcohol, furanic polymers and furanic pesticides are some of the chemicals. Pharmaceuticals like Furazolidone and diloxanide furoate have antibacterial properties. Furfurilic alcohol, another product from bagasse, is a source of a large number of useful compounds. Sucrolin, α-Cellulose, a highly purified form of cellulose, xyliytol etc., are some other products from sugarcane bagasse. Bagasse-based pesticides also form an agriculturally important product .At National Sugar Institute, Kanpur, India, bagasse based detergent has been developed at a laboratory scale. It is claimed to be eco-friendly with no chemicals being used and the cleaning of clothes are done in a very efficient way, with no damage to texture or colour. Besides, the reports say that the detergent requires less water for washing clothes and is not harsh on fabric. One kilogram of bagasse detergent could be produced from raw material that costs just Rs 20. Efforts are on to produce the detergent at a commercial scale.



Several chemicals are produced from molasses which have wide applications. Not all these are being synthesized and utilized at a commercial scale but some of these are already manufactured on a large scale. Some of the molasses derived chemicals are dextran, sorbitol, lactic acid, oxalic acid, tartaric acid, maleic and fumaric acid, citric acid, succinic acid, glycerol, Mono Sodium Glutamate (MSG), L-lysine, β- Carotene, Butanol ,acetone aconitic acid and itaconic acid. Ephedrine hydrochloride, an ingredient of cough syrups is produced from molasses at a commercial level in some countries including India. Phytohormones like cytokinin are also produced from molasses. In Cuba, explosives using cane molasses and ammonium nitrate have also been manufactured as a bio-product from sugarcane.

Bio-plastics from ethanol: Ethanol produced from sugarcane molasses can be converted to ethylene and then to polyethylene, a very widely used form of plastic. Sugarcane bagasse is also found to be plasticized by modification with phthalic anhydride. Even though the bioplastic industry is slowly picking up, several manufacturers have already established themselves are important players in this field. AT&T in US initiated the use of plant-based packaging, with 30% of the material sourced from sugarcane-based ethanol. In Brazil several companies are already manufacturing bioplastics at commercial scale.

Bio-gas and Bio-CNG: Compressed bio-gas is another source of bio-energy from sugar industry, which has a significant role in bringing in self-reliance in the energy sector for the country. The anaerobic digestion of filter cake results in the production of bio-gas/compressed bio-gas. Approximately 1 kg of CNG can be produced from 25 to 30 kg of filter cake, which makes the process lucrative. Apart from providing bio-energy this is a value-addition of the industry by-product. Out of the total compressed bio-gas potential of the country (approximately 62.0 million tons), around 3% (around 2.0 million tons) can be produced from sugar industry by-products like spent-wash/filter cake/press mud. Spent wash/vinasse, an effluent from ethanol production process can also be a valuable source of bio-energy. It is estimated that around 500 MW power can be produced from the present available alcohol production (3000 million litres in a year).

Bio-products fom sugarcane are expected to be a significant part of the shift to bio-economy. As of now, apart from sugars and sweeteners, the production and utilization of other products have not reached a commercial scale in many countries, except for bio-ethanol and bagasse-based co-generation. Bagasse-based cogeneration has picked up at a commercial scale in most of the sugar producing countries in Asia. The paradigm shift from "Biomass is free and it has little commercial value" to "Biomass is precious with high commercial value" has been brought about by fossil-fuel crisis and climate change effects. However, it is also necessary to start thinking of what can be beyond ethanol, sugar and co-generation for the sugar sector. Fortunately, the sugar industry also generate plenty of biomass/wastes in the form of pressmud cake (PMC), sugarcane bagasse (SCB), sugarcane trash (SCT), spentwash (SW) etc. It is desirable that each and every part of sugarcane crop as well as the wastes generated are valorized effectively. The sugar industry has a potential to produce 0.375 million tonnes of CBG per annum with a revenue of Rs.17000 million per annum. India is the fourth biggest consumer of potash after China, Brazil and USA and is a net importer. Potash recovery from incineration boiler ash will save foreign exchange. Considering the valorization potential of SCB, cogeneration is not the best option under the changing scenario of availability of low cost electricity from alternate source. SCB and SCT can be valorized to form several value added products such as 2G bio-butanol, sustainable aviation fuels (SAF). CBG and chemicals such as lactic acid, succinic acid, gluconic acid, xylitol, lignin derivatives, potash based fertilizers etc. through a bio-refinery approach which can play an important role in county's energy requirement in future.

Literature reviewed

Solomon,S and Swapna.M (2022) Indian Sugar Industry: Towards Self-reliance for Sustainability. *Sugar Tech* volume 24, pages630–650 (2022)

https://www.niti.gov.in/sites/default/files/2021-08/10_Report_of_the_Task_Force_on_Sugarcan%20 and_Sugar_Industry_0.pdf

Chapter No. 2: Varietal degeneration in sugarcane in India and its management

Dr. R. Viswanathan
Director, ICAR-Indian Institute of Sugarcane Research, Lucknow
E-mail: r.viswanathan@icar.gov.in

Abstract
Vegetative propagation in sugarcane favours accumulation of pathogens inside the canes and carryover of pathogenic inoculum through planting materials. Disease-infected setts serve as a primary source for disease spread for most of the diseases in the crop, except foliar diseases. In case of fungal diseases, planting infected setts leads to disease builds up in plant crop and probably death of the affected clump. However, in case of non-fungal diseases continuous accumulation of pathogens systemically leads to loss of vigour in sugarcane varieties referred to as 'varietal degeneration' and this result in loss of yield potential in elite commercial varieties. Previous decades witnessed many such instances of degeneration in popular sugarcane varieties and their replacement with new ones. With the development of sensitive molecular diagnostic tools the associated pathogens are being precisely identified. Under Indian conditions, it was found that combined or separate infections of viruses causing mosaic and yellow leaf disease (YLD), phytoplasmas causing grassy shoot and leaf yellowsand bacterium causing ratoon stunting disease (RSD) are associated with varietal degeneration. The degeneration was rapid and severe when all these pathogens infect sugarcane together as compared to their separate infections. However, among all these diseases, YLD contributes more towards degeneration of sugarcane varieties. The disease occurrence to epidemic levels in different states is a serious concern for sugar industry and due to that longevity of the affected varieties in the field is threatened. Meristem-tip culture combined with hot water treatment and molecular diagnosis was found effective to detect and free the cane from these pathogens. Developing disease-free nurseries is imperative to sustain productivity of sugarcane and to realize yield potential of popular sugarcane varieties in India.

Introduction
More than 50 diseases caused by fungi, bacteria, virus, phytoplasma and nematode are reported to infect sugarcane in India and other countries (Rao et al., 2002; Rott et al., 2000). Red rot caused by *Colletotrichumfalcatum* had been a serious threat to sugarcane cultivation in the Subcontinent for the more than a century and it is responsible for the elimination of many commercial varieties (Viswanathan, 2021a). During each epidemic,the crop was saved by releasing new varieties with red rot resistance. Although the efforts were continued, the pathogen remained dominant and determined varieties under cultivation in the red rot endemic areas of subtropical plains, East Coast regions and Gujarat. Although other fungal diseases like smut and wilt were not destructive as like red rot they have also played a decisive role in varietal selection for cultivation in certain regions. The diseases caused by viruses, bacteria and phytoplasmas were never considered as threats to sugarcane cultivation in the country.However, these non-fungal pathogens associated with yellow leaf disease (YLD), mosaic, grassy shoot and ratoon stunting disease (RSD) systemically infect sugarcane. Over the years, such systemic accumulation of these pathogens reduces cane and sugar yield. In contrast to fungal diseases, where very severe losses to crop yield are expected in the field, these non-fungal pathogens in sugarcane causes gradual decline in varietal performance. Although these viral/ bacterial pathogens cause limited symptoms in the field, continuous vegetative propagation results in enhanced pathogen titre that would increase the pathogenic potential to cause severe symptoms. Combined infection of viral/bacterial/phytoplasmalpathogens accelerates the damage to the crop and this is due to infection of one pathogen making the plant more susceptible to another. In this way, a variety degenerates faster and its potential comes down in the field after some years in the field. This phenomenon is referred to as 'varietal degeneration' in sugarcane (Viswanathan and Padmanaban 2008). The popular cv Co 419 degenerated in the past due its high susceptibility to mosaic, YL and RSDin Karnataka state. Similarly the cvs Co 740 and CoC 671 popular varieties of tropical region degenerated due their high susceptibility to

mosaic and YLD in different parts of Karnataka and Maharashtra. The cv Co 86032 has replaced them in large areas in these states due to their degeneration. The author has conducted extensive studies on varietal degeneration by taking up systematic studies on the associated pathogens, characterized the pathogens and developed management strategies in the country (Viswanathan 2016, 2018, 2021b). The lecturecritically analyses the factors contributing to varietal degeneration in sugarcane due to non-fungal diseases, their diagnosis and management.

Spectrum of virus(es) infection in sugarcane

YLD caused by Sugarcane yellow leaf virus (ScYLV) and mosaic caused by Sugarcane mosaic virus (SCMV) and Sugarcane streak mosaic virus(SCSMV) are the major viral diseases in India. Detailed studies were taken up on the prevalence of these viruses in varieties originated from 11 different states in the country through RT-PCR revealed that 93.44% of varieties were infected with SCSMV, 31.15% with SCMV and 27.87% with ScYLV. Of the 61 varieties, 47.5% were infected with SCSMV alone, 3.28% with SCMV alone and 4.92% with SCSMV alone. However, 21.3% of them had combined infections of SCSMV and SCMV and similarly 16.4% of them had combined infections of SCSMV and ScYLV. About 6.5% had mixed infections of all the three viruses. Overall, the assay results indicated that SCSMV is predominant among the three viruses and it has been found as a major causative virus of sugarcane mosaic (Viswanathan and Karuppaiah 2010). This study also revealed extensive spread of these viruses in sugarcane varieties practically and none of them is free from any of the viruses. Leaf fleck caused by Sugarcane bacilliform virus (SCBV) is a lesser known disease of sugarcane in India. Recent PCR assays with 28 samples for SCBV revealed that the virus is amplified in 75.0% of the samples. Among them 89.5% were commercial cultivars, which revealed that majority of the varieties under cultivation,having the virus infection (Viswanathan and Rao, 2011). Although impact of this virus on sugarcane growth was not established, it occurs widespread in the field suggests that it may become a threat in future years (Viswanathan et al. 2019).

Impact of YLD on sugarcane

Earlier studies conducted at ICAR-Sugarcane Breeding Institute (SBI), Coimbatore indicated that drastic reduction in number of millable canes in sugarcane cvs Co 6511, Co 86032, CoS 687 and CoV 92101 due to ScYLV infection (Viswanathan et al., 2006). Previously, Viswanathan (2002) showed that the disease infection results in reduction in cane diameter and photosynthetic rate in most of the affected varieties. However, the reduction was significant in cvsCoS 510, CoS 767, CoS 8407 and Co 775. In endemic locations of South India such as Tamil Nadu, Karnataka and Andhra Pradesh diseased canes recorded 37.23% reduction in cane weight, 15.25% in diameter, 5.03% in intermodal length and 19.45% in juice yield from cane (Viswanathan and Rao, 2011).Recent studies of Viswanathan et al. (2014) assessed physiological parameters in symptomatic and asymptomatic plants of 10 different cultivars and a genotype and established that among several physiological parameters, photosynthetic rate (A), stomatal conductance (gs) and SPAD metervalues were significantly reduced in cultivarsseverely infected with ScYLV. Virus-infected varieties recorded significant reductions in growth/yield parameters, such as stalk height,stalk thickness and number of internodes. In addition to reductions in stalk weight, height and girth, ScYLV infectionalso reduced juice yield in the affected canes up to 34.15%.

Under field conditions the major impact on YL infection was found on cane thickness and height in sugarcane. Fresh weights of comparable internodes of the infected plants are only 20-65% of the weight of healthy plants. It is estimated that severe infection of the virus reduces cane yield by 30 to 50 % and sugar recovery is reduced significantly in the mills (Viswanathan, 2012a). Since the loss caused by the disease is phenomenal in the field as well as in the mills, both the cane growers and millers suffer due to the disease.Globally impact of the disease on sugarcane growth and yield has been well documented. ScYLV-infected asymptomatic plants showed CO_2 assimilation rates and stomatal conductance 10-30% lower than healthy plants, and water relations resembling those of salinity- and drought-stressed plants (Lehrer and Komor, 2009). In addition, reductions were found in the contents of photosynthetic leaf pigments and in the chlorophyll a/b ratio (Gonçalves et al. 2005) along with ultrastructural changes in Krans cell chloroplasts (Yan et al. 2009). Carbohydrate content in the leaves also increased as a secondary effect of the ScYLV infection, suggesting a reduction of assimilate export in infected plants. The virus affects total reducing sugars, leaf areas and chlorophyll content and sugar transport (Fontaniella et al. 2003, Izaquirre-Mayoral et al., 2002; Gonçalves et al. 2005, Lehrer et al. 2007). Overall, asymptomatic plants suffer a yield decline of 10-30% depending on cultivar and ratoon cycle (Lehrer et al., 2007; Grisham et al., 2009; Rassaby et al., 2003).

Although the disease was there in different parts of India for more than 10 years, its prevalence are ignored probably due to leaf mid rib yellowing is thought to be a phenotypic character in leaves. The epidemic occurrence of the disease has taken a toll on many varieties without being noticed by the concerned people that the poor performance of the varieties is due to YLD.In ratoon crop, the intensity of the disease will be much higher than in plant crop. However, when YLD-infected planting materials are used for planting, the disease expresses in the plant crop and the disease severity in ratoons will be much more than expected.

Impact of mosaic

In India, the presence of this disease in sugarcane was first authenticated by Barber (1921), since then its widespread occurrence was reported from all the sugarcane growing tracts in the country. Despite, mosaic is not a major problem in some countries; it has caused substantial yield losses in other countries by severe outbreaks of the disease (Koike and Gillaspie, 1989). Advancements made in diagnosis of the viruses through serological and molecular techniques led to precise diagnosis of the virus(es) and established the losses with more assurance and authority. Koike and Gillaspie(1989) observed that the yield loss due to mosaic does more pronounced as the virus/viral strains remains in infected cane for generations which leads to decline in cane yield and sucrose content.Varietal degeneration due to mosaic is a serious concern that results in near extinction of elite cultivars from cultivation as witnessed to the erstwhile ruling varieties in the tropical region (Viswanathan and Balamuralikrishnan, 2005) and in the subtropical region (Singh *et al*., 2003) in India.Earlier, Agnihotri (1996) reported appreciable damage caused by SCMV in susceptible varieties and observed that even 10-15 per cent yield loss due to this disease is highly significant because of extensive cultivation of the crop. Virus infection significantly reduced the net CO_2 assimilation rate during the grand growth period. At harvest, cane stalks from virus-infected plots recorded a significant reduction in cane diameter, cane weight and number of internodes. Results of juice analysis revealed that virus infection reduced brix, sucrose per cent, purity and commercial cane sugar per cent in both sugarcane varieties. Overall, the study has established a clear impact of mosaic on sugarcane growth and yield in the popular varieties (Viswanathan and Balamuralikrishnan 2005).

Combined infections of RSD and sugarcane viruses

The RSD pathogen colonies xylem vessels which conducts water and minerals from root to leaves when bacterial colonization increases inside the vessels, the sap movement is restricted. Similarly ScYLV colonizes sieve tube elements systemically affecting movement of photosynthates from leaves to other tissues. Such impairment in vascular system directly affects various metabolic processes, photosynthesis and transpiration in the plant. Although the pathogen does not affect these processes directly, its effect on water/nutrient movement to various tissues indirectly cause moderate to severe impairment to plant growth and metabolism when sugarcane is infected either by ScYLV or bacterium, severe impact on cane growth and yield is expected. Such combined infections cause comparatively more severe impact on plant growth and development (Viswanathan, 2004a). This type of varietal degeneration due to combined infections of more pathogens was demonstrated in many varieties by comparing the growth in disease free and disease infected planting materials.

Agnihotri (1990) observed that a synergy between SCMV and RSD also exists and greater losses are incurred when sugarcane is infected with both the pathogens simultaneously than their separateinfections. Since occurrence of YLD was not known that time it may be difficult to relate its association with varietal degeneration recorded before 1990s.Decline in varietal performance over the years in the popular varieties is mainly due to accumulated pathogens inside the stalk affecting cane growth and photosynthetic efficiency, which directly results in reduced cane yield and sugar yield. Although these viral/ bacterial pathogens cause limited symptoms in the field, continuous vegetative propagation results in enhanced pathogen load that would increase the pathogenic potential to cause disease. Combined infection of two or more viral/bacterial pathogens accelerates the damage to the crop in the field and this is due to infection of one pathogen makes the plant more susceptible to another. In this way, a variety degenerates faster and its potential comes down over the years.

Recently, Bagyalaksmi et al. (2019) have demonstrated severe degeneration caused by combined infections of SCMV, SCSMV and ScYLVin the popular cvCoJ 64. Symptomatic plants of the variety exhibited significant reductions in germination and growth as compared to the asymptomatic plants and maintained a poor vigour. Such plants recorded significant reductions in different physiological parameters such as photosynthetic rate, stomatal conductance, transpiration rate, chlorophyll fluorescence ratio and leaf chlorophyll content. A drastic reduction in the juice yield by 30.13 - 36.04% was found at the time of harvest. Further the study established a threshold limit of three RNA viruses causing varietal degeneration in sugarcane.

Phytoplasmas diseases in sugarcane

Many phytoplasma diseases infecting sugarcane such as grassy shoot, white leaf, green grassy shoot and leaf yellows were reported worldwide (Rott et al., 2000). Of them, grassy shoot caused by sugarcane grassy shoot (SCGS) phytoplasma has been reported to cause severe impact on cane growth and yield throughout the country. Very high yield losses due to grassy shoot were reported in India for many years(Viswanathan, 2000, Nithya et al. 2020a). Ratoon crops always record severe symptoms of the disease with more impact and due to increase in pathogen load. Studies conducted at SBI showed that phytoplasma infection can cause 35% reduction in stalk height, 15% reduction in stalk girth, 50-60% reduction in length of internodes. Above all 50-75% plant crop infection resulted in 100% failure in millable cane production in the ratoon crop of a clone ISH 152 (Viswanathan, 2000).Kumar et al. (2015) reported on the association of 16SrI-B subgroup phytoplasma associatedwith Sugarcane leaf yellows in the country. The disease has been reported in a severe form on the popular varieties CoLk 94184 and CoSe 92423 in Uttar Pradesh. Since YLD and leaf yellows cause almost similar symptoms in sugarcane there could be combined infections of ScYLV and leaf yellows phytoplasma in sugarcane. However, detailed studies on the associated pathogen(s) of YLD with diverse varieties revealed that only ScYLV is associated with the disease no sugarcane leaf yellowsphytoplasma is found in the country. The associated phytoplasma was found to be of SCGS-phytoplasma (Nithya et al. 2021b) and in cases of phytoplasma association, GSD expression symptom was not found probably due to low pathogen titre.

Diagnosis of sugarcane pathogens through serological and molecular techniques

In the past, ELISA has been extensively used for the diagnosis of Lxx infection in sugarcane (Viswanathan, 1997, 2001). Further, sensitivity of ELISA was compared with dot-blot and tissue blot assays and the results revealed that ELISA and TBIAwere equally effective it detecting Lxxand were more efficient than DBIA (Data not shown). Several variations in serological techniques were developed and used in different countries to develop RSD-free planting materials (Bailey et al., 1994, Croft et al., 1994, Hoy et al., 1999, Viswanathan, 2004b, Young and Brumbley, 2004). PCR assays were also developed for Lxx diagnosis in sugarcane (Fegan et al., 1998; Taylor et al. 2003). Although PCR technique is more sensitive, inhibitors found in the sap continue to limit its sensitivity (Grisham, 2004).Association of the virus with YL was established through DAS-ELISA technique at SBI, Coimbatore (Viswanathan, 2002; Viswanathan and Balamuralikrishnan, 2004). Later RT-PCR techniques were found to be more sensitive to detect SCYLVbefore symptom expression and in tissue culture raised plants (Viswanathan *et al.*, 2008a, 2009). Assays were also developed to detect more than one virus in a reaction through duplex and multiplex-RT-PCRs (Viswanathan et al., 2008b, 2010,Xie *et al.,* 2009). In addition to the viruses, PCR assays were developed to detect phytoplasmas associated with grassy shoot and leaf yellows (Rao et al., 2008, 2012, 2014, Kumar et al., 2015, Viswanathan et al., 2005). Recently RT-LAMP assays were developed to detect RNA viruses of sugarcane and these assays do not require PCR machine. These assays were found to be more sensitive than RT-PCR assays (Anandakumar et al. 2018, 2020) however, the test costs of these assays are high due to more number of primers and consumables. Recently, a nanocatalysis-based high sensitive lateral flow immunochromatographic assay (LFIA) was developed to simultaneously detect SCMV and SCSMV associated with mosaic disease in sugarcane. In the assay, gold nanoparticles were used as signal enhancement system. Such a method is developed for the first time for sugarcane viruses with the linear detection sensitivity range of 10^{-6} to 10^{-12}, almost equivalent to PCR detection range (Thangavelu et al. 2022).

Management of varietal degeneration in sugarcane

In sugarcane, disease resistance has been successfully exploited to manage major fungal diseases such as red rot, smut and wilt in India and other South Asian countries. However, there is no systematic breeding or screening programmeto develop resistance to grassy shoot, RSD, YL and mosaic of sugarcane in these regions. Addition of new selection traits will complicate varietal selection process in the current varietal developmental programme and also the process will become more cumbersome. The diseases associated with varietal degeneration can be managed successfully through healthy seed nursery programme whereas this approach is not sufficient to manage fungal diseases in the crop. Hence three-tier seed nursery programme was advocated to manage non-fungal diseases of sugarcane such as grassy shoot and RSD during the last 3-4 decades in the country (Viswanathan, 2013; Viswanathan and Rao, 2011). Heat therapy, either aerated steam or moist hot air was employed to inactivate grassy shoot phytoplasma / Lxx in seed canes in this programme. Partial or complete inactivation of these pathogens was adequate to manage these two important diseases contributing towards varietal degeneration in a five year seed cycle. Since heat therapy is ineffective against viral diseases, tissue culture methods were employed to eliminate systemic virus(es) infection in sugarcane in different countries.

Meristem culture has been exploited for the production of virus-free plants by meristem culture in many vegetatively propagated crops. By this approach, it has been possible to eliminate SCYLV and other viruses from many sugarcane commercial varieties worldwide. Ever since YL became a serious constraint to sugarcane production in different countries efforts were made to manage the disease through different strategies. Among the different approaches, going for meristem culture technique was found to be more effective in the elimination of the causative virus from the systemically infected plants (Ramgareeb et al., 2010, Snyman et al., 2011). At our conditions incorporation of nucleic acid analogues like ribavirin improved the efficiency of SCYLV elimination from the infected mother plants. Since these virus elimination techniques are not 100% efficient to eliminate the virus there is a need to index the sugarcane seedlings using precise techniques. At seedlings stage the disease symptoms are not expressed. Also symptom expression in meristem derived plants in the field may be suppressed due to very low titre of the infective pathogens. Many improved diagnostic techniques based on serological and molecular techniques were developed to detect thesepathogens. Meristem culture combined with molecular diagnosis was proved to be successful to effectively manage the disease. Detailed studies conducted at SBI proved that SCYLV elimination can be achieved through meristem culture combined with molecular diagnosis. The virus-free plants have maintained good crop stand under field conditions and recorded higher yield than the conventional seed planted fields (Viswanathan,2012b). Earlier Chatenet et al. (2001) and Parmessur et al. (2002) reported successful elimination of SCYLV by tissue culture from infected sugarcane plants from France and Mauritius, respectively.

The potential for eradicating pathogens via rapid regeneration of plants directly from leaf roll discs was explored in South Africa. The technique, NovaCane®, has been used successfully to remove SCYLV (Snyman et al., 2008). In addition, this process enabled elimination of bacterial pathogens from diseased sugarcane plants while simultaneously enabling large-scale micro propagation. Cheong et al. (2012)

developed procedures for the *in vitro* elimination of SCMV, Sorghum mosaic virus (SrMV), SCSMV, ScYLV and Fiji disease virus (FDV) from infected sugarcane and they standardized *in vitro* shoot regeneration, elongation and virus elimination through meristem tissue culture originating from both apical and axillary shoots and found 61–92% virus-freedom among elongated shoots. Overall, clean seed programme initiated through tissue culture benefit sugar industry in different sugarcane growing countries. Production of ScYLV-free seedlings has ensured supply of YLD-free planting materials to the growers fields and such fields showed renewed vigour in the crop. Detailed studies conducted in the factory areas in Tamil Nadu revealed that adoption of tissue culture derived YLD-free nurseries resulted in a better crop stand with good vigour. Such fields recorded as high as 250 tonnes per hectare cane yield in Erode Dt in Tamil Nadu (Viswanathan et al., 2018). Degeneration in the popular cv Co 86032 has been addressed through a systematic study and viable strategy has been developed to address varietal degeneration in the country (Viswanathan, 2021b). In addition, adoption of sett treatment device to deliver different agro inputs have improved settling vigour in settling nurseries has been demonstrated (Viswanathan et al. 2017).

Conclusion

Cane productivity remained static over the last five decades in India. Although newly introduced varieties were superior in yield and quality, under field conditions we could not harness the improved potential of yield and quality. The major reason for this situation is attributed to slow degeneration of the new varieties due to systemic accumulation of non-fungal pathogens in the canes. By the time the new variety becomes popular, it succumbs to different stages of degeneration depending on seed replacement programmes. The varietal degeneration was not recognized in the country till YLD reached an epidemic level across the states. The crop loses about 2 to 3 months of its active growth depending on the pathogen load and plant or ratoon crop. The overall loss caused by YLD and other pathogens associated with varietal degeneration could be several billion rupees in India, hence a clean seed programme is recommended to tackle this constraint. Adoption of disease-free nurseries raised from tissue (meristem) culture combined with molecular diagnosis resulted in a significant improvement in cane yield.In the long run, adopting disease-free nurseries will lead to enhanced cane productivity in the country and the elite commercial varieties will have an extended life with vigour.

References

Agnihotri, V.P. 1990. *Diseases of sugarcane and sugar beet*. Oxford & IBH Publishing Co Pvt Ltd, New Delhi.

Agnihotri V.P.1996. Current sugarcane scenario and management strategies. *Indian Phytopathology* 49: 109-126.

Anandakumar, L., K. Bagyalakshmi, K. Nithya, B. Parameswari and R. Viswanathan 2018. Reverse transcription loop-mediated isothermal amplification (RT-LAMP) assay for rapid diagnosis of *Sugarcane yellow leaf virus* in sugarcane. Sugar Tech 20:708-716 DOI: 10.1007/s12355-018-0606-2

Anandakumar, L., K. Bagyalakshmi, T. Raja Muthuramalingam, K. Nithya, B. Parameswari and R. Viswanathan 2020. Reverse Transcription Loop-mediated Isothermal Amplification based rapid detection of *Sugarcane mosaic virus* and *Sugarcane streak mosaic virus* associated with mosaic disease of sugarcane. *Indian Phytopathology*73:349-358 DOI: 10.1007/s42360-020-00219-w

Bagyalakshmi, K., R. Viswanathan, V. Ravichandran 2019. Impact of the viruses associated with mosaic and yellow leaf disease on varietal degeneration in sugarcane. *Phytoparasitica*47: 591–604 DOI: 10.1007/s12600-019-00747-w

Bailey, R.A. and S.A. Tough.1992. Ratoon stunting disease: survival of *Clavibacterxyli* subsp. *xyli* in field soil and its spread to newly planted sugarcane. *Proceedings of South African Sugar Technologists Association Congress* 66: 75-77.

Barber, C.A. 1921. The mosaic mottling disease of the sugarcane. *International Sugar Journal* 23: 12-19

Chatenet, M., C. Delage, M. Ripolles, M. Irey, B.E.L. Lockhart andP. Rott. 2001. Detection of *Sugarcane yellow leaf virus* in quarantine and production of virus-free sugarcane by apical meristem culture. *Plant Disease* 85: 1177-1180.

Cheong, E.L., R. Mock and R. Li. 2012. Elimination of five viruses from sugarcane using *in vitro* culture of axillary buds and apical meristems. *Plant Cell Tissue and Organ Culture* 109:439–445.

Croft, B. J., A. D. Greet, T.M. Leaman and D.S. Teakle. 1994. RSD diagnosis and varietal resistance screening in sugarcane using the EB-EIA technique. *Proceedings of Australian Society of Sugar Cane Technologists* 16:143-151.

Fegan, M., B.J. Croft, D. S. Teakle, A. C. Hayward and G.R. Smith. 1998. Sensitive and specific detection of Clavibacterxyli subsp. xyli, causal agent of ratoon stunting disease, with a polymerase chain reaction-based assay. *Plant Pathology* 47:495-504.

Fontaniella, B., C. Vicente, E.M. Legaz, R. de Armas, C.W. Rodriguez, M. Martínez, D. Piñón, R. Acevedo and M.T. Solas. 2003. Yellow leaf syndrome modifies the composition of sugarcane juices in polysaccharides, phenols and polyamines. *Plant Physiology Biochemistry* 41: 1027.1036.

Gonçalves, M.C., J. Vega, J.G. Oliveira and M.M.A. Gomes. 2005. Sugarcane yellow leaf virus infection leads to alterations in photosynthetic efficiency and carbohydrate accumulation in sugarcane leaves. *FitopatologiaBrasileira* 30: 10-16

Grisham, M. P. 2004. Ratoon stunting disease. In: *Sugarcane Pathology*, Volume III: Bacterial and Nematode Diseases. Rao G. P., Saumtally A. S., and Rott P., (eds) pp 77-96, Science Publishers, Inc., Enfield, NH, USA.

Grisham, MP.., G. Eggleston, J. W. Hoy and R.P. Viator. 2009. Effect of Sugarcane yellow leaf virus infection on yield of sugarcane in Louisiana. *Sugar Cane International* 27: 91-94.

Hoy, J. W., M.P. Grisham and K.E. Damann. 1999. Spread and increase of ratoon stunting disease of sugarcane and comparison of disease detection methods. *Plant Disease* 83: 1170-1175.

Izaguirre-Mayoral, M.L., O. Carballo, C. Alceste, M. Romano and H.A. Nass. 2002. Physiological performance of asymptomatic and yellow leaf syndrome-affected sugarcane in Venezuela. *Journal of Phytopathology* 150:13-19.

Koike, H. and A.G. Gillaspie. 1989. Mosaic. In: *Diseases of Sugarcane: Major Diseases*. Ricaud C, Egan BT, Gillaspie AG, Hughes CG, eds. 301-322, Elsevier, Amsterdam

Kumar, S. A.K. Tiwari, S.K. Holkar, S.K. Duttamajumder and G.P. Rao. 2015. Characterization of a 16SrI-B subgroup phytoplasma associated with Sugarcane leaf yellows disease in India. *Sugar Tech* DOI 10.1007/s12355-014-0318-1

Lehrer, A.T., P. Moore and E. Komor. 2007. Impact of Sugarcane yellow leaf virus on the carbohydrate status of sugarcane: comparison of virus-free plants with symptomatic and asymptomatic virus-infected plants. *Physiological and Molecular Plant Pathology* 70: 180-188

Lehrer, A.T. and E. Komor. 2009. Carbon dioxide assimilation by virus-free sugarcane plants and by plants which were infected by *Sugarcane yellow leaf virus*. *Physiological and Molecular Plant Pathology* 73: 147–153.

Nithya, K., B. Parameswari, A. Bertaccini, G. P. Rao and R. Viswanathan 2020a. Grassy shoot: the destructive disease of sugarcane. *PhytopathogenicMollicutes* 10(1): 10-24 doi: 10.5958/2249-4677.2020.00002.X

Nithya, K., B. Parameswari, and R. Viswanathan 2020b. Mixed infection of sugarcane yellow leaf virus and grassy shoot phytoplasma in yellow leaf affected Indian sugarcane cultivars. Plant Pathology Journal 36(4): 364-377 https://doi.org/10.5423/PPJ.OA.06.2020.0092

Parmessur, Y., S. Aljanabi, S. Saumtally and A. Dookun-Saumtally. 2002. Sugarcane yellow leaf virus and sugarcane yellows phytoplasma: elimination by tissue culture. *Plant Pathology* 51: 561–566.

Ramgareeb, S., S.J. Snyman, T. Van Antwerpen and R. S. Rutherford. 2010. Elimination of virus and rapid propagation of disease-free sugarcane (*Saccharum* spp. cultivar NCo 376) using apical meristem culture. *Plant Cell Tissue Organ Culture* 100: 175–181.

Rao, G. P., R. Viswanathanand S.B. Singh.2002. Current situation of sugarcane diseases in India. In: *Sugarcane Crop Management*, Singh S. B., Rao G. P., Eswaramoorthy S. (Eds.), pp 1-9, SCI TECH Publishing LLC, Houston, Texas, USA.

Rao, G.P., S. Srivastava, P.S. Gupta, A. Singh, M. Singh, and C. Marcone. 2008. Detection of sugarcane grassy shoot phytoplasma infecting sugarcane in India and its phylogenetic relationships to closely related phytoplasmas. *Sugar Tech* 10: 74–80.

Rao, G.P., S. Mall, and C. Marcone. 2012. Recent biotechnological approaches in diagnosis and management of sugarcane phytoplasma diseases. In: *Functional plant science & biotechnology*, eds. Rajarshi Kumar Gaur et al. 6, Special issue 2, 19–29. Recent trends in biotechnology and microbiology. USA: Global Science Books.

Rao, G.P., Madhupriya., A.K. Tiwari, S. Kumar and V.K. Baranwal. 2014. Identification of sugarcane grassy shoot-associated phytoplasma and one of its putative vectors in India. *Phytoparasitica* 42: 349-354.

Rassaby, L., J.C. Girard, P. Letourmy, J. Chaume, M.S. Irey, B.E.L. Lockhart, H. Kodjaand P.Rott. 2003. Impact of *Sugarcane yellow leaf virus* on sugarcane yield and juice quality in Réunion Island. *European Journal of Plant Pathology* 109: 459-466.

Rott, P., R.A. Bailey, J.C. Comstock, B.J. Croft and S. Saumtally. 2000. *A Guide to Sugarcane Diseases*. Montepellier: CIRAD-ISSCT, CIRAD Publication Services.

Singh, V., O.K. Sinha andR. Kumar. 2003. Progressive decline in yield and quality of sugarcane due to sugarcane mosaic virus. *Indian Phytopathology* 56: 500–502.

Snyman, S.J., G.M. Meyer, M. Banasiak, T.L. Nicholson, T. Van Antwerpen, P. Naidoo and J.D. Erasmus.2008. Micropropagation of sugarcane via Novacane®: Preliminary steps in commercial application. *Proceedings of South African Sugar Technologists Association* 81: 513 - 516

Snyman, S.J., G.M. Meyer, A.C. Koch, M. Banasiak and M.P. Watt. 2011.Applications of *in vitro* culture systems for commercial sugarcane production and improvement.*In Vitro Cellular and Developmental Biology-Plant* 47:234–249

Taylor, P. W. J., L. A. Petrasovits, R. Van der Velde, R.G. Birch, B.J. Croft, M. Fegan, G.R. Smith and S. M. Brumbley. 2003. Development of PCR-based markers for detection of *Leifsoniaxyli* subsp. *xyli* in fibrovascular fluid of infected sugarcane plants. *Australasian Plant Pathology* 32:367-375.

Thangavelu RM, K. Nithya, B. Parameswari, R. Viswanathan 2022.Ultrasensitive nano-gold labelled, duplex lateral flow immunochromatographic assay for early detection of sugarcane mosaic viruses.*Scientific Reports* 12:4144 https://doi.org/10.1038/s41598-022-07950-6

Viswanathan, R. 1997. Detection of ratoon stunting disease (RSD) bacterium by ELISA. *Madras Agricultural Journal* 84: 374-377.

Viswanathan, R. 2000. Grassy shoot. In: *A guide to sugarcane diseases*ed. P. Rott, R.A. Bailey, J.C. Comstock, B.J. Croft, and S. Saumatally, 215-220, Montpellier, France, CIRAD.

Viswanathan, R. 2001. Growing severity of ratoon stunting disease of sugarcane in India. *Sugar Tech* 3(4): 154-159.

Viswanathan, R. 2002. Sugarcane yellow leaf syndrome in India: Incidence and effect on yield parameters. *Sugar Cane International* 20(5): 17-23.

Viswanathan, R. 2004a. Ratoon stunting disease infection favours severity of yellow leaf syndrome caused by sugarcane yellow leaf virus in sugarcane. *Sugar Cane International* 22(2): 3-7.

Viswanathan, R. 2004b. Serodiagnosis of *Leifsoniaxyli* sub sp. *xyli* causing ratoon stunting disease in sugarcane. In: *Sugarcane Pathology*: Vol. III, *Bacterial and Nematode Diseases*, Rao G. P., SaumtallyS., Rott P., (Eds) pp 155-173, Oxford & IBH Publishing Co Pvt Ltd, New Delhi,

Viswanathan R. 2010. *Plant Disease: Red rot of Sugarcane*. Anmol Publications Pvt Ltd, New Delhi, 301p.

Viswanathan, R. 2012a. Need for a paradigm shift in sugarcane disease management In: *Perspectives in Sugarcane Agriculture*, Nair N.V., PuthiraPratap D., Viswanathan R., Srikanth J., Bhaskaran A., Bakshi Ram (Eds), pp 171-206, Society for Sugarcane Research and Development, Coimbatore, India.

Viswanathan, R.2012b. *Sugarcane Diseases and Their Management*, Sugarcane Breeding Institute, Coimbatore, p140.
Viswanathan,R. 2013. Sustainable ecofriendly disease management systems in sugarcane production under the changing climate – A review. *Journal of Mycology and Plant Pathology* 43: 12-27.
Viswanathan R. 2016. Varietal degeneration in sugarcane and its management in India.*Sugar Tech* 18: 1–7.
Viswanathan R. 2018. Changing scenario of sugarcane diseases in India since introduction of hybrid cane varieties: path travelled for a century. *Journal of Sugarcane Research* 8 (1): 1 – 35.
Viswanathan R 2021a.Red rot of sugarcane (*Colletotrichum falcatum* Went). CAB Reviews 16, No. 023, doi: 10.1079/PAVSNNR202116023
Viswanathan R. 2021b. Impact of yellow leaf disease in sugarcane and its successful disease management to sustain crop production. Indian Phytopathology 74: 573–586 DOI:10.1007/s42360-021-00391-7
Viswanathan, R. and M. Balamuralikrishnan. 2004. Detection of sugarcane yellow leaf virus, the causal agent of yellow leaf syndrome in sugarcane by DAS-ELISA. *Archives of Phytopathology and Plant Protection* 37: 169-176
Viswanathan, R. and M.Balamuralikrishnan. 2005. Impact of mosaic infection on growth and yield of sugarcane. *Sugar Tech* 7(1): 61-65.
Viswanathan, R., M. Balamuralikrishnan and R. Karuppaiah.2006. Yellow leaf disease of sugarcane: Occurrence and impact of infected setts on disease severity and yield. *Proceedings of Sugar Technologists Association India* 67: 74-89.
Viswanathan, R., M. Balamuralikrishnan and R. Karuppaiah.2008a. Identification of three genotypes of sugarcane yellow leaf virus causing yellow leaf disease from India and their molecular characterization. *Virus Genes* 37: 368-379.
Viswanathan, R., M. Balamuralikrishnan and R. Karuppaiah. 2008b. Duplex - reverse transcription - polymerase chain reaction (D-RT-PCR) - a technique for the simultaneous detection of viruses causing sugarcane mosaic. *Sugar Tech*10: 81-86.
Viswanathan R., M. Balamuralikrishnan and M. Poongothai. 2005. Detection of phytoplasmas causing grassy shoot disease in sugarcane by PCR technique. *Sugar Tech* 7 (2&3):71-73.
Viswanathan, R.,C. Chinnaraja, P. Malathi, R. Gomathi, P. Rakkiyappan, D. Neelamathi and V. Ravichandran. 2014. Impact of *Sugarcane yellow leaf virus* (ScYLV) infection on physiological efficiency and growth parameters of sugarcane under tropical climatic conditions in India. *ActaPhysiologiaePlantarum*36:1805–1822
Viswanathan, R. and R. Karuppaiah. 2010. Distribution pattern of RNA viruses causing mosaic symptoms and yellow leaf in Indian sugarcane varieties. *Sugar Cane International* 28(5): 202-205.
Viswanathan R, Karuppaiah R, Bagyalakshmi K, Balan S,Kaverinathan K 2019. Emergence of leaf fleck caused by *Sugarcane bacilliform virus* in sugarcane as a serious disease under field conditions in India.*International Sugar Journal* 121:146-153.
Viswanathan, R., R. Karuppaiah and M. Balamuralikrishnan. 2010. Detection of three major RNA viruses infecting sugarcane by multiplex reverse transcription polymerase chain reaction multiplex-RT-PCR. *Australasian Plant Pathology* 39: 79-84.
Viswanathan, R., R. Karuppaiah, P. Malathi, V. Ganesh Kumar andC. Chinnaraja. 2009. Diagnosis of sugarcane yellow leaf virus in asymptomatic sugarcane by RT-PCR. *Sugar Tech* 11: 368-372.
Viswanathan R, P.Malathi, D.Neelamathi2018.Enhancing sugarcane yield per hectare through improved virus-free seed nursery programme.*ICAR NEWS* 24(4): 4-5.
Viswanathan R, P.Malathi, C.N.Prasanth, R.Naik, S.J.K.Annamalai 2017b.Sett way of growing sugarcane for fungal treatment.*ICAR NEWS* 23 (2) 1-3
Viswanathan, R. and P. Padmanaban. 2008. *Hand book on sugarcane diseases and their management*. Sugarcane Breeding Institute, Coimbatore, 80p.

Viswanathan, R. and G. P. Rao. 2011. Disease scenario and management of major sugarcane diseases in India. *Sugar Tech* 13: 336–353.
Xie, Y., M.Wang, D. Xu, R. Li andG. Zhou.2009. Simultaneous detection and identification of four sugarcane viruses by one-step RT-PCR. *Journal of Virological Methods* 162: 64–68
Yan S.-L., A.T. Lehrer, M.R. Hajirezaei, A. Springer andE. Komor. 2009. Modulation of carbohydrate metabolism and chloroplast structure in sugarcane leaves which were infected by *Sugarcane yellow leaf virus* (SCYLV). *Physiological and Molecular Plant Pathology* 73:78–87.
Young, A. and S.M. Brumbley.2004. Ratoon stunting disease of sugarcane: History, management and new research. In:*Sugarcane Pathology* Vol. III: *Bacterial and Nematode Diseases*, Rao, G. P., Saumtally, S. and Rott, P. (Eds), pp. 97-124, Science Publishers, Enfield, USA.

Chapter No. 3: Sugarcane Research and Development in India

A.D. Pathak
Principal Scientist & Ex-Director
ICAR-Indian Institute of Sugarcane Research, Lucknow

Sugarcane is grown in about 26 million ha in the world with total production of nearly 1900 million tonnes. Approximately, 75% of total sugar production comes from sugarcane and the rest from sugar beet. Currently, about 110 countries produce sugar from either cane or beet and eight countries produce sugar from both cane and beet. Sugarcane, on average accounts for nearly 80% of global sugar production, Last October-September season, the top ten producing countries (India, Brazil, Thailand, China, the US, Mexico, Russia, Pakistan, France, Australia) accounted for nearly 70% of global output. India had emerged as the largest sugar exporting nation in the world. with the share of 4.55% in total sugar export. The major export destinations for Indian sugar were Myanmar, Somalia, Sudan, Sri Lanka and UAE. Due to sustained higher sugar production in India, thus, negligible amount of sugar was imported from global market under quota system.

Indian sugar industry is quite vibrant, supports approximately 6.5- 7.5 million farmers through sugarcane cultivation and other related industries. This crop is cultivated on about 5 million ha i.e., 3.52% of net sown area and produces approximately 350-380 million tonnes sugarcane with average productivity of 70 tonne per ha. The area, production and productivity of sugarcane in India during 1950-51 to 2021-22 given in Table 1, clearly revealed the continuous upward trend. Although national average productivity has been hovering around 80 t/ha, tropical states record higher productivity ranging from 80 to 105 t/ha.

Table1 : Area, production and productivity of sugarcane in India

Year	Area (000 ha)	Production (000 tonnes)	Productivity (t/ha)
1950-51	1707	54823	32.1
1960-61	2415	110001	45.5
1970-71	2615	126368	48.3
1980-81	2667	154248	57.8
1990-91	3686	241045	65.4
2000-01	4316	295956	68.6
2010-11	4886	342382	70.1
2017-18	4732	376905	79.6
2018-19	5114	400157	78.25
2019-20	4603	370500	80.50
2020-21	5010	397770	79.42
2021-22	5080	414700	81.20

The perusal of the data embodied in Table 2 on area, production and productivity of sugarcane in major sub-tropical states of India like Uttar Pradesh, Bihar, Punjab, Haryana and Madhya Pradesh revealed an upward trend during last decade. Only in Uttarakhand, area under sugarcane has been decreased during last decade but production and productivity of sugarcane has been enhanced during the same period.

Table 2 : Area, production and productivity of sugarcane in major sub-tropical states of India

Year	Area (000 ha)	Production (000 tonnes)	Productivity (t/ha)
		Uttar Pradesh	
2008-09	2084	109480	52.3
2009-10	1977	117140	59.3
2010-11	2125	120545	56.7
2011-12	2162	128819	59.6
2012-13	2212	132427	59.9
2013-14	2228	134689	60.5
2014-15	2141	133061	62.1
2015-16	2169	145385	67.0
2016-17	2160	140169	64.9
2017-18	2234	177056	79 .26
2018-19	2724	179715	80.81
2019-20	2208	179539	81.31
2020-21	2180	177262	81.31
		Bihar	
2008-09	112	4960	44.3
2009-10	116	5033	43.4
2010-11	248	12764	51.5
2011-12	218	11289	51.8
2012-13	250	12741	51.0
2013-14	258	12882	49.9
2014-15	254	14034	55.3
2015-16	244	12649	51.8
2016-17	240	13036	54.3
2017-18	236	13982	59.2
2018-19	226	11661	51.7
2019-20	224	13579	60.65
2020-21	219	15005	68.43
		Punjab	
2008-09	81	4670	57.7
2009-10	60	3700	61.7
2010-11	70	4170	59.6
2011-12	80	5653	70.7
2012-13	83	5919	71.3
2013-14	89	6675	75.0
2014-15	94	7039	74.9
2015-16	90	6607	73.4
2016-17	88	7152	81.3
2017-18	96	8024	83.58
2018-19	95	7774	81.83
2019-20	91	7302	80.24
2020-21	95	7855	82.60
		Haryana	
2008-09	90	5130	57.0
2009-10	74	5335	72.1
2010-11	85	6042	71.1
2011-12	95	6959	73.3
2012-13	101	7437	73.6
2013-14	102	7499	73.5
2014-15	97	7169	73.9
2015-16	93	6692	72.0

2016-17	102	8223	80.6
2017-18	114	9633	84.5
2018-19	94	7571	80.37
2019-20	96	7730	80.27
2020-21	93	7567	81.19
		Madhya Pradesh	
2008-09	71	2975	41.9
2009-10	62	2535	40.9
2010-11	65	2667	41.0
2011-12	69	2677	38.8
2012-13	59	2642	44.8
2013-14	73	3173	43.5
2014-15	111	4567	41.1
2015-16	103	5281	51.3
2016-17	92	4730	51.4
2017-18	98	5430	55.41
2018-19	118	6956	58.95
2019-20	125	7434	59.47
2020-21	106	5666	53.45
		Uttarakhand	
2008-09	107	5590	52.2
2009-10	96	5842	60.9
2010-11	107	6498	60.7
2011-12	108	6311	58.4
2012-13	110	6785	61.7
2013-14	104	5940	57.1
2014-15	102	6165	60.4
2015-16	97	5886	60.7
2016-17	93	6477	69.6
2017-18	90	6304	70.04
2018-19	91	6329	69.55
2019-20	92	6938	75.41
2020-21	84	6913	82.30

The data on number of factories in operation, average actual capacity, total cane crushed and recovery of sugar depicted in Table 3 also revealed increasing trends. Sugar production has also been increasing continuously, touching a new height of 32.47 million tonnes during 2017-18 (Table 4). India's sugar production has increased in last 10 years at CAGR of 2.63 per cent. During the same period, India's sugarcane production has increased at CAGR of 2.40 per cent and area under cultivation at CAGR of 3.19 per cent. Molasses production in the country has also been recording upward trend. (Table 4). State-wise sugar production has been shown in Table 5.

Table 3 : Number of factories in operation, average annual capacity, total cane crushed, recovery of sugar and average duration of the mills in India

Year	Number of factories in operation	Average actual capacity (tonnes) per 24 hours	Total cane crushed (000 tonnes)	Recovery of sugar (% cane)	Average duration (days)
1950-51	138	859	10971	10.03	101
1960-61	173	1175	31109	9.74	167
1970-71	216	1408	38204	9.78	137
1980-81	314	1707	51598	9.98	105
1990-91	385	2088	122319	9.85	166

2000-01	436	3180	176651	10.48	139
2010-11	527	3650	239807	10.17	136
2017-18	525	4439	301198	10.73	141
2018-19	531	4760	301179	11.01	130
2019-20	464	4985	252837	10.86	126
2020-21	506	5126	300952	10.36	136

Table 4 : Sugar and molasses production in India

Year	Sugar production (000 tonnes)	Molasses production (000 tonnes)
1950-51	1101	402
1960-61	3028	1240
1970-71	3740	1620
1980-81	5147	2126
1990-91	12046	5444
2000-01	18519	7820
2010-11	24394	10970
2017-18	32328	13980
2018-19	33163	13885
2019-20	27385	11916
2020-21	31192	14906

Table 5: State-wise sugar production as on May 15, 2022

Sl. No.	State	No. of Working factories		Net Sugar Production (Without diversion)		Estimated Sugar Diversion into ethanol		Sugar production (After diversion)	
		2021-22	2020-21	2021-22	2020-21	2021-22	2020-21	2021-22	2020-21
1.	Uttar Pradesh	20	21	213.95	115.6	12.50	6.9	101.45	108.7
2.	Maharashtra	69	5	146.72	113.28	11.29	7.12	135.43	106.16
3.	Karnataka	0	0	65.89	47.50	7.37	5.02	58.52	42.48
4.	Tamil Nadu	15	11	8.99	6.53	0.19	0.08	8.80	6.45
5.	Gujarat	7	2	12.09	10.22	0.14	0.05	11.95	10.17
6.	Others*	5	6	35.26	31.71	2.58	0.90	32.68	3.81
	Total	116	45	382.91	324.89	34.08	20.07	348.83	304.77
	Difference			58.07		14.01		44.06	

*Others include –AP, Telangana, Bihar, Punjab, Haryana, Rajasthan, MP, Chhastisgarh, Uttarakhand and Odisha

The year 2018-19 was good year for sugar production in India recording the highest ever sugar production of 331.63 lakh tonnes. Uttar Pradesh produced the highest ever 120.46 lakh tonnes of sugar during 2017-18 and the longest crushing period was recorded by sugar mills. Maharashtra produced 107.05 lakh tonnes of sugar. About 36.58 lakh tonnes of sugar was produced by Karnataka. Sugar production in Bihar, Punjab and Haryana reached record levels in their history at 7.16 lakh tonnes, 8.24 lakh tonnes and 8.44 lakh tonnes, respectively. Other states like Gujarat, Tamil Nadu, Andhra Pradesh and Telangana produced 10.67, 6.92 and 5.30 lakh tonnes of sugar, respectively.

During 2021-22 sugar season, Maharashtra mills together might produce a record 136 lakh tonnes of sugar this season as the crushing will continue till May end. About 4M MT of sugarcane is still standing in the fields and 130 harvesters are in operation to cut the excess crop. The State government has announced a grant to sugar mills to crush the excess cane. As of now, majority of the uncrushed sugarcane is in Marathwada region. Sugar Mills are likely to crush 130.7M MT of sugarcane by the end of this season. Industry players say that the State government's assistance to mills has played a major role to convince mill directors to crush all the available sugarcane in the locality. According to the Indian Sugar Mills Association (ISMA), sugar production in Maharashtra till April 15, 2022 was 12.64 M MT compared with 10.395 M MT tonnes produced in the same period previous season. In the current 2021-22 sugar season, reportedly 45 mills have closed their crushing operations in the State and 153 sugar mills are operating. On the corresponding date in last season, only 54 mills were in operation in the State, which went on to add another about 0.25M MT of sugar production last year.

The sugar recovery is hovering around 10.5% for the past decade with maximum recovery of 12.4% in Maharashtra. There are two distinct sugarcane growing zones in India – the tropical zone (contributing 45% of total sugarcane area) and sub-tropical zone (contributing 55% of total area). The average sugarcane productivity in the sub-tropical zone was lower (nearly 72 t/ha) as compared to the tropical zone (approx. 85 t/ha). India is a major producer as well as consumer of sugar in the world with annual sugar production of 25-32 million tonnes. Indian sugar contributes nearly 15-17% to global sugar production. Due to its potential as a feedstock for renewable energy, sugarcane is becoming the preferred crop not only for sugar production but also for bio-fuel, green energy and other by-products like bio-plastics, bio-polymers etc. Bio-ethanol is emerging as a preferred renewable and eco-friendly energy source.

UP cane growers receive record cane payment

Sugarcane growers in Uttar Pradesh received a record sugarcane payment of more than INR 1,70,938.95 crore (US$2,231.06) from 2017 to April 2022, which represents 1.5 times higher than the payment made by the previous government. The UP Govt. has already made it clear that the payment of the sugarcane price must be made to the producer within 14 days without delay. About 6.5 million farmers are associated with the plantation of sugarcane in the state. The Government is also making efforts to increase current sugarcane productivity from 81.5 tonnes per hectare to 84 tonnes/ha over the next five years.

It is estimated that India may require nearly 51 million tonnes of white sugar by 2050 for 1.65 billion population of the country at the rate of per capita consumption of 35 kg /year. In order to meet the growing demand of sugar and energy by 2050 in India, around 630 million tonnes of sugarcane with a recovery of 11.5% will be required. Of the total sugarcane produced, 70% would be crushed for white sugar, 20% for *gur* and *khandsari* and remaining 10% for seed and other purposes. This will entail an average cane productivity requirement of 105 tonnes/ha as the area under sugarcane cultivation may not increase beyond 6 million hectare. Sugarbeet is an intercrop in sugarcane may also supplement sugar production and the crop is also visualized as a potential one for bioethanol production from beet juice.

Since July 2018, the Govt. has also allowed ethanol production directly from sugarcane juice, to avoid surplus sugar production. This permission will pave a long way for its blending with petrol and will be helpful in saving lot of precious foreign exchange on import of crude oil. For this, the sugar industry will require the varieties suitable for higher biomass. The Govt. of India on Feb. 2, 2021 an excise duty of INR 2 (US$ 0.027) per litre on unblended fuel, effective from Oct. 1, 2021 aiming to incentivize ethanol consumption and production. The new tax aims to encourage the efforts for blending fuels.

Major challenges in sugarcane cultivation

With its present level of sugarcane and sugar production, we may be satisfied for the self sufficiency in meeting the internal demands of sugar and other sweeteners. In spite of that, there are a large number of challenges to meet the future demands for food, fuel and energy. With an ever increasing population, there is immense pressure on the available natural resources like land and water. The non-availability of favourable factors of growth, fast declining factor productivity in major cropping systems and rapidly shrinking resource base are the major challenges to meet the future demand of food, highlighting the need to develop new methods, technologies and know-how for improved varieties, better soil and water management practices, improved cropping systems and better crop management. The management of water for the cane cultivation is the major area of concern. The irrigation efficiency estimated at around 30% needs to be raised to at least 50% which would be helpful in contributing immensely in enhancing sugarcane production. Resource conservation technologies that improve input use efficiency, and conserve and protect our natural resources need to be promoted aggressively. Climate change has emerged as a major challenge to the farm sector. The aberrations like intra-seasonal variability of rainfall and extreme events and unseasonal rains cause heavy losses to sugarcane production every year and results in cyclic movements in sugar prices. This highlights the speeding up of our efforts to evolve climate-resilient crop varieties,

Cropping patterns and management practices

It is imperative to understand the strengths and weaknesses in the sugarcane production and utilization systems, so that available resources can be judiciously utilized for enhanced sugarcane production. The scenario as outlined envisages a stiff target and needs improvement in all fronts to achieve the desired level, to serve the national interest *per se*. There is hardly any possibility of bringing additional area under sugarcane, primarily due to decreasing availability of arable land. Sugarcane is also facing stiff competition from food grains, oilseeds, pulses and other high value crops including vegetables in the share of area due to continuous rise in their prices with the further assumption of availability of additional area from intercropping of other crops in a sugarcane based cropping system. Thus, the target of sugarcane production has to be met primarily by increasing the productivity and quality of the crop. The average productivity level needs tremendous boost by crossing 100 tonnes/ha mark. To meet the targeted white sugar requirement, average drawl of cane to sugar mills for sugar production has to be increased to at least 70 per cent.

The liberalization in industrial sector has resulted in more number of sugar mills and consequently for more cane. However, due to area limitations, many new processing units have come up in zones having sub-optimal potential for sugarcane. This demands a careful consideration in relation to cane productivity and quality, its production and availability for sugar processing.

Limited water resources

The water requirement of sugarcane crop is very high and it accounts for nearly 30 per cent of the cane production cost. At present, nearly 80 to 85 per cent of area under sugarcane is supposed to be irrigated, though only 34.6 per cent of the area has assured irrigation. The crop is grown under limited irrigation in the remaining 65.4 per cent of the area. It is estimated that nearly 43 per cent of the cane production comes from about 29 per cent of the area which is irrigated, whereas the rest 57 per cent of the production is obtained from 71 per cent area which is largely under limited irrigation facilities. This calls for development of efficient surface and sub-surface water saving technologies for sugarcane crop.

Limited utilization of available germplasm

India is yet to tap the vast potential of its rich diversity with respect to sugarcane germplasm to our advantage. Limited utilization of basic germplasm (at the species level) in India has narrowed down the genetic base of the commercial cane varieties and the plateauing effect has become apparent in terms of sugar recovery and cane productivity over the years. Tapping of the huge available genetic potential will be helpful in breaking both the barriers of sugar recovery and yield.

Varietal spectrum of sugarcane varies from state to state and from region to region depending on the location specific suitability of a particular variety. Large numbers of excellent varieties developed in the past have ruled the sugar industry, but were gradually phased out due to various factors like varietal decline, susceptibility to biotic and abiotic stresses etc. Quick replacement of the old and denotified varieties can help in sustaining sugar productivity at the existing level. Considerable time elapses before the variety covers sizeable area (even in case of availability of suitable replacement) due to slow rate of seed multiplication in sugarcane and lack of an organized quality seed production and replacement system in this crop.

Issue of sustainability

The issue of sustainability is of prime importance which is very closely linked with the maintenance of productivity potential and soil health. Sugarcane being a long duration crop with large canopy, is a heavy feeder of N, P and K. Hence, the growing demands of nutrient sources are likely to make the mineral nutrient cost prohibitive in future. Introduction of practices like Integrated Nutrient Management with synergistic use of green manures, organics and bio-fertilizers, along with judicious blend of minerals in the sugarcane production programme needs to be encouraged. Fertilizers and irrigation like essential production inputs always remained the major bottlenecks for any profitable venture of sugarcane farming and thus, always hindered a steady supply of cane to the mills. In spite of release of disease resistant and pest tolerant varieties, sporadic attacks of pests and diseases always impair the yield and quality of cane. These bottlenecks, coupled with limitations imposed by climatic factors like exposure of the crop to extremes of temperatures that limits the growth phase, lower the average productivity of cane in the sub-tropics and therefore, sub-tropical cane varieties remained more climate resilient than the tropical cane varieties. Agronomic practices such as planting geometry, fertilizer application, irrigation scheduling, and cultural operations that sustain a higher shoot population might break the present yield barrier and may enhance productivity. To sustain high-population shoot density, tiller mortality has to be curbed. Through hormonal treatment and adjustment in planting geometry, tillers are forced to initiate rooting soon after emergence. This method prevents the tillers from remaining dependent on the mother-shoot for growth resources and increases their survival rate.

Biosecurity

Biosecurity has a direct relevance to sustainability in agriculture and providing crop insurance to growers, as it should cover protection against large scale incidence of diseases and insect pests, long duration drought or water logging, introduction of GMOs, etc. In a larger context, biosecurity takes into consideration the security with respect to the crop biodiversity as well as parasites and predators of insect pests. Development of climate-resilient varieties would be helpful in overcoming the adversities of nature. Moreover, crop diversification through intercropping of short duration crops in sugarcane can mitigate the monetary loss of growers. There is a need to develop minimum 4 to 5 varieties for a location or zone for avoiding the risks involved in monoculture of single variety. Development of bio-intensive measures will also be helpful in warding off the population of natural enemies of insect-pests.

Mechanization

Around 50% of the operational cost of sugarcane production is spent on manual labour who works right from preparatory cultivation to harvesting. Being a long-duration crop of 12 months and its planting spreading the period between October and May, sugarcane requires about 250 to 400 man-days labour per ha as most of the operations are carried out manually and mechanization is mostly limited to field preparation prior to planting. To address the issue of the labour scarcity and for ensuring timely farm operations along with the reduction in human drudgery, mechanization of cane agriculture from planting to harvesting and loading is necessary which will also improve the overall energy use efficiency of the sugarcane-based farming.

Intensive research efforts are required to enhance cane quality and productivity at national level, especially in the subtropics. India has to gear up to the new challenges of higher cane and sugar production to meet the future requirement.

Way Forward

To achieve the desired growth in area, productivity and recovery of sugarcane in different agro-ecological zones of the country and to extent appropriate information and technologies to the end users, the issues of low levels of cane yield and sugar recovery, high cost of cane cultivation and decline in factor productivity need to be addressed vigorously. We should be committed to bring about a demand driven and technology-led enhanced growth in sugarcane agriculture in the country, for improving the livelihood of farmers and for ensuring sustainable cane agriculture. For achieving the targeted goals, we should focus ourselves on development of cost-effective, profitable and sustainable agro-techniques for improved plant and ratoon productivity, mechanization to suit location specific needs of small and marginal farmers, development of improved varieties for high yield, high biomass and high sugar, encompassing multiple stress tolerance, input efficiency and better ratoonability under sub-tropical conditions through conventional breeding and molecular methods, conventional and non-conventional approaches to enhance cane yield, sucrose content, red rot resistance, tolerance to abiotic stresses and thermo-insensitivity, location-specific bio-intensive crop-protection strategies, climate change mitigation strategies including development of climate resilient varieties, crop production and diversification *vis-a-vis* value addition for enhanced profitability and sustainability, technology assessment, transfer and refinement, impact assessment of technologies and capacity building of scientists and other staff.

Chapter No. 4: Green technologies for improving cane yield and sustaining soil fertility in sugarcane based cropping system

S K Shukla, Lalan Sharma and V P Jaiswal
ICAR-Indian Institute of Sugarcane Research, P.O. Dilkusha, Lucknow
Email:sudhirshukla151@gmail.com

Abstract

Sugarcane is a long duration and huge biomass accumulating crop. It requires number of operations from planting to harvesting of crop. It is also a wonder crop where after harvesting of main crop, subsequent ratoon crop is generated through established root system. Adoption of green technologies are viable options to improve sugarcane productivity and sustainability. Tuning the green technologies, different methods/techniques of crop production, planting methods (cane node technologies and planting through Cutter Planter), nutrient management strategies (intercropping, green manuring, pressmud, bio-fertilizers etc.) insect-pest and disease management options (cultural and physical methods, use of bio-agents, bio-pesticides, botanicals etc.) and management of adverse climatic conditions (drought and flood) and or crop residue recycling and trash management technologies may not only improve soil health and cane productivity but also eco-friendly and environmentally safe. These green technological interventions are being applied in sugarcane and sugarcane-based production system in the country. Improvement in the crop productivity *vis –a-vis* sustaining natural resources are key components to be addressed through these technologies. Thus reduction in cost of production, improvement in soil health, increased crop productivity and overall improvement in crop productivity and farmers' income would be possible through adoption of green technologies. Adoption of green technologies in sugarcane cultivation will certainly improve sugarcane yield and sugar recovery besides enhancing farmer's income and sustainability. In the present paper, the various aspects of increasing sugarcane and sugar yields, reducing cost of production and increasing farmers income through adoption of green technologies are being discussed. Adoption of these technologies by sugarcane growers will certainly safeguard environment (soil, water and air) and improve sustainability.

Introduction:

During past hundred years, average temperature of earth has increased by 0.89°C. Temperature rose due to burning of fossil fuels and anthropogenic activities as well as gases generated in agricultural fields. Increased temperature may adversely affect temperature and rainfall of equatorial belt which covers tropical and sub-tropical regions of the world. Sugarcane is a C_4 plant and can tolerate certain limits of changing climatic conditions compared to C_3 plants. However, cane yield and productivity of C_4 plant also gets adversely affected by changing climatic conditions worldwide. Lower temperature can affect sprouting in sugarcane while prolonged water scarcity affects cane growth and development. Besides this, variable climatic conditions will also affect juice quality parameters and sugar recovery.

The sugarcane cultivation and sugar industry plays a vital role towards socio-economic development in the rural areas by mobilizing rural resources and generating higher income and employment opportunities. It requires more nutrients and water because of production of higher biomass and nutrient removal. Sugarcane crop is attacked by large number of insect-pests and diseases. The application of chemical fertilizers for supplying nutrients and pesticide to control insect–pest in sugarcane is increasing day by day to harvest higher yields. The prolonged and over usage of chemicals has, however, resulted in human and soil health hazards along with environmental pollution. Adoption of green technologies in sugarcane cultivation will certainly improve sugarcane yield and sugar recovery besides enhancing farmer's income and sustainability. In the present paper, the various aspects of increasing sugarcane and sugar yields, reducing cost of production and increasing farmers' income through adoption of green technologies are being discussed. Adoption of these technologies by sugarcane growers will certainly safeguard environment (soil, water and air) and improve sustainability.

Improved Sugarcane Varieties

In India, state agricultural universities and state research organizations, two ICAR institutes *viz.*, ICAR-Indian Institute of Sugarcane Research, Lucknow and ICAR –Sugarcane Breeding Institute, Coimbatore are contributing research activities for development of high yielding and high sugar varieties as well as breeding for resistance to biotic and abiotic stresses. Besides, a private institution like VSI, Pune is also going on the same way particularly for Maharashtra state. All India Coordinated Research Project (AICRP) on Sugarcane is coordinating sugarcane research at the national level. AICRP on Sugarcane has 22 regular and 15 voluntary centres in 16 sugarcane growing states of the country. So far, one hundred twenty four sugarcane varieties have been identified for sugarcane producing zones in India and out of these sixty three have been released and notified by the Central Varietal Release Committee. The sugarcane varieties have also been developed for tolerance to drought and flood conditions under AICRP on Sugarcane. These are performing well and can tolerate abiotic stresses up to critical stage.

Sugarcane varieties have been widely adopted and occupied larger share in sugarcane area viz., (Co 86032 (70%) in Pennisular zone, Co 0238 (>60%) in North Western Zone and Central Zone, and CoLk 94184 (28%), BO 91 (20%), Co 6907 (20%) and Co Bln 9104 (18%) in Eastern Zone of the country. Impact analysis of Co 86032 has been done at ICAR-SBI, Coimbatore by Ram *et al,* 2017indicated that the cane yield level could be maintained around 100 t/ha throughout growing period except during severe drought years. The variety spread in almost all the states of Tropical India (Tamil Nadu, Karnataka, Maharashtra, Gujarat, unified Andhra Pradesh and Kerala). The variety covered 11.96 m ha area and approximately generated Rs. 20354 crore as additional monetary benefits. Similarly, monitory benefits accrued to the farmers/millers by adoption of variety Co 0238 in sub-tropical Indiaduring 2013-14 to 2016-17. Because of this, additional income generated to the farmers about Rs. 34196/ha and to sugar mills Rs. 12499 on hectare basis. Some prominent sugarcane varieties recommended for various sugarcane growing zones are given below.

Organics in sugarcane

Organic matter is considered a major binding agent that stabilizes soil aggregates. Aggregate stability depends on the binding mechanisms of clay and organic matter, such as chemical bonding of organic compounds and physical binding of particles by fungal hyphae and plant roots. Manure amendment is a management practice that can improve the nutrient status of the soil and increase soil organic carbon (SOC) levels. Nutrient concentrations in FYM are usually small and vary greatly depending upon source, conditions, and duration of storage. The N, P and K contents of fresh FYM range widely from 0.01 to 1.9 percent on dry weight basis due to variable nature of manure production and storage (Inoko, 1984). Several researchers all over the world have shown various benefits of the application of FYM on soil properties and productivity of crops (Prabhakar et al. 2010). Application of organic sources encouraged the growth and activity of mycorrhizae and other beneficial organisms in the soil and is also helpful in alleviating the increasing incidence or deficiency of secondary and micronutrients and is capable of sustaining high crop productivity and soil health (Nambiar et al. 1992). Application of well decomposed FYM/compost @ 10-15 t/ha or composted press mud @ 5 t/ha is recommended (Srivastava et al. 2005).Sharma et al. (1999) reported that organic fertility amendments enhanced beneficial soil microorganisms, reduced pathogen population, total carbon, and cation exchange capacity, and lowered down bulk density, thus improved soil quality (Singh et al. 2002). Application of 20 t/ha FYM/ compost along with inorganic fertilizers applied on the basis of soil test crop response for targeted yield or on the basis of general recommendation for the region has shown positive effect on sugarcane growth and yield both in plant and ratoon crops. Response of sugarcane to bio-fertilizers (*Azotobacter/ Acetobacter/ Azospirillum/* PSB) was more pronounced in Peninsular Zone in India. Use of organic sources of nutrients in plant-ratoon system brought forth substantial enhancement of soil health parameters in most of the sugarcane growing soils. Bagasse is produced from local sugarcane crusher and sugar miller. It has nutrients which can be used for mass multiplication of bio-fertilizers (Rocha et al. 2011). After crushing hundred tonnes of sugarcane about three tonnes of press mud is produced (Gupta et al. 2011). It contents 50–70% moisture which is most favourable for soil micro-organisms, especially earthworms (Dominguez 1997). Pressmud also contains significant amounts of iron, manganese, calcium, magnesium, silicon, and phosphorus, and enhances the suitability of sulphitationpressmud (SPM) as a source of plant nutrients (Yadav and Solomon 2006).

Response of sugarcane to green manuring varies greatly depending upon the environments. Before chemical fertilizers came in use in sugarcane farming, green manuring was considered as an indispensable practice. The principal leguminous crops used for green manuring include sannhemp (*Crotolariajuncea*), dhaincha (*Sesbania aculeata*), senji (*Melilotus alba*) etc. Green manuring of *Sesbania*, green gram and cow pea increased soil microbial biomass carbon and soil microbial biomass nitrogen after decomposition indicating the key role in sustaining soil fertility and crop productivity (Bhander et al. 1998). Green manure legumes preceding sugarcane gave a benefit of 27-43 per cent increase in spring sugarcane yield and contributed 41-71 kg N ha^{-1} through biological nitrogen fixation (Mishra, 1971).

Green approaches are also applied for weed management through botanical / herbicides prepared at farm from local plants and animal origin products. Cultural operations are also adopted for management of insect–pest and diseases. Mono-culturing of sugarcane and continuous ratooning should be avoided for sugarcane smut management (Mansoor et al. 2016). Ratoon stunting disease can be controlled by planting healthy seed cane and sterilising cane knives and harvester blades. Use of disease free seed or stock and resistant varieties are the best preventive practice in pest management. Maintenance of biodiversity, effective crop rotation, multiple cropping, habitat manipulation and use of trap crops are also effective practices which can keep the population of insect-pest below economical threshold limit (ETL). Removal of affected plants and plant parts, collection & destruction of egg masses and larvae, installation of bird perches, light traps, sticky colour plates and pheromone traps are most effective mechanical methods of pest control.

Planting materials, growth regulators and planting methods:

Cane node technology of sugarcane planting was developed and found useful in reducing seed cane quantity in sugarcane cultivation in addition to rapid germination of cane buds. The highest germination of 77.87% was recorded under single node cane segments as against 40.52% under 3 bud setts at 40 days after planting. The cane yield obtained under single node technology was higher to the tune of 11.14% than that of 3 bud setts planted crop. Rapidmultiplication of newly released varieties of sugarcane is possible because of low seed requirement (17-18 qtl/ha against 60-80 q/ha under conventional method of planting). In India where soil moisture does not deplete rapidly mainly in Peninsular zone, planting of primed cane node are generally recommended while in North West Zone, conventional planting of 3-bud setts is recommended.Seed cane primed with ethrel (100 ppm for overnight soaking) showed early and higher germination (55%) than control (25%). Primed cane and phasic application of GA3 improved cane yield to the tune of 300 t/ha cane yield in autumn planted sugarcane variety CoLk 94184 at the ICAR-IISR, Lucknow.

Planting of sugarcane 2 or 3 bud setts in field trenches at a depth of 30 cm and spacing at 120/150 cm is recommended to get higher yields and good ratooning. It avoids crop lodging in light soils and increased input use efficiencies. Wider row spacing of 150 cm is recommended for tropical region of the country to facilitate mechanical harvesting as well as sustaining higher cane yields (Shukla et al. 2017). However, in sub-tropical region, increasing row spacing beyond 120 cm reduced cane yield. Development and adoption of thick varieties (Co 0238, Co 0118, CoS 8272, CoLk 11203 and CoLk 11206) particularly for subtropical region has great scope to improve the crop productivity through trench planting.

Trench method of planting in sugarcane is usually recommended in coastal areas which is prone to climatic conditions. But now it is being recommended and adopted in sub -tropical India also. Due to strong winds during rainy season, sugarcane crop may lodge. To save the crop from the strong winds, trenches are dug at a distance of 90-120 cm, with the help of ridger mounted tractor. The trenches should be about 30 cm deep. Setts in trenches are planted end to end method. Trenches are filled up with loose soil after planting. Besides this, Paired Row Trench Planting (30:150 cm) is modified version and is being adopted in various parts of the subtropical India. About 12-15 tonnes / ha seed cane is required through planting of 3 bud setts in paired row planting in trenches. However, the sugarcane yields >100 t/ha could be easily obtained through adoption of this planting method in subtropical India. However, in Maharashtra and other tropical regions because of higher individual cane weight, spacing may be increased up to 150 cm in single row planting. Trench planting avoids lodging of cane in both plant and ratoon crops. Paired row planting is the best practice for surface / subsurface drip irrigation system and involving maximum resource use efficiency and higher cane productivity. In sub tropical India, 25-30% cane yield could be increased. Besides 55–60% water saving has been reported through adoption of drip irrigation system in trenches. At ICAR-IISR, Lucknow, machine for trench planting and laying of drippers / laterals under sub surface drip have been developed. Planting through paired trench planter can increase multiple ratooning in the sugarcane system. Farmers can take 3-4 ratoon crops easily through adoption of trench method of planting and subsurface drip system. The adoption of this technology improved the sugarcane productivity and farmers income as well. The results of adoption of trench method of planting in Uttar Pradesh are being summarized below.

Furrow Irrigated Raised Bed technology (FIRB) of sugarcane planting has been developed at ICAR-IISR, Lucknow. The technology is recommended for subtropical region of the country. FIRB technique is an advanced technique of sugarcane planting after wheat sowing. In this technique, 3 rows of wheat are sown in the month of November on raised beds and sugarcane planting is done in the month of February in the furrow irrigated raised beds at distance of 80-85 cm. The technology is also promoted for cultivation of different vegetable crops in West Bengal, Maharashtra, Karnataka and Tamil Nadu. Sugarcane gives about 30% higher cane yield as compared to wheat-sugarcane sequential system without reduction in wheat yield. In this system, irrigation is applied only in furrows which requires less volume of water (20% water saving). The intercropping with autumn sugarcane crop is becoming key component in doubling farmers' income. Irrigation water and wheat seed up to 25% each could be saved. Farmers can apply N and irrigation water at grain filling stage to improve protein content without inducing lodging (Singh et al. 2005). Reduced lodging can have a significant positive effect on crop yield as many farmers do not irrigate after heading precisely to avoid lodging. Weeds between the beds can be controlled mechanically early in the crop cycle. Herbicide dependence is reduced. Hand weeding and hoeing between rows are easier. Compaction of soil is limited only to the furrows used as tramlines (tractor tracks). FIRB technique is the way of food security and economic growth of the farmers (Singh et al. 2002). Similarly, Ridge and Furrow method and Broad bed and furrow (BBF) system have also advantages including *in-situ* conservation of rainwater in furrows, better drainage of excess water and proper aeration in the seedbed and root zone.

Intercropping/Crop diversification:

In sub-tropical India, autumn cane intercropped with mustard / potato / rajma (French bean) is profitable. Intercropping of pulses especially green gram and black gram, and vegetables (onion) with spring sugarcane are recommended to provide opportunity to cane growers to earn extra income per ha.In tropical India, usefulness of vegetables like onion, knolkhol and cabbage in pre-seasonal planting are profitable. Simultaneous planting of wheat and sugarcane in the month of December particularly in western U.P. also increases the sugarcane productivity. In the areas where sugarcane planting is delayed and may leads up to May, technology provides ample scope of increasing crop productivity and farmers income. Sugarcane and wheat planting in FIRBS (Furrow Raised Bed System) is another option of increasing wheat and sugarcane crop yields. Besides, planting of gladiolus, marigold and other high value crops with sugarcane are becoming profitable. The selection of component crop may also depend upon the location and market demand. Selection of short duration crops / varieties and compatible with sugarcane are key components. The cost of production of the crop may be reduced due to common irrigation and field management practices in component crop and sugarcane (main crop). In general crop to the time of component crop in the field, the management revolves around component crop. After harvesting of the component crop, sugarcane management practices and input application are adopted.

Integrated Weed Management:

Sugarcane crop is affected by several weeds during the growing season. So for the economic management of weeds in sugarcane, three manual hoeings during tillering stage at 45, 90 and 120 days of the planting are recommended. However, under limitations of manpower-availability and labour cost etc., pre emergence application of either of atrazine @ 2.0 kg a.i./ha or metribuzin @ 1.0 kg a.i./ha (800- 1000 litres water/ha). In sugarcane ratoon, manual hoeings at 30, 60 & 90 days after ratooning can be successfully practiced. Further, trash mulching in between sugarcane rows also controls the weed growth. Application of trash and use of 2, 4 D @ 1kg ai /ha at 30 days after planting for control of broad leaved weeds improved the growth and yield of ratoon crop.

Irrigation management:

In present scenario, it has been observed that mean annual rainfall is decreasing in most of the sugarcane growing zones. Although, sugarcane is irrigated crop but cultivated under moisture stress environment in most of the states. Maharashtra, Karnataka, Andhra Pradesh. Tamil Nadu and western Uttar Pradesh are water stress states for growing sugarcane. The annual irrigation water requirement of sugarcane in subtropical India is about 1600–2300 mm. However, it ranges from 2000-3500 mm in tropical India. Thus sugarcane requires 6-8 irrigations in northern part and 30-40 irrigations in southern part of the country.

Keeping the scarcity and importance of water, drip irrigation method is being recommended to the sugarcane growers in water deficit areas. In drip irrigation, water is supplied directly to the root zone using a network of tubes and rippers/emitters nozzles placed along the water-delivery line. This involves precise control and manipulation of soil moisture temporally and spatially, which improves water economy, growth and ultimately crop yield. The uniformity of water application in drip irrigation would be as high as 95%, if the system is properly planned, designed and operated. In another customised irrigation system, sub-surface irrigation method is also recommended for sugarcane growers. This system needs proper care and monitoring of infrastructure developed. It reduces wastage of irrigation water and crop achieves better growth and development. About 50-60% irrigation water could be saved through adoption of drip method. It also saves fertilizers and improves nutrients use efficiency. The cost of drip system in sugarcane on per ha basis is Rs. 1.25 to 1.5 lakhs. However, in surface drip system laterals can be removed and inter-culture operations can be done easily. In subsurface system, drip system leads for one plant crop and minimum three ratoons without removal of dippers and laterals. Drip system of irrigation is encouraged by the Govt. and 80-90% subsidy is offered by the Govt. to minimize the burden on installation cost, effective resource use and increase farmer's income.

The experiments conducted under AICRP(S) also resulted in surface and sub-surface drip irrigation in sugarcane effectively saved water (up to 40%) and increased crop productivity to the tune of 20%. Fertigation with drip resulted in 25% saving of nitrogen compared with surface irrigation. Drip irrigation system once installed could be effectively used for 5 years (up to fourth ratoon crop). Under skip-furrow/alternate furrow irrigation, a practical and effective approach of saving irrigation water by 30–40% water without reduction in cane yield has been considered effective in which one row is skipped and irrigation is applied in each furrow. In alternate furrow method, alternating furrows for irrigation each time has also economized water use and the method is recommended under limited water availability conditions.

Insect - pest & Disease Management

Sugarcane is an annual crop and attacked by number of insect-pests and diseases. In changing climatic conditions, some minor diseases and insect – pests may cause economic damage to the crop. The management will be very important to improve the cane yield and productivity. The management of insect-pests and diseases of sugarcane crop requires strategic and effective management technologies to improve the benefit cost ratio. The management strategies include from selection of seed cane, sett treatment, monitoring of crop fields and need based application of cultural operations and protection technologies. Biocontrol agents, botanicals and bio-fertilizers *cum* bio-agents are being widely advocated to manage adverse situation while safeguarding our environment. Although sugarcane varieties through All India Coordinated Programme are identified on the basis of red rot, wilt and smut tolerance. Despite, after continuous use of seed of single variety, red rot symptoms may appear in selected pockets. Thus varietal diversification is important to control these diseases. Management of borer pests is also possible through natural enemies. Many plants are known to have pesticidal properties and the extract of such plants or their refined forms can be used in the management of pests. Among various plants identified for the purpose, neem has been found to be most effective. It is very effective botanical against variegated grasshoppers, green rice leaf hopper and cotton jassids (Chaudhary et al. 2017). Neem is also fairly good in managing beetles, aphids and white flies, mealy bug, scale insects, adult bugs, fruit maggots and spider mites (Gajalakshmi et al. 2004).

Beneficial microbes like fungi and bacteria have great potential in management of pathogenic microbes of the crop. *Trichoderma* spp. is among the most commonly isolated soil fungi. Due to their ability to protect plants and contain pathogen population under different soil conditions, these fungi have been widely studied and commercially marketed as bio-pesticides and growth regulators. *Trichoderma* spp. also produces numerous biologically active compounds, including cell wall degrading enzymes, and secondary metabolites (Yadav et al.; 2009). Efficacy of *Trichoderma* spp.,to manage the red rot disease was also observed along with moist hot air treatment (MHAT) and other treatments with an aim of modulating host resistance for red rot. The lower incidence was recorded in highly susceptible sugarcane variety. Use of pest predators and pathogens has also proved to be effective method of keeping pest problem below ETL. *Trichoderma viride*or *T. harazianum*or *Pseudomonas fluorescence* formulations @ 4 g/kg seed either alone or in combination to manage most of the seed borne diseases. Mass multiplication of *Diphaaphidivora*, the predator of sugarcane woolly aphid is recommended for sugarcane woolly aphid susceptible variety (Balikai et al. 2003).

Crop residue recycling:

Sugarcane is huge biomass generating crop. About 10–12 t/ha crop residue is generated through a sugarcane crop yielding about 80-100 t/ha. Trash is lignocellusic biomass which principally contains cellulose, hemi-cellulose and lignin. Its management is very important for sustainable sugarcane based cropping. It is good source for plant nutrients and conserves soil moisture, controls weeds and creates favourable rhizo-microbiome environment for optimizing nutrients availability and crop growth. Trash mulching (8-10 cm thick) in between rows of sugarcane ratoon has been recommended. Trash mulching conserves soil moisture, controls weed growth, and improves soil organic carbon (SOC) and availability of nutrients in ratoon crop (Yadav et al. 2009).

Mechanization in sugarcane cultivation:

Advancement in sugarcane cultivation comes with adoption of farm machinery. Sugarcane is annual crop and takes 10 to 12 months for maturity. The crop growth and productivity is directly linked with soil tilth. So in preparing good tilth for sugarcane cultivation, role of farm machinery is important. The farm machines (from simple to advanced labour saving devices) are developed by the Government and private organizations. A number of machines have been designed and developed at the Indian Institute of Sugarcane Research, Lucknow keeping in view the soil and agro-climatic conditions and prevailing agronomic practices. Sugarcane cutter planter, ratoon management device, planter for inter crops, trench planter and residue shredder are few of these machines recommended for profitable cultivation. Farmers may use these machines on their own fields. Sugarcane cutter planter has been developed by ICAR-IISR, Lucknow. Ridger type sugarcane cutter- planter, PTO driven is being widely used and performs major operations during cane planting at an adjustable row spacing. It has also effective capacity of planting one ha in 4-5 hours and saves approximately 60% cost of planting operation. The planting operations *viz.*, opening of furrows, planting the setts, placing the fertilizers and pesticides and covering the setts have been combined in single pass. Planting through sugarcane cutter planter conserves soil moisture and improves germination. This is very much favourable under hot and drier conditions in subtropical India particularly in the month of April – May. The machines may be purchased on custom hiring basis through collaborations of sugar mills / cooperative societies.

Ratoon management

Ratooning is a common practice of growing sugarcane crop from sprouts of underground stubble left in the field after harvest of the main crop. It is an important crop because ratooning saves the cost of seedbed preparation, seed, and planting operations. Ratoon crop matures earlier than the main crop. However, most often, cane yields of ratoon crop are lower than the main crop due to many factors including soil compaction (Verma 2002), decreased soil fertility (Hunsigi 2001) and inefficient use of applied fertilisers (Sundara and Tripathi 1989). In sugarcane plant – ratoon system, at initiation dismantling of ridges, stubble shaving and off-barring is recommended for good ratoon yields. Gap filling with slip setts / pre-germinated setts / poly bag raised settlings is a must if gaps exceed 10-15% of normal crop stand. More than 60 cm distance between subsequent clumps is considered as gap in ratoon crop. At IISR Lucknow, paired row system of planting (120:30) reduced gaps and optimized plant population in subsequent ratoon. Low stubble population due to gaps and poor bud sprouting in winter season were found to be major bottlenecks in increasing ratoon productivity. ICAR-Indian Institute of Sugarcane Research has developed tractor operated ratoon management device (RMD). RMD performs dismantling of ridges, interculturing between rows, placing organic manures, fertilizers and mild earthing up in single pass at the time of initiation. Besides, trash chopper has also been developed for *in-situ* trash mulching. It creates favourable soil environment for better bud sprouting and further growth of ratoon crop.

Ratoon crop matures in 10 months and gives an advantage of early maturing variety. Harvesting of plant crop close to the ground level is recommended to improve the stubble bud spouting. However, if the harvesting of crop close to the ground level could not be done, stubble shaving is recommended. The ridges should be dismantled after harvesting of plant crop. In order to improve the soil physical condition and also to prune the stubble roots, the inter-row spacing must receive deep cultivation (off-barring) followed by irrigation. Three splitting of fertilizer nitrogen may be done at the time of initiation, 45 days and 75 days of ratoon initiation. Twenty five percent higher N is recommended in ratoon crop as compared to the plant crop. The ratoon crop should be fertilized with K at the rate of 80 kg K_2O/ha to avoid the lodging and improve sugar recovery. The requirement of K_2O and phosphorus could be ascertained by soil testing. Earthing–up in the month of July-August and wraping/propping should be done to check the growth of excessive tillers and avoid lodging in crop.

Conclusion:

Sugarcane is vegetative propagated crop and requires 10 to 12 months for maturity. The changes in atmospheric conditions can affect plant biomass, cane & juice quality and sugar recovery. Adoption of green technologies from seed selection to harvesting are very important to improve the productivity and sustainability. Sugarcane crop encounters all seasons and faces extremes of climatic conditions and also attacked by several insect-pests, diseases and weeds. It becomes very difficult to sugarcane cultivators to grow crop in adverse climatic conditions and achieve maximum cane productivity and sugar recovery under limited application of inputs. So to minimise the adverse effect of climate, high yielding and high sugar varieties have been developed under AICRP(S) in addition to advanced crop production and protection technologies.

The small interventions of green technologies will certainly provide benefits to the farmers. Comprehensive approaches including micro-irrigation techniques, use of biofertilisers and crop residue recycling to minimise the use of chemical fertilisers and improving soil health is required. Nutrient management, water management, weed management, ratoon management, integrated pest management (IPM) and integrated disease management (IDM) technologies have been developed and these technologies are being adopted on farmer's fields.

Sugarcane crop is not exhaustive rather than soil fertility restorer, if the crop products/ by products are being managed well in soil-sugarcane– sugar production system. In this scenario, trash, press mud cake, vinasse, composted bagasse, rhizodepositions of stubble plays great role in sustaining soil fertility and increasing crop productivity. Intercropped green manuring through dual purpose legume crops such as cow pea, green gram & black gram are the viable options. Integrated weed management in ratoon through trash mulching, one hoeing and single application of atrazin @ 2 kg ai/ha during ratoon initiation minimizes crop weed competition during tillering phase. Adoption of skip furrow/alternate furrow techniques effected water saving up to 35-40% without yield reduction. Planting in FIRB method particularly in sugarcane–wheat system improves the sugarcane yield besides improving water use efficiency (WUE) and nutrient use efficiency (NUE). Adoption of IPM reduces burden of chemicals on the soil and crop besides increasing population of beneficial insects. Use of organics, biofertilizers reduces the amount of chemical fertilizers and improves the NUE and response of the crop to nutrients. Besides increased water holding capacity and nutrients availability provides sustainability to sugarcane based system. Sugarcane productivity in India has increased to >79 t/ha. However, keeping in view the achievable potential of the crop, we have still scope to double the productivity and farmers income while safeguarding environment (soil, water and air).

Further Readings/ References

Shukla, S.K., Solomon, S., Sharma, L., Jaiswal, V P., Pathak, A D., Singh Priyanka. (2019). Green technologies for improving cane sugar productivity and sustaining soil fertility in sugarcane based cropping system. Sugar Tech.21(2):186-196

Shukla, S.K.,Singh K. K, Pathak, AD., Jaiswal, VP., and S. Solomon (2017). Crop Diversification Options Involving Pulses and Sugarcane for Improving Crop Productivity, Nutritional Security and Sustainability in India.Sugar Tech.19(1):1-10

Chapter No. 5: All India Coordinated Research Project in Sugarcane; Impact on varietal development and improving sugar recovery

S.K. Yadav*, S.K. Shukla, and A.D. Pathak
ICAR-Indian Institute of Sugarcane Research, Lucknow, Uttar Pradesh-226002, India
*Corresponding author E mail: sanjaybhu05@rediffmail.com

Importance of Sugarcane

Sugarcane is one of the multi-product main cash crop of India and its use for sugar and renewable energy (production of ethanol) has become more challenging than ever before to cope-up the demand of adequate sugarcane production in spite of the shrinking available natural resources. According to estimates by various agencies, the population of the country is expected to swell to 1.65 billion by 2050. It is estimated that the per capita consumption of sweetener is likely to increase up to 35 kg (28 kg white sugar and 7 kg gur) by 2050. At this rate of consumption and population growth, requirement of sugar by 2050 would be double (nearly 51 MT) against the present requirement of 25-26 Million tonnes. The government's policy on bio-ethanol for blending with petrol will boost the demand of sugarcane as raw material in the country. In order to meet the growing demand of sugar and energy by 2050 in India, around 630 million tonnes of sugarcane as against 350 million tonnes today with a recovery of 11.5 per cent as against 10.7 per cent will be required.

About AICRP on Sugarcane

The AICRP on Sugarcane was sanctioned by ICAR during 1970-71 for providing a platform at the national level to develop and coordinate the research on varietal/technological advancement on sugarcane by involving ICAR Institutes, State Agricultural Universities, State Government Departments and NGOs. At present, the research work is being pursued by involving scientists of four disciplines *viz*. Crop Improvement, Crop Production, Entomology and Plant Pathology under national network mode to address the issues of different zones. At present, there are 22 regular centres and 15 voluntary centres for conducting research and multi-location testing of technology. As per the mandate, main emphasis is laid on the development of improved sugarcane varieties, crop production and protection technologies suited to commercial cultivation under different agro-climatic conditions in the country. Under flagship programme of varietal development, 131 sugarcane varieties were developed for commercial cultivation in different parts of the country. The impact of location specific improved sugarcane varieties and technological advances resulted into consistent increments in sugarcane and sugar productivity at the national level.

Brief history of AICRP on Sugarcane

AICRP on Sugarcane started its operation with seven main centres located at Jalandhar, Pantnagar, Pusa, Anakapalle, Padegaon, Lucknow and Coimbatore and eleven sub-centres at Uchani (Haryana), Bethuadahari (West Bengal), Sehore (Madhya Pradesh), Cuddalore (Tamil Nadu), Mandya (Karnataka), Kolhapur (Maharashtra), Navsari (Gujarat), Thiruvalla (Kerala), Lucknow University (Uttar Pradesh), Jorhat (Assam) and Bhubaneswar (Odisha). At the same time, Foundation Seed Programme (FSP) was launched in 1971 as part of the AICRP on Sugarcane and was implemented in 1975 at eight centres viz., Lucknow, Jalandhar, Pusa, Hisar, Bethuadahari, Pravaranagar, Jaora and Shahjahanpur for producing disease-free seed cane through heat therapy. FSP continued till end of VII Five Year Plan, i.e., 1992 as healthy seed cane production work was taken up under Sugarcane Adaptive Research Project. The FSP centre, Shahjahanpur became regular centre of AICRP on Sugarcane. Later on Sehore, Jorhat, Bhubaneswar and Jalandhar centres were shifted to Powarkheda, Buralikson, Chiplima and Ludhiana, respectively. During 8^{th} Five Year Plan, three new regular centres at Sankeshwar, Faridkot and Kota were sanctioned, whereas sub- centre at Lucknow University was closed. In 1997, Sriganganagar centre was included as a regular centre in 1997. Again Chiplima centre was shifted to Nayagarh and Ludhiana centre to Kapurthala. Since 9^{th} Five Year Plan, 22 main (regular) centres with no sub-centre are continuing. At present, there are 22 regular centers and 15 voluntary centers for conducting research and multi-location testing of technology.

Mandate

- Evaluation of locally adapted sugarcane varieties with improved yield and quality as well as resistance to biotic and abiotic stresses.
- Development of package of practices for higher cane & sugar production.
- Development of low cost technologies for sugarcane production.
- Intensifying and extending the networking facility and information generation for transfer of technology to the farmers and sugar industry.

Objectives

- To coordinate multilocation testing of germplasm and advance breeding materials for evaluating appropriate region/location specific improved varieties.
- To organize and conduct strategic and applied research of inter disciplinary nature for evolving appropriate region/location specific package of practices for crop production.
- To develop region or location specific strategies for integrated disease and pest management.
- Enhancement and maintenance of disease free nucleus seed material for distribution to the cooperating organizations.
- To disseminate generated information and technology.

Agro-climatic zones for sugarcane cultivation under AICRP on Sugarcane

Sl. No	Zone	States
1	North West Zone	Punjab, Haryana, Rajasthan, Central and Western Uttar Pradesh and Uttarakhand
2	North Central Zone	Eastern Uttar Pradesh, Bihar and West Bengal
3	North East Zone	Assam
4	East Coast Zone	Coastal Tamil Nadu & Andhra Pradesh and Odisha
5	Peninsular zones	Gujarat, Maharashtra, Karnataka, Kerala, Interior of Tamil Nadu & Andhra Pradesh, Madhya Pradesh & Chattisgarh

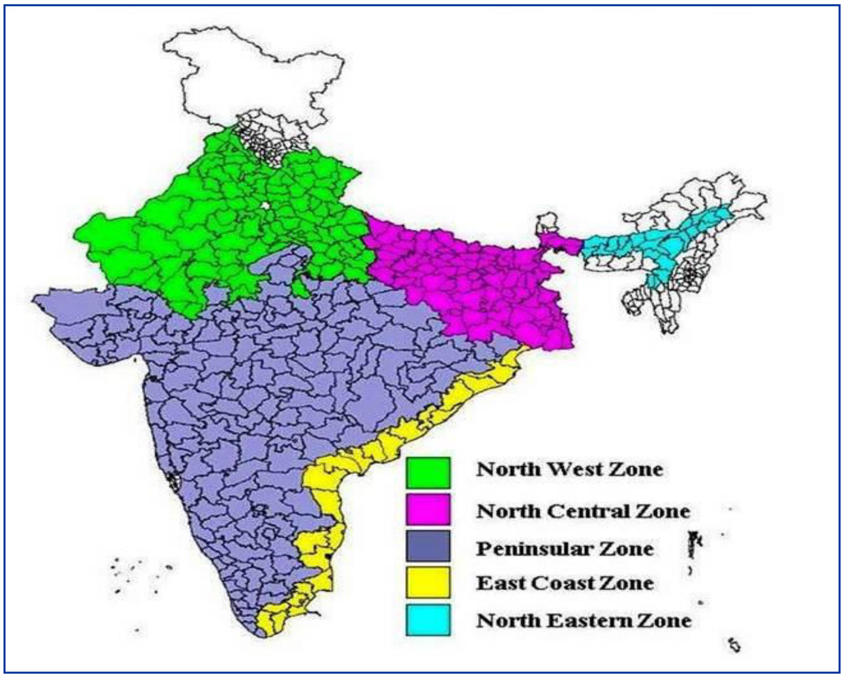


Fig. Agro-climatic zones for sugarcane cultivation under AICRP on Sugarcane

Location specific (Zone/centre wise) Constraints

Sl. No.	AICRP Centre	Constraints
North West Zone		
1.	ICAR-IISR, Lucknow	Low yield and sugar recovery, short elongation phase, erratic distribution of rain fall and high temperature during summer.
2.	UPCSR, Shahjahanpur	Low yield, low sugar content, soil salinity, red rot & pests incidence.
3.	ARS, Kota	Very high temperature during May & June, unavailability of good quality seed and problem of insect pests & diseases.
4.	ARS, Sriganganagar	Higher temprature about 50^{o}C, low humidity during May & June, high borer infestation, low yield of ratoon crop due to iron deficiency.
5.	RRS, Uchani	Soil salinity, moisture stress, heat stress, flowering in varieties and poor ratoon.
6.	GBPUAT, Pantnagar	Poor yield, low recovery, pokkah boeng, borers, water logging and moisture stress.
7.	PAU RRS, Kapurthala	Hot & dry weather, extremely high temperature (>45^{o}C), frost in winters, moisture stress, red rot, wilt, early shoot borer, top borer & Pyrilla.
8.	PAU RS, Faridkot	Brackish & salty water, low annual rainfall, more evapo-transporation rate and saline-alkali soils.
Peninsular Zone		
9.	ICAR-SBI, Coimbatore	Erratic distribution of rainfall, low sugar recovery and yellow leaf disease.
10.	RSJRS, Kolhapur	Flood prone area, high incidence of insect-pests especially white grub & diseases.
11.	MSRS, Navsari	Heavy rainfall, water logging, salinity and mono-cropping.
12.	CSRS, Padegaon	Low cane and ratoon productivity, soil salinity & drought, brown spot, rust, YLD, pokkah boeng and white grub.
13.	ZARS, Powarkheda	Low rainfall, poor ratoon yield, lack of seed cane of improved varieties.
14.	ARS, Sankeshwar	Moisture stresses, salinity, water logging, white grub and moderate to low productivity of ratoon.
15.	ZARS, Mandya	Depletion of organic carbon in soil, quality seed availability and borers.
16.	SRS, Thiruvalla	Flood and water stagnation, non-availability of improved weedicides / pesticides.
East Coast Zone		
17.	RARS, Anakapalle	Low sugar recovery, water logging, lodging of crop and infestation of borers pests.
18.	SRS, Cuddalore	Conducive climatic for occurrence and spread of red rot of sugarcane.
19.	SRS, Nayagarh	Drought, water logging, flood, high temperature, salinity and high cost of cultivation.
North Central Zone		
20.	SRS, Bethuadahari	Poor cane yield and low recovery, Plassey borer.
21.	SRI, Pusa	Water logging.
North Eastern Zone		
22.	SRS, Buralikson	Water logging, poor cane yield, low sugar recovery, borers & wilt.

Impact of the varietal development under AICRP on Sugarcane

Sugarcane varieties developed under this Project since 1970-71 for all the 5 sugarcane growing zones in the country brought about 2.7 times increase in sugarcane production and added significantly to the National Exchequer. Different varieties made the dent during their productive periods. At present following outstanding varieties went like wild fire among the farmers and increased the sugarcane and sugar productivity. Based on the certain parameters and experiences, a brief account of impact assessed/estimated is given as under-

1. **Tropical Region:**

Impact analysis of Co 86032 as done by Ram *et al*, 2017 indicated that that the cane yield level was maintained at about 100 t/ha throughout the period except during drought year corresponding with the cultivation of CO 86032 in Tamil Nadu. The variety spread in almost all the states of Tropical India including Tamil Nadu, Karnataka, Maharashtra, Gujrat, unified Andhra Pradesh and Kerala. The variety covered 11.96 m ha area which approximately generated Rs. 20354 crore as additional monetary benefits. The impact analysis of variety on sugar recovery with the base year of 1999-2000 revealed that with introduction of the variety Co 86032, the average sugar recovery increased to 9.45% compared to previous varieties (8.69%). The improvement in the sugar recovery was calculated in monetary value.

2. **Subtropical Region:**

Impact analysis of one of the popular varietie Co 0238 in the subtropical region worked out in monetary terms during 2012-2017. Additional cane produced due to increased yield of Co0238= 79.64 lakh tonnes and due to increased sugar recovery (%) was estimated to be 2,71,687.84 tonnes which amounted to be of Rs 815.06 crore The total value of additional sugarcane and sugar was worked out to be 2229.92+815.06=3044.98 crore. Thus, per ha additional income to the farmers comes to about Rs 34196/ha and additional income to the sugar mills comes around Rs 12499 on hectare basis.

Area expansion under improved varieties of AICRP (S) in Uttar Pradesh

The trend of area expansion over total cultivation of sugarcane and depicted through Fig.1. The data as obtained from the office of Cane Commissioner Government of Uttar Pradesh clearly indicated that there has been an exponential growth of area brought under improved varieties developed under this project. The total cultivated area of AICRP varieties was increased from 5.93 % to 93.4% over the same period in Uttar Pradesh.

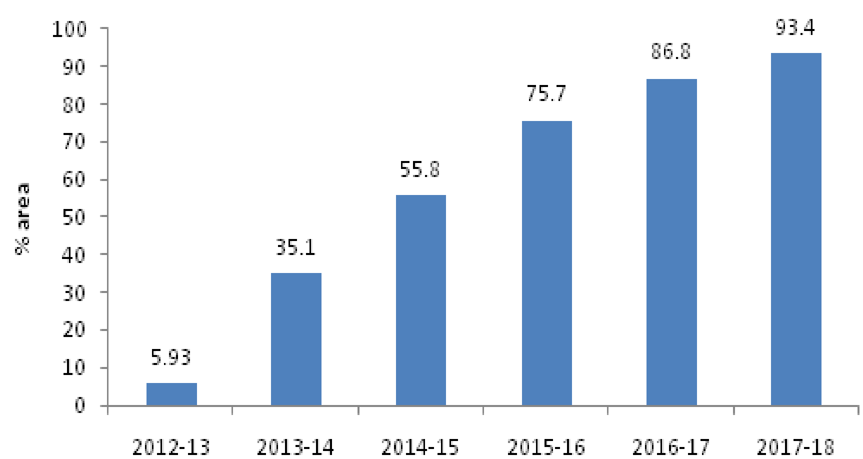


Fig.1 Adoption trends of AICRP Early varieties in UP at farmer's field

Spread of AICRP varieties during 2016-17 in subtropical India

The area under top four popular varieties (Co 0238, Co 0239, Co 0118 and Co 98014) in subtropical India comprising major sugar producing states (such as Punjab, Haryana, Uttar Pradesh and Uttarakhand) is about 9.97 lakh ha (41.8%) during 2016-17 crop season. Out of these four varieties, Co 0238 occupied about 8.63 lakh ha (36.19%) area in these four states and spread faster than other new varieties (Fig. 2).

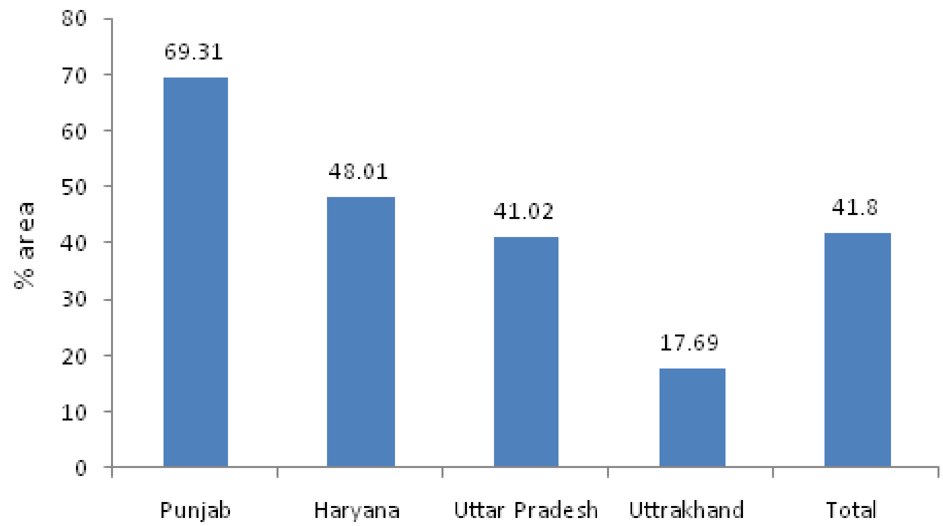
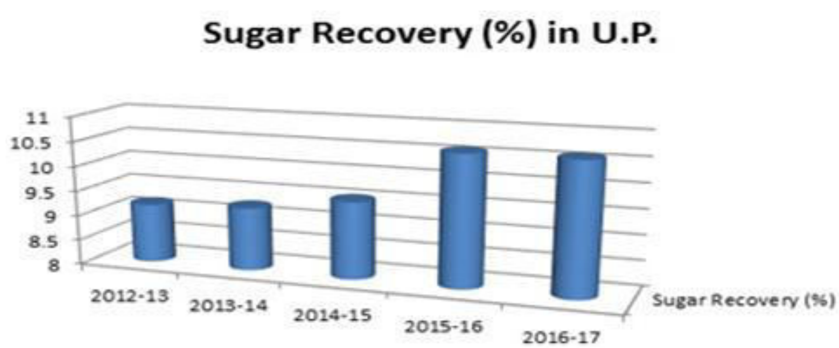


Fig. 2 Percent area of four AICRP varieties in total sugarcane cultivation in subtropical india during 2016-17

Source: Ram et al. 2017. (Ram Bakshi, Hemaprabha G and Murali P. 2017. Karnal Wonders: Early maturing varieties of Sugarcane for sub tropical India. Indian Farming 67(02): 69-72.

Technological interventions of AICRP (S) for sugar recovery

Uttar Pradesh occupied largest area under sugarcane cultivation in India. Stagnant cane yield and low sugar recovery became the identity of sugar industry in Uttar Pradesh over the years. There was a challenge to break this jinx with large scale adoption of technological interventions. This challenge was accepted and started working with deciding strategic plan encompassing identification of technological interventions, sensitization of stakeholders, deploying scientific manpower with active cooperation and logistic support from cane development department, Govt. of U.P. & sugar mills. Unavailability of healthy seed material was major impediment in replacement of old cane varieties with newly released varieties. This was addressed with implementation of entrepreneurship development programme in seed cane production in farmers' fields. Every year 2000 t of breeder seed of new cane varieties was produced and multiplied in nurseries and cane development department of state government of Uttar Pradesh ensured that it reached to the actual field of the farmers. In this way, scarcity of healthy seed material of new cane varieties was mitigated to a great extent. Before year 2012 State cane department was unwilling to recommend varieties tested under AICRP (S) and subsequently released by Central Variety Release Committee (CVRC). This issue was raised before State Government of U.P. and since 2012, CVRC released varieties was also added in the list of variety recommended for cultivation in the State.



This paved the way for large scale adoption of early maturing high sugar variety specially Co 0238 and CoLk 94184 in Uttar Pradesh. Introduction of these varieties changed the sugarcane and sugar production scenario of U.P. Dramatically another breakthrough in planting was achieved by the adoption of Trench method in about 2.0 lakh ha leading to cane yield enhancement by 15-20 t/ha. Post-harvest losses remained major concern as it greatly impairs sugar recovery. This problem was addressed with spraying a mixture of sodium metasilicate (0.5%) + benzalkonium chloride (0.2%) solution on cane after harvest. This led to gain in sugar recovery by 0.3 to 0.5 units. The large scale adoption of different variants of sugarcane planters helped farmer to complete planting timely amidst labour scarcity and this also helped gain in yield by 8-10%. Likewise, introduction of ratoon promoter machine enhanced ratoon cane yield by 10-15%. Overall impact of these technological intervention developed by AICRP on sugarcane platform, resulted in higher sugar recovery in Uttar Pradesh.

Impact of AICRP on sugarcane in the country

As per the mandate, main emphasis is laid on the development of improved sugarcane varieties, crop production and protection technologies suited to commercial cultivation under different agro-climatic conditions in the country. Under flagship programme of varietal development, 131 sugarcane varieties were developed for commercial cultivation in different parts of the country.

In India, more than 95% area is occupied by sugarcane varieties developed through AICRP on Sugarcane network. The technological advances in sugarcane cultivation have triggered average sugar production in the country from 3.9 mt during 1970-74 to 30.78 mt during 2017-20. (7.89 times).The increasing trend of sugar recovery from 9.72 to 10.56% during the above period was achieved. The impact of location specific improved sugarcane varieties and technological advances resulted into consistent increments in sugarcane and sugar productivity at the national level.

Chapter No. 6: Recent Advancements in Jaggery Manufacturing Process and its Export Potential

R D Singh and S I Anwar
Principiapl Scientist
ICAR-Indian Institute of Sugarcane Research, Lucknow

Introduction

In India, sugarcane is normally processed for making sugar, jaggery (gur) and khandsari. Out of 350 million tonnes of sugarcane produced annually about 67 per cent is used for making sugar and about 21 per cent is utilized by jaggery and khandsari under the decentralized sector. Remaining is used for seed, feed, chewing or raw juice drinking purposes. Liking for jaggery by the people in general and rural mass in particular cannot be easily ignored. On one hand, sugar and khandsari are merely sweeteners; jaggery is a food material as well. It is also liked for its medicinal properties. It is cooling, diuretic, aperient, act as tonic, refreshing, improving throat conditions, normalizing semen and sperms, aphrodiac, lactogenic and cardiac tonic. Jaggery is more nutritious than sugar and is a good source of minerals like calcium, iron and phosphorus. It also has substantial quantity of reducing sugars in the form of glucose and fructose, thus it provides instant energy. It is a natural sweetener of rural areas. Sugarcane contributes about 90 per cent of the sweeteners' production. About 32 per cent demand of total sweeteners' consumption in the country is met out with jaggery and khandsari, mostly in the rural areas.

Unit operations in Jaggery Manufacturing

i. Sugarcane juice extraction

Traditionally, sugarcane juice extraction is done with the help of bullock operated vertical crusher from a long time . The capacity and efficiency of these crusher is low. After the availability of mechanical power and electricity, capacity of theses crusher were improved . For further enhancement of the capacity and efficiency horizontal crusher were developed. They are operated with 10 hp electric motor. Rollers fitted in these crushers horizontal and 4 in number. For safety of the operator/ user protecting shield are also provided. The capacity of the crushers are reasonably high. Presently, 4- roller crusher has been developed and used in jggery industry. These crusher have capacity of 10 q per hour and extraction percentage to the tune of 65-70%

ii. Heating and clarification

The extracted juice is collected through underground PVC pipeline into a juice settling tank covered with thick muslin cloth for removal of trash and bagasse particles. Settling helps in removal of heavy impurities. Clean juice is then pumped into open pan on the furnace for concentration. The juice is heated in open pan furnace and vegetative clarificants are added into it for its' clarification. These clarificants help in formation of thick froth having colloidal impurities on juice surface, which is removed using strainer. Out of various vegetative clarificants Deola (Hibiscusficulneus) was found to be the most effective (Singh 1998;Banerji 2008). The removed scum is poured in scum set-tling tank, which helps in recovery of juice going as wastewith scum. Introduction of this tank into the prevalent juice clarification process improves jaggery recovery by 0.4%(Baboo 1994) besides light colour and crystalline texture.

iii. Juice boiling and concentration

After clarification, juice is boiled vigorously over the furnace. A little quantity of ustard/coconut oil is added to check excess frothing. Based on requirements of jiggery production, the furnace may have single, two, three, four or five pans. Indian Institute of Sugarcane Research (IISR), Lucknow has developed improved/efficient two-pan (Singh et al. 2009) and three-pan furnaces (Singh 2009) which save bagasse. To further improve The efficiency; pans oftwo-pan furnace have been modified providing fins to their bottoms which resulted in saving of fuel (28%) and juice processing time (17%) (Anwar 2010; Anwar et al. 2009).Extra pans are also provided in jaggery making furnaces to further improve the efficiency by trapping waste heat going along flue gases through chimney and are utilized for pre-heating of juice. The triple pan furnace developed at IISR Lucknow possesses these special features which had34.3% heat utilization efficiency (Singh2009).

iv. Moulding

The concentrated juice with appropriate consistency is transferred into a wooden tray and puddled using ladle. The concentrate (slurry) is then transferred into the moulds, dried, packed, stored and marketed. The jaggery manufacturing system developed at IISR is shown in Fig. 1. Earlier, jaggery used to be produced by different traditional methods in different shapes and sizes in India which ranged from 15 to20 kg bucket shape to irregular shapes and varied from place to place. Some of these shapes posed problems in moulding, drying, packaging and distribution etc. To overcome these problems, IISR Lucknow developed moulding frames and the techniques for moulding jaggery into different desired shapes and sizes viz; brick (500 and 250 g), cubes (25 mm cube, weighing 20–22 g each; Fig. 2) and rectangular shapes (25 9 25 9 12.6 mm, weighing about 10–11 g each). Of these, 25 mm jaggery cubes packed in attractive packages are hygienic, helpful in distribution and has become very popular among consumers.

Packaging

Jaggery packed with hessian cloth lined with polyethylene sheet alone or packed with tin foil covered with polyethylene or hessian cloth was found better than wooden and card board boxes, thick gunny bags, plastic containers and earthen pots. Three ply (PET/Al.FOIL/POLY) packaging material helped more in checking the inversion rate. Gupta et al.(2002) observed that nitrogen packaging of solid jaggery maintained freshness for longer period compared to vacuum packaging which hardened the jaggery samples.

Value Addition of Jaggery

To make jaggery more nutritious, it is fortified with cleaned, shredded/grated and dried natural source of vitamin C viz; Indian gooseberry (Aonla–Emblica officinalis L.) using IISR jaggery moulding frames (Anwar *et al*. 2010)

Export o f Jaggery

Presently, jaggery and alternative sweeteners worth more than Rupees 2,000 crore are being exported to different countries viz; U.S.A., Canada, U.K., U.A.E., Kuwait, Oman, USSR (former), Philippines, Bangladesh, etc.

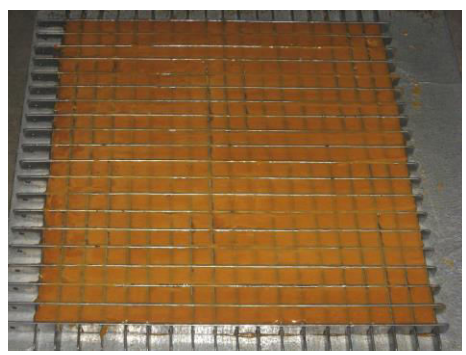
(a) Sugarcane variety CoLk 09204

(b) Sugarcane crushing

(c) Juice filtration

(d) Juice boiling and concentration

(e) Puddling of concentrated mass



(f) Moulding of jaggery in IISR moulding frame

Fig.1. Preparation of jaggery

References

Anwar, S.I. 2010. Fuel and energy saving in open pan furnace used in jaggery making through modified juice boiling/concentrating pans. Energy Conversion and Management 51: 360–364.

Anwar, S.I., R.D. Singh, and J. Singh. 2009. Value addition of jaggery (gur) through natural source of vitamin C. Indian Journal of Sugarcane Technology 24(1 & 2): 48–51

Banerji, R. 2008. Clarification of sugarcane juice for quality jaggery.In Processing, handling and storage of sugarcane jaggery, ed.Jaswant Singh, and R.D. Singh, 65–69. Lucknow: Indian Institute of Sugarcane Research

Gupta, R., P. Singh, and A. Suman. 2002. An investigation on packaging of jaggery in vacuum and nitrogen environment. In Proceedings of National Seminar on status, problems and prospects of jaggery & khandsari, ed. Jaswant Singh, 193–196. Lucknow:IISR.

Singh, J. 1998. Jaggery and khandsari research digest, 140. Lucknow: Indian Institute of Sugarcane Research

Singh, J. 2009. A three -pan furnace for sugarcane juice concentration to make jaggery. Indian Journal of Sugarcane Technology, 24(1&2): 45–47.

Singh, R.D., B. Baboo, A.K. Singh, and S.I. Anwar. 2009. Performance evaluation of two pan furnace for jaggery making. Journal of Institution of Engineers (India) 90: 27–30.

Chapter No. 7: Future prospects of artificial intelligence in sugarcane culture and in sugar industry

Rajesh U Modi
Scientist, Agricultural Engineering Division
ICAR-Indian Institute of Sugarcane Research, Lucknow
Email: rajesh.modi@icar.gov.in

Introduction

Sustainability in the sugarcane (*Saccharum spp. hybrids*) production system depends on the natural inputs, climate aberrations, and environmental impact aiming to maintain the shrinking natural resources at adequate levels for the production of sugarcane, quality sugar, and allied products. As an industrial crop, sugarcane plays a crucial role in socio-economic development with an increasing human population. It is widely cultivated in over 130 countries on 26.47 million hectares, producing1869.7 million tonnes per year (Anon., 2022a). In the present context of climate change, sugarcane is prone to yield loss (12-83%) due to various aspects including inappropriate agronomic, crop engineering, and plant protection management practices (Hossain *et al*., 2001; Suganthi *et al*., 2019; Sushil *et al*., 2022). The biggest question that lies in front of the sugarcane scientist is how to address these issues and responsibly attain sustainable sugarcane production. The most optimal strategy to address this is data-driven agriculture with cutting-edge smart farming technologies such as precision farming, the internet of things, application of sensors, robotics and artificial intelligence (AI). Amongst all, AI gained momentum in the last decade and dynamically adopted in various sectors, including agriculture, in assisting with precision farming and mechanized technologies.Technology based on artificial intelligence is being used to solve the world's issues with food and agriculture. With the use of AI in sugarcane cultureand sugar industry (Fig. 1), it is now possible to gather a lot of data from the fields and make effective judgments that are supported by the data. However, the question comes to mind, what is AI: It is a technique for teaching a computer, a computer-controlled robot, or software to think intelligently in the same way that humans do. AI is achieved by examining human brain patterns and assessing the cognitive process implemented through machine learning (ML) and deep learning (DL). ML and DL havethe potential to process numerical as well as digital image-based data at high speed by channelizing accurate results without human interference and error.

Machine learning allows AI to learn, and it is accomplished by employing algorithms to find patterns and develop insights from the data to which they are exposed. While DL, being the subcategory of machine learning, gives AI the capacity to replicate the human brain's neural network and make sense of data patterns, noise, and causes of confusion. Deep learning is a very new and cutting-edge method that has a lot of potential for image processing and shows early signs of success. Convolutional neural network (CNN) models for deep learning (DL) had a multi-layer structure, with each layer providing a feature response and passing the pertinent features to the subsequent layer structure.The typical structure of a deep learning-based convolution neural network is shown in Fig 2. The machine runs through numerous elements of photos and identifies them based on their features, and extracts themautomatically. Later this machine categorizes each photo based on the learned feature and feature qualities it contains. There are three main layers of a neural network: the input, hidden, and output (Fig 2). The input layer depicts the filter that scans the image for features in the first step. Next, hidden layers are accountable for all the mathematical computations during feature extraction on input layers which serve as substitutes. The number of hidden layers determines how complex the data input and output are. The complexity of the input data and the number of hidden layers both affect how accurately the output is predicted. Ultimately, the output layer provides separated images as output in terms of class or detection of objects.

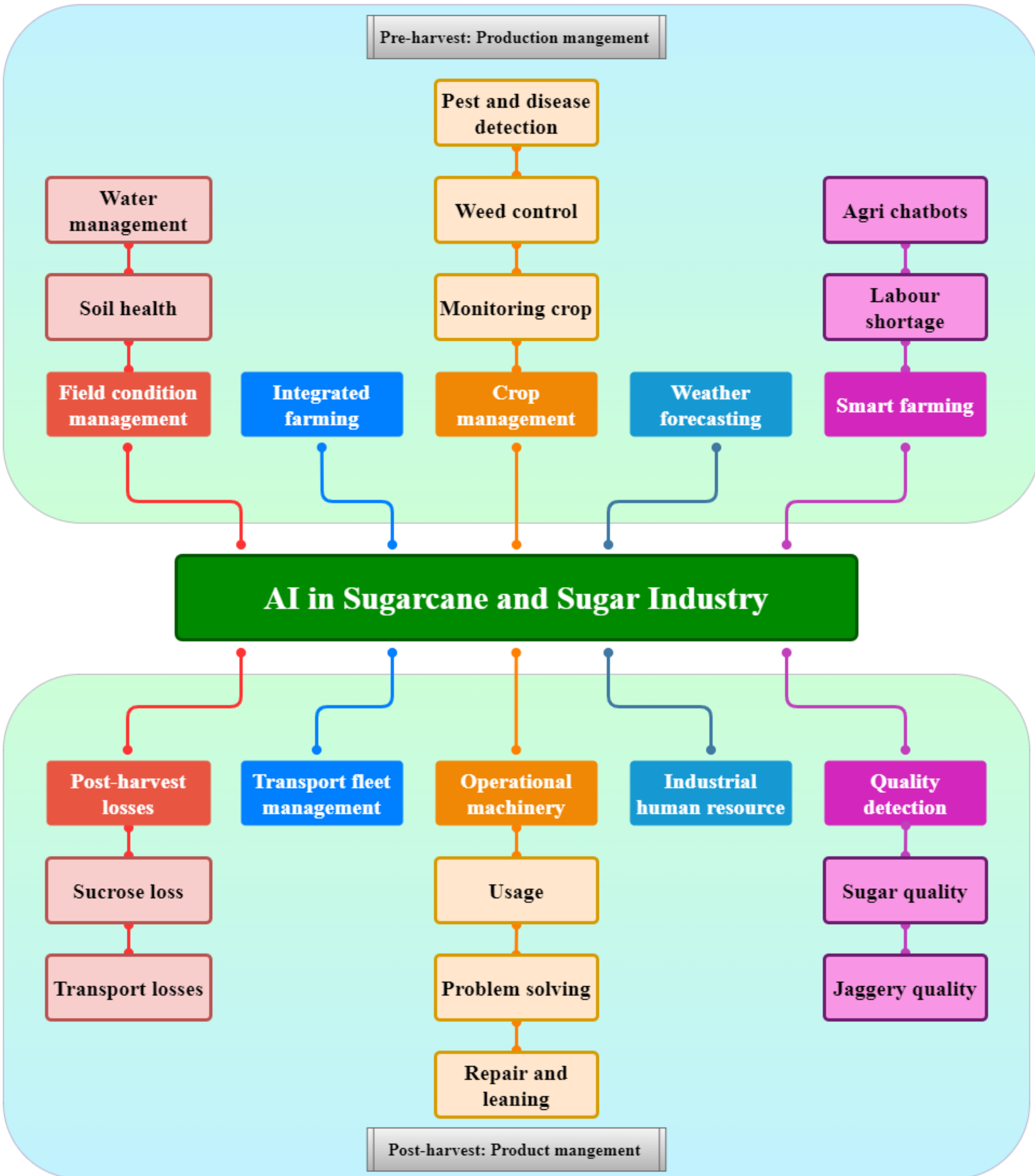


Fig. 1 Applications of AI in sugarcane culture and sugar industry

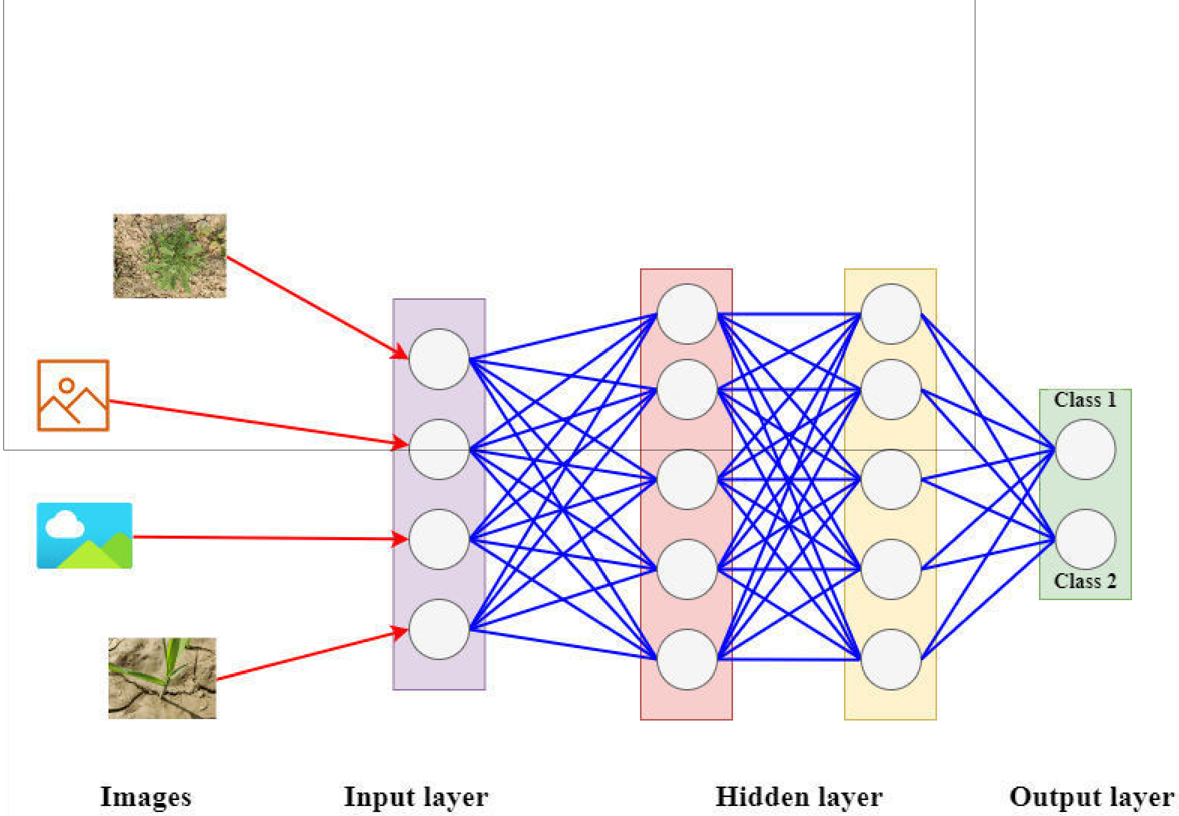


Fig. 2 The typical structure of a deep learning-based convolution neural network

Advantages of AI in sugarcane

- Boost productivity without endangering the environment
- Strengthen the sugarcane farming and sugar business
- Producing good quality and nutritious sugar and jaggery-based products
- Pests and disease management
- Improvement in crop management practices
- Identify and address issues that farmers confront
    - changing climates
    - lack of resources
    - infestation

Keeping the above view point in mind this chapter deals with the applications and future prospectus of AI-driven ML and DL techniques in terms of sugarcane farming operations such as tillage and seedbed, planting, intercultural and weeding, irrigation, nutrient management, plant protection, harvesting, post harvesting and sugar industry.

Future prospects

There are enormous applications of AI in sugarcane culture and the sugar industry which are discussed on an operational basis:

Tillage and seedbed

AI-driven data rich agricultural automation enables the production of fresh, faster, and sustainable cane produce. Machines, unlike humans, can run for longer periods of time because they do not need to eat or sleep, and they have a lower margin for error. This means that intended work is faster and profit returns are more consistent, especially starting from tillage and seedbed preparation. As a result, agricultural firms are making investments in self-driving or autonomous tractors. These have the ability to perform tillage operation followed by seedbed preparation once commanded either day or night. An AI-based autonomous tractor performing tillage operation without a driver.

Planting

Currently, Microsoft Corporation is working with farmers and providing farm consulting services in Andhra Pradesh, India, using Power BI and machine learning, which allows for the transformation of data into Intelligent Actions. The average crop yield per hectare increased by 30% as a result of this pilot project's use of an AI-based sowing application that makes recommendations to farmers regarding sowing date, preparation of cultivable land, fertigation based on soil analysis, FYM requirement and application, seed treatment and selection, and optimization of sowing depth (Kumar *et al*., 2019). Using real-time Moisture Adequacy Data (MAI) from daily rainfall figures and soil moisture, AI models may also be used to identify the ideal time to sow in different seasons, build forecast charts, and provide farmers with advice on when to plant sugarcane. Farm machinery industries have initiated planting robots, manipulators, autonomous planters, etc. for automation in planting operations while bulky nature of the sugarcane is the constraint to move fast. Some devices have been developed for planting sugarcane buds with autonomous fungicide applications. Now, there is a gradual shift from planting 2-3 budded cane to the bud chip method which is attracting atomization in the transplanting of the sugarcane with transplanting fingers, and AI-based detection robots for picking and transplanting it.

Intercultural and weeding

Smart agricultural machinery for intercultural operation such as automatic path detection, and sugarcane row identification can be established in the autonomous tractors integrated and machinery with remote controlled mode for intercultural operations. In Brazil, efforts were made for discriminating weed species and sugarcane using image processing techniques with 94% efficiency for identifying broad-leaf plants (Santiago *et al*., 2014). Advancement to this, ICAR-IISR Lucknow has developed a weed identification AI framework based on convolution neural networks. It is a deep learning-driven weed identification that classifies sugarcane and weed with accuracy and an F1 score value (>99%). It includes the DL DarkNet53 model that exhibited a high level of accuracyand can be integrated into a vision-based system for effective weed control in sugarcane fields (Modi, 2022).The retrofit of this model for the development of weed management systems based either on detection-cum-precise chemical spray or mechanical weeding systems reflects an achievable vision to deal with biotic crop stress.

Irrigationsolutions

AI models are programmed to determine the optimal level of water required for a sugarcane plant based on a type of interconnected factors such as variety, species, climatic data, temperature, soil moisture, soil type, and irrigation system. Human error of approximation can be eliminated with the advent of automated irrigation systems when combined with AI models.de Melo *et al.*(2022)developeda non-destructive AI-basedsystem using DL models through thermal imaging based on that outperformed as compared to the human assessment and aided in classifying the sugarcane water stress. The technique took less than a minute to categorize 1000 photos and deliver superiorperformance with high accuracy of 83 %.In light of this, the method created in this work is a less time-consuming, more cost-effective, non-destructive, and efficient instrument for determining the water condition of sugarcane plants in the field. In the future, establishing the combined use of thermal imaging and machine learning technologies integrated for automatic water application is a cutting-edge and effective method for optimal water footprints and ultimately saving water for sustainable sugarcane cultivation. Moreover, an AI-based drip irrigation/fertigating system can detect the crop water/fertilizer demand and provide the inputs as desired whenever necessary through the ML-drivenintegrated sensors and microcontroller board system. These approaches also provide farmers, who are the technology's end users, with a quick, non-destructive, and accurate way to deploy water for the sugarcane field automatically.

Nutrient management

In order to generate crop metrics in terms of nutrient deficiency over a large area, remote sensing methods, multispectral imaging, hyperspectral imaging, and AI techniques are crucial. It can bring about a radical shift in how farmers manage agriculture from a time and effort viewpoint. Sugarcane crops will also be monitored using this technology during their whole existence, with reports being generated in the event of irregularities for future crop management.

Plant protection

A Pest Risk Prediction Application Programming Interface (API) that takes advantage of an AI-driven ML approach to predict the likelihood of a pest attack on a sugarcane crop is being developed by Microsoft in partnership with United Phosphorus Limited. Based on the weather, crop development stage, and field conditions, insect infestations are predicted to be in three major classes such as high, medium, or low (Kumar *et al*., 2019).Grijalva *et al.* (2023)deployed AI-builtdeep learning models to automatically classify aphid infestation on sugarcane leaves based on aphid density levels.Out of four deep learning models, InceptionV3 and Xception performed best as compared to DenseNet121 and ResNet50 for aphid classification accuracy of 86%. The ICAR-IISR has developed five various AI-based models (AlexNet, DarkNet53, InceptionV3, MobileNetV2, and ResNet50) to identify the symptoms of insect pest damage in sugarcane based on multiple (11 class) damage classes. Out of these five models, after a rigorous evaluation,DarkNet53 was found to be the best AI model with higher accuracy of more than 99%(Raj *et al*., 2022). This sugarcane protection approaches based on artificial intelligence project an innovative progressive mindset to modernize pest monitoring and management in the future through unmanned aerialvehicles, field robots, autonomous sprayers, and detection-based targeted drones for advancement in the IPM strategies to enhance sustainable sugar production.

Harvesting

The development of intelligent sugarcane harvesters requires the rapid and precise identification of sugarcane stem nodes, obstacle detection, path tracking, and night vision in the complex natural sugarcane environment, especially in entangled fields.In a complex natural environment, harvesting is difficult either manually or mechanically. Several research efforts have been put forth for autonomous or semi-autonomous sugarcane harvesting and it stands challenging.Modi *et al*.(2022) developed an autonomous sugarcane lodging detection AI model using computer vision techniques at ICAR-IISR, Lucknow. ResNet50 had the highest robust lodging prediction accuracy of about 98%, as compared to basic AI models such as GoogLeNet, and AlexNet at maximum of 30 epochs. This AI-based autonomous lodging assessment could help yield predictions and management of intercultural and harvest resources.Also, AI is capable to predict real-time sugarcane yield using a machine learning-based Radom Forest model. Maldaner *et al.* (2021) installed a scale yield monitor on the sugarcane harvester elevator to offer the georeferenced yield data and the RF model was trained using the four-engine parameters such as engine rotation, engine power, fuel consumption, and specific fuel consumption. The RF model provided the best predictions for sugarcane yield based on engine characteristics, with a mean absolute percent error and a root mean square error (RMSE) of 5.6% and 7.0 Mg/ha, respectively.

Sugar industry

The scheduling of sugarcane transport vehicles, quality of sugarcane harvest, trash inflow, sucrose content during crushing, farmers' payment, etc. can be managed with ML techniques as well as DL-driven image processing applications for real-time updates to the farmer and industry. Also, the quality of sugar, shape and size of sugar, jaggery and will be analyzed with AI techniques using detection cameras and micro-controller boards. It will collaborate with current operators and sugar mill systems to give predictive decision support. This may aid in enhancing the productivity and quality of sugar production, cutting production costs, maximizing the use of equipment, and enhancing the decision-making processes used by factory workers in the operational areas of the fugal and sugar mill crystallization stages.Also, human resource management in the sugar industry has dealt with DL-driven face recognition systems.

Limitations

AI adoption and widespreadin agriculture especially in sugarcane may be slow down due tothe absence of simple solutions that smoothly incorporate and embed AI.The majority of farmers do not have digital skills followed by time to research AI solutions on their own. Innovative AI solutions need to be integrated into established and legacy systems and equipment that farmers already use in fact necessary to perfectly incorporate and embed AI within agriculture.Farmers are not conversant with such technologies and suffer due toa lack of technical knowledge. The sugarcane sector followed by the sugar industry may become semi-autonomous as awareness level increases and technologies become more affordable to the average farmer, with AI leading the way.

Conclusion

AI-enabled technologies predict weather conditions, analyze crop sustainability, and evaluate farms for the presence of diseases or pests and inadequate plant nutrition, using data such as temperature, precipitation, wind speed, and solar radiation in conjunction with ML algorithms and images captured by satellites and drones.AI-driven data analysis and prediction techniqueswould save time and enable farmers to efficiently cultivate the planted sugarcanefollowed by ratooncrop inassistancewiththe selection of the best cultivar, land preparations, soil condition, crop health, and other climatic factors analysis.ML applications based on the sensors and DL-driven image processing in sugarcane cropping systems can optimize and automate the water application and reduce labour dependency.It also predicts crop seasons, weather, climatic aberrations, and other factors for the next following year.Farmers who have Wi-Fi access can use AI applications to get an AI-tailored farm plan. AI-based forecasts make it possible to recommend the right selections at right time, right place, and right genetics in terms of pesticides and cropsbefore diseases spread widely.AI will be used in sugarcane culture and the sugar industry to improve the entire sugarcane cultivation process followed by quality products.

References

Anon. (2022a).Food and Agriculture Organization of the United Nations. https://www.fao.org/faostat/en/#data/QCL (accessed on 19.05.22).

Anon. (2022b). https://www.bearflagrobotics.com/autonomous-farm-tractors/ (accessed on 16.11.2022).

de Melo, L. L., de Melo, V. G. M. L., Marques, P. A. A., Frizzone, J. A., Coelho, R. D., Romero, R. A. F., & da Silva Barros, T. H. (2022). Deep learning for identification of water deficits in sugarcane based on thermal images. *Agricultural Water Management*, *272*, 107820.

Grijalva, I., Spiesman, B. J., & McCornack, B. (2023). Image classification of sugarcane aphid density using deep convolutional neural networks. *Smart Agricultural Technology*, 3, 100089.

Hossain, M.A., Kuramochi, H., Ishimine, Y., Akamine, H., 2001. Application timing of asulam for torpedograss (Panicum repens L.) control in sugarcane in Okinawa island. https://doi.org/10.1046/J.1445-6664.2001.00021.X.

Kumar, A., Chand, H. & Kamat, D. N. (2019). Artificial intelligence applications in sugarcane. *Indian Farming* 69(08): 03–04.

Maldaner, L. F., de Paula Corrêdo, L., Canata, T. F., & Molin, J. P. (2021). Predicting the sugarcane yield in real-time by harvester engine parameters and machine learning approaches. Computers and Electronics in Agriculture, 181, 105945.

Modi, R. U. (2022). Deep learning-driven weed identification framework for sugarcane crop. Paper presented during 56th Annual Convention of Indian Society of Agricultural Engineers, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, November 09-11, 2022. Pp 115.

Modi, R. U., Chandel, A. K., Chandel, N. S., Dubey, K., Subeesh, A., Singh, A. K., Jat, D. and Kancheti, M. (2022). Deep learning driven automated sugarcane lodging identification. Paper presented during 7th IAPSIT International Sugar Conference and SUGARCON 2022, ICAR-IISR, Lucknow during October 16-19, 2022. Pp 28.

Raj, C., Singh, S., Modi, R. U., Joshi, R. C., Baitha, A., Blessy, V. A., Sushil, S. N., Hasan, S.S. & Dutta, M. K. (2022). Multiclass image classification of sugarcane insect pest damage using deep convolutional networks based on transfer learning. *SSRN*: http://dx.doi.org/10.2139/ssrn.4208521

Santiago, W. E., Barreto, A. R., Figueredo, D. G., Teruel, B. J., Leite, N. J., & Martins, G. A. (2014). Digital image analysis to detect weeds in crops of sugarcane aiming at a localized treatment. In *2014*

Montreal, Quebec Canada July 13–July 16, 2014 (Pp 1). American Society of Agricultural and Biological Engineers.

Suganthi, M., Muthukrishnan, P., Chinnusamy, C., (2019). Crop weed competition in sugarcane - a review. *Agricultural Reviews* 40, 239–242.

Sushil, S. N., Joshi, D., Roy, S., Rao, G. P., & Pathak, A. D. (2022). Plant quarantine regulations with reference to sugarcane in India: Strengths and challenges. *Sugar Tech*, 1-11.

Chapter No. 8: Sugarcane Production and Ethanol Blending Programme: Future Prospects

Pushpa Singh[1]*, Anam[1], Nidhi Tripathi[2]
[1]ICAR-Indian Institute of Sugarcane Research, Lucknow
[2]Anurag Memorial College, Magadh University, Bodh Gaya, Gaya, Bihar

Abstract

The ethanol production from sugarcane juices /molasses is established technology. Efforts are being made to develop indigenous technology for production of ethanol from lignocellulosic biomaterials to replace /supplement petroleum based liquid biofuels. About 625 million tons of agricultural residues (AG) /biomass is produced each year in our country, of which about 150 million tons can be available for industrial use. Apart from sugarcane molasses, AG constitutes a sustainable and "green" bio-source of organic raw materials, chemically, the lignocellulosic biomaterials to replace /supplement petroleum based liquid biofuels. The future plans for sustainable technology for energy and bio-molecules production shall pertain to strengthening of bioethanol production from sugarcane/agricultural residues lignocellulosic biomass. The nation needs to focus upon improving state of existing infrastructure and establishment of proper mechanism for production, collection, transportation and handling of biomass feedstock, sustainable utilization of sugarcane/agricultural residue based ligno-cellulosic resource (bagasse, straw, roots trash) as "*an inexpensive year round available feed stock"* for production of ethanol" coupled with cost effective delivery at the plant site, development of efficient microbial strains/new enzyme biocatalysts for cellulose conversion and higher ethanol recovery through molasses/ B-molasses / sugarcane juice, cellulosic plants to focus on low-lignin agricultural waste feedstocks - corn stover, wheat straw, sugarcane bagasse, sugar beet for increasing 2G ethanol production and initiate *Indo Agro Energy Plan* for combining best technologies for optimal sugar crops value chain focusing on bioethanol production.

Introduction

Ethanol blending in petrol is an effective way of increasing domestic petrol availability. India, has a target of blending 10 per cent ethanol with petrol by 2022 to cut dependence on imports. To achieve the target, approx. 313 crore litres of ethanol is required. According to the Union Ministry of Petroleum and Natural Gas, the current ethanol availability is only about 300 crore litres. Of this, about 130 crore litres goes into making of liquor, which is non-negotiable for states as liquor is a major revenue source for them. That leaves around 170 crore litres, out of which about 60 to 80 crore litres goes into making chemicals. That leaves only about 100 to 120 crore litres for blending, which obviously is in sufficientto achieve the blending targets.

Sugarcane molasses are the major feedstock for bio-ethanol production and inconsistency of raw material supply is the major cause behind the sluggish response to blending targets. Since sugarcane production is cyclical, ethanol production also varies accordingly and does not assure optimum supply levels needed to meet the demand at any given time. The blending targets are thus partially successful in the years of surplus sugar production but remain unfulfilled when it declines. The National Bio-fuels Policy, 2018, has therefore sought to widen the range of feedstock for ethanol production from the present sugar-molasses to other waste such as agricultural cellulosic and ligno-cellulosic biomass and rural-urban garbage, in line with the "***waste-to-wealth***" concept. The permissible feedstocks includes ***sorghum, sugar-beet, cassava, decaying potatoes, damaged grain including maize, wheat, rice, and most importantly, crop residue such as wheat and rice stubble.*** This shall allow the farmers to sell their surplus output to ethanol manufacturers, when prices slump.

In a slew of decisions, the government has permitted the sugar mills to divert from sugar and boost ethanol production. Keeping in view, the surplus sugarcane and sugar production, if about 1/3rd of whole cane used for sugar production, is diverted for direct fermentation, it can fetch another 70-100 crore litres of ethanol to achieve the country's blending requirement. This shall make available about approximately 200 crore litres of ethanol available for blending without any change in the crop area. Rest of it will be dependent on other agricultural crops like sugar beet, their residues, cellulosic and ligno-cellulosic biomass for achieving 20 % target by 2022. Ethanol production using the stalks of sweet sorghum as feedstock is an alternative potation, technologically similar and proven for the production of bio-ethanol. Sweet sorghum route provides an agronomically successful and economically viable pathway that could produce simultaneously fair quantities of food grain and substantial amounts of ethanol feedstock.

Table 1: Ethanol Availability and Demand in India

Year	Total ethanol demand (BL)		
	5%*	10%	20%
2020-21	4.3	6.3	10.2
2025-26	5.7	8.6	14.4
2030-31	7.5	11.9	20.5

*5%, 10% and 20% blending targets

The ethanol production in the country has rose to 2000 million litres in 2018-19 from 380 million litre during the year 2013-14. The current blending levels stand at 6.20 per cent. Next year, it is expected that 2600 million litre of ethanol will be supplied for blending and may meet 7 per cent of the blending level. Currently, three major issues will govern the ethanol production from sugarcane. There will be a serious need for cane requirement with better biomass and quality, varietal improvement and crushingschedule apart from dependency on 2G ethanol (Table 1).

Crushing Scheduling By Sugar Mills

Generally, the sugar recovery is low during beginning (October-November) and in the end (after 1st fortnight of April) of the sugarcane crushing season in the country. During this period about 38-40 million tonnes of sugarcane is processed by the sugar mills and the recovery of sugar is about 8 - 9 % only. So, the sugar mills could use these canes for ethanol production and the quantity available is good enough to produce about 2500 million litres of fuel ethanol production. This option can effectively use 12-15 % of the total cane crushed by the sugar mills in the country. Normally, crushing of sugarcane in the country ends in June and in some cases, it will be prolonged up to August. The probable quantity of sugarcane production with recovery of sugar and stock position will be known during the period of October to December. Using sugarcane for ethanol production in the start and end of the season would therefore provide more scope for deciding the quantum of production of white sugar, ethanol, stock to use ratio and moderation of sugar prices aligning with production scenario existing in the country on yearly basis without much fluctuation in the domestic sugar market.

Cane quality for better ethanol recovery

Although, the present policy of Ethanol Blended Petrol (EBP) Programme allows bioethanol to be produced from sugarcane juice, B-molasses and non-food feed stock like molasses, celluloses and lignocellulosic material through petrochemical route, sugarcane quality needs to be taken care of for enhancing ethanol production. Owing to improvement in cane quality, the yield has almost been doubled in the progressive farmers and average sugar recovery was improved more than 1.5 units which has resulted significant sugar surpluses in the country. The need of the hour is to divert sugarcane in a meaningful way for the production of fuel ethanol. This will help to reduce sugar surpluses as well as significant quantity of fuel ethanol production to meet out blending target of EBP. All these existing scenarios need to be addressed in a comprehensive way to provide solution to sugar surpluses, meeting the demand of ethanol blending program and bring a balance between food and fuel production with price stability.

Sugarcane Varietal Requirements

Novel varieties exclusively for increasing ethanol production in comparison with the cultivated varieties should be explored. The newly developed high sugar varieties are suited for ethanol production and energy canes (with high biomass and less sucrose from the institute) shall be ideal for second generationethanol production.

Need for 2G Ethanol - For Blend Rate of 10 Percent by 2025

India's new biofuel policy seeks to achieve a national average of 20 percent blending of ethanol with gasoline by 2030 (assuming current consumption growth rate for fossil fuels), an estimated 10.9 billion litres of ethanol will be required to meet E-20 mandate). It is envisioned that the targets will be met through: i) growth in domestic biofuel production (1-Generation (G), 2-G and 3-G2); ii) use of multiple feedstocks (Creation of the National Biomass Repository is proposed) and iii) encouraging biofuel blending to supplement gasoline and diesel use in transportation, as well as in stationary and portable applications (for example, diesel generators or water pumps for irrigation).

Table 2: Current and future requirements of petrol and ethanol in the country

Year	Petrol demand Million litres (M.L)	Ethanol blending requirements Million litres (M.L)			
		5 %	10 %	15%	20 %
2015-16	30061	1353	2706	4059	5412
2019-20	39707	1787	3574	5361	7148
2021-22	43361	1951	3902	5853	7804
2024-25	49482	2227	4454	6681	8908
2029-30	60203	2709	5418	8127	10836

Since India's domestic production of crude oil can meet only about 25 percent of her national demand, bio-ethanol to blend in gasoline for the transportation sector presents itself as a natural alternative for reducing India's dependence on foreign oil imports. The present EBP mandate is to achieve a 10 percent national average blend by the year 2022 (Table 2). Therefore, going beyond 2022, it is farfetched to imagine achieving E-20 by 2030 due to:

i. the general inability of the cane industry to supply India's ethanol demand (especially if fuel ethanol use is increased) even at current levels (sugarcane production is cyclical and therefore ethanol production varies accordingly and does not assure targeted fuel ethanol supply levels needed to meet the OMC tenders at any given time).
ii. Imports are managed in a way that minimizes the supply role they can play.
iii. it will be well beyond a decade before "advanced fuels" will be capable of large-scale commercial production even with huge subsidy outlays.

Understanding both the need and the benefits of using biofuels, the GOI has a mandated blend rate of 5 percent for ethanol as part of its Ethanol Blending Program (EBP), and a target of 20 percent by 2022. To meet its targets, GOI resorted to the adoption of first-generation technologies and thereafter (owing to the limitations of first-generation technologies) to second-generation technologies for the production of bio fuels in a bid to meet its blending mandates.

1G Ethanol from sugarcane in India

The first-generation bio ethanol is defined based on the source from which the fuel is derived rather than the physical nature of the fuel itself. The main feedstock sources for 1G bioethanol are food crops such as starch, sugar and vegetable oil and animal fats. If 342.4 Mt (the entire sugarcane crop in 2010- 11) is used for sugar production, the corresponding estimated production of molasses would be about

15.4 Mt and the associated estimated ethanol yield would be about 3.6 BL. In reality, however, only about 70 to 80 percent of the sugarcane that is produced in India is used for sugar production, with the remaining being diverted towards the production of alternative sweeteners (jaggery and khandsari) and seeds. Also, 32.5 percent of the available molasses is used in alcoholic beverages, 25 percent by industry, and 3.5 percent for other applications. The surplus available alcohol is diverted for blending with transportation fuel. Under these circumstances, if India is to achieve the 20 percent blending targets without compromising with industrial, potable and other needs, the country will need to produce 6.7 BL of ethanol by 2020 and 10.4 BL by 2030, which is approximately three times the current level of production (Table 3). Considering the GOIs blending mandate and the estimated shortfalls, 2G (and beyond) bioethanol seems to be natural route to follow though not without its limitations.

2G Bioethanol-A Primer

While both 1G and 2G biofuel production were spurred by some common drivers, most notably energy security (reduced demand on oil imports), lower GHG emissions and an all-around low carbon, sustainable economy, an additional impetus for 2G biofuels arose from the need for liquid biofuels from feedstocks not used for human consumption. This led to the use of lignocellulosic materials from herbaceous crops, hardwood and softwood, as the main feedstocks for the production of bioethanol. Second-generation bioethanol is produced from cellulose, hemicellulose or lignin. Lignocellulosic (LC) biomass, also called cellulosic biomass, is a complex composite material consisting primarily of cellulose, hemicellulose and lignin bonded to each other in the plant cell wall. LC biomass such as agri-residues (e.g., corn stover, wheat and barley straws), agri-processing by-products (sugarcane bagasse and trash, seed cake, etc.), woody biomass (hardwood and softwood) and energy crops (e.g., switch grass, poplar, banagrass, miscanthus, etc.) do not compete with food and feed and are considered to be renewable feedstocks for ethanol production. 2G cellulosic ethanol yields greater energy output than fossil fuels and can thus be extracted from a larger array of feedstock options, minimize competition on land and have much lower environmental impacts.

Table 3: Ethanol Availability for 1G Biofuels in India

Year	Ethanol production from molasses (BL)	Ethanol use (BL)			Net ethanol availability for blending (BL)
		Potable	Industry	Other	
2010	2.72	0.88	0.68	0.10	1.06
2015	3.01	1.04	0.79	0.11	1.08
2020	3.22	1.22	0.91	0.13	0.96
2025	3.43	1.44	1.06	0.15	0.79
2030	3.64	1.69	1.23	0.17	0.56

2G Ethanol Feedstocks

India, being agriculturally enriched, has copious amounts of agro residues like sugarcane bagasse/leaves, wheat straw, banana stem, sunflower stalk, sweet sorghum, weeds like *Saccharum spontaneum*, *Typha latifolia, Eicchornia crassipes, Prosopis juliflora, Lantana camara* which can be utilized to produce 2G bioethanol. The area wise projection of availability of lignocellulosic biomass in India and an illustration depicting the state wise availability of LC is given in Figure 1& 2. Residue use varies by region and depends on the calorific values, lignin content, density, palatability by livestock, and nutritive value. While a lot of cereals and pulses have fodder value, the woody nature of others (sugarcane bagasse / leaves, rice husk /straw, maize stalks and cobs and ligneous residues) makes them a natural choice to be used as feedstock in the production of ethanol. This accounts for approximately 53 percent of total residue available in the country.

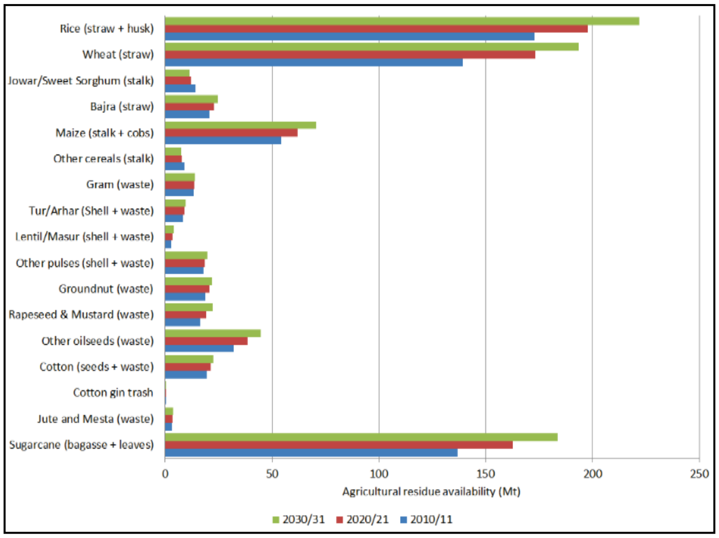


Figure 1: 2G ethanol feedstocks projections in India

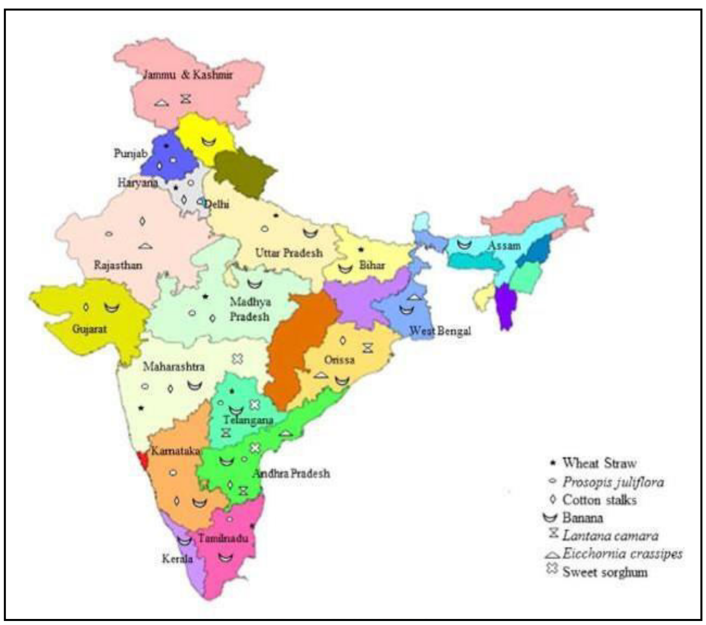


Figure 2: 2G ethanol feedstocks state-wise availability in India

Available Technologies for 2G Ethanol Production

There are two main channels for production of second-generation biofuels from lignocellulosic feedstocks. Figure 3 below shows the basic process of converting biomass in to bioethanol and co products. Briefly, they can be summarized as follows:

i. **Biochemical** - enzymes and other micro-organisms are used to convert cellulose and hemicellulose components of the feedstocks to sugars prior to their fermentation to produce ethanol.

ii. **Thermo chemical** - pyrolysis/gasification technologies produce a synthesis gas ($CO + H_2$) from which a wide range of long carbon chain biofuels, such as synthetic diesel or aviation fuel, can be reformed.

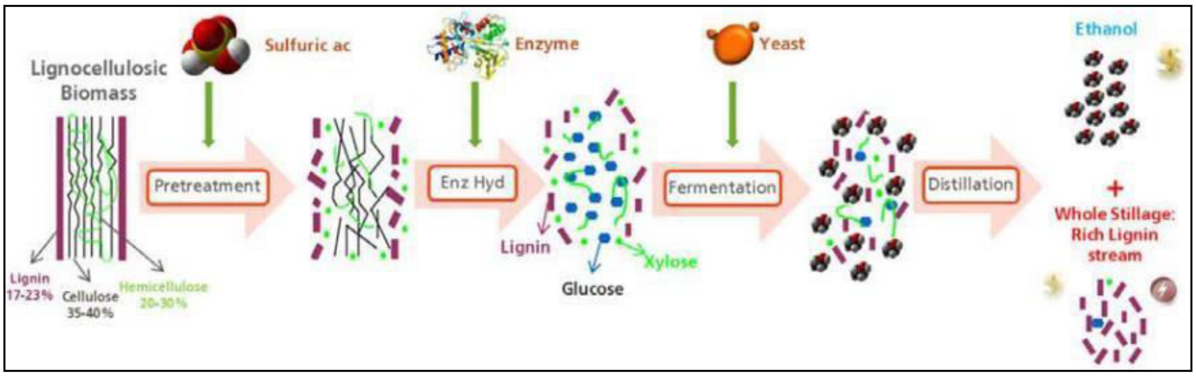


Figure 3: 2G Biofuel Production from Lignocellulosic Biomass

Bio-ethanol Potential of Sugarcane Lignocelluloses

Sugarcane (*Saccharum spp*.), a C4 photosynthetic large stature perennial grass and has one of the most efficient photosynthetic mechanisms, among commercial crops since it allows it to fix almost 2 - 3 percent of radiant solar energy and transforms it into chemical energy. The high photosynthetic capability also allows it to show a high coefficient of CO_2 fixation, comparable to the moderate climate zone woods thus contributing to the decrease of the greenhouse effect. A hectare of sugarcane produces about 100 tonnes of green matter every year, which is more than twice the agricultural yield of most other commercial crops. A crop of 100 tonnes leaves around 60 -65 tonnes of dry matter (8-10 tonnes of trash (dry leaves) in the field, while after extraction of sucrose, nearly 50-60 tonnes of bagasse is generated in factory zones). Sugarcane dry matter when burned has the potential of producing 4000 Kcal per Kg (7200 Btu / lb.). Its total dry matter content has a fuel equivalent of about 10 to 20 tonnes of oil and an efficient use of the energy potential of sugar cane can result into approximately 1 tonne of oil equivalent for every tonne of sugar produced. Bagasse is generally being used as a raw material for heat energy to run the sugar mills and also for co-generating electricity, whereas trash except its use as mulch is yet to be exploited for its fuel potential. Practically all products and by-products obtained from sugar cane may become substrates for liquid or solid-state fermentation processes and via usage of the available second and third generation technologies, a significant number of production processes could be developed.

Sugarcane thus has a significant advantage as a renewable raw material, in the production of basic chemicals, with a yield not equalled by any other plant. Since the energy delivering capacity of sugarcane is equivalent to five times that used by the crop, the quantification of energy produced by cane plant and variations among different varieties or germplasm is extremely important in exploitation of cane a renewable and sustainable bioenergy/biofuel crop. All these factors taken together and the possibilities offered by further genetic improvement, turns sugar cane into the ideal energy crop for the next century.Keeping in view, A muliti-disciplinary (Organic chemistry and Microbiology) AP Cess project entitled "Development of pre-treatment and hydrolysis process for conversion of sugarcane biomass to ethanol" was taken up in the year 2004, with a visionof utilizing sugarcane trash, bagasse and stubble (the complex lignocellulosic material with high lignin, ash content, cellulose and hemicelluloses) as a resource of low cost feedstock for production of fuel ethanol. The objectives were to design processes for making the cellulose and hemicelluloses components easily accessible from sugarcane biomass (bagasse, trash and stubble), evaluation and optimization of the processes for effective hydrolysis of the biomass and finally the fermentation of C5 and C□ sugars for ethanol production and further distillation. The research objectives were successfully implemented by developing chemical processes for breaking the physiological, structural and compositional barriers that hinder the conversion of the lignocelluloses to fermentable sugars. For biological pretreatment protocols, eight bioagents were procured from NCIM, NCL Pune. The biological pretreatment of sugarcane biomass using the above microorganisms rendered easy accessibility of the cellulosic and hemicelluloses components for bioconversion into fermentable sugars. The objectives were achieved and in order to increase the ethanol yields by preventing the formation of inhibitors, studies continued in project entitled "Identification of inhibitors in sugarcane biomass hydrolyzates and their effect on ethanol yields" during the last decade. Thus pre-treatment techniques for making the cellulose and hemicelluloses components easily accessible from sugarcane biomass (cane bagasse, trash and crop residues) have been standardised. The hydrolysis processes have been optimized for fermentation of C5 and C6 sugars for ethanol production.

Further Reading

1. Das, S. (2020). The National Policy of biofuels of India–A perspective. Energy Policy, 143, 111595.
2. Dey, B., Roy, B., Datta, S. et al. Comprehensive overview and proposal of strategies for the ethanol sector in India. Biomass Conv. Bioref. (2021). https://doi.org/10.1007/s13399-021-01546-2
3. Gaurav Kumar (2021) Ethanol blending program in India: An economic assessment, Energy Sources, Part B: Economics, Planning, and Policy, 16:4, 371-386, DOI: 10.1080/15567249.2021.1923865
4. Liu, Chen-Guang; Xiao, Yi; Xia, Xiao-Xia; Zhao, Xin-Qing; Peng, Liangcai; Srinophakun, Penjit; Bai, Feng-Wu (2019). Cellulosic ethanol production: Progress, challenges and strategies for solutions. Biotechnology Advances, (), S0734975019300382. doi:10.1016/j.biotechadv.2019.03.002
5. Lynd, Lee R; Liang, Xiaoyu; Biddy, Mary J; Allee, Andrew; Cai, Hao; Foust, Thomas; Himmel, Michael E; Laser, Mark S; Wang, Michael; Wyman, Charles E (2017). Cellulosic ethanol: status and innovation. Current Opinion in Biotechnology, 45(), 202–211. doi:10.1016/j.copbio.2017.03.008
6. Singh Pushpa, Suman A, Singh P, Arya N and Shrivastava AK (2007). Biological pretreatment of sugarcane trash: A potential source for production of ethanol World J Microbial & Biotechnology, 24: 667-673. DOI: 10.1007/s11274-007-9522-4
7. Saini, M. K., Garg, N., Singh, A. K., Tyagi, A. K., Niyogi, U. K., & Khandal, R. K. (2010). Ethanol blended fuel in India: an overview. Journal of Biofuels, 1(2), 209-219.
8. Sarwal R, Kumar S, Mehta A, Varadan A,Singh SK, Ramakumar SSV, Mathai R (2021). Roadmap for Ethanol Blending in India 2020-25: Report of the Expert Committee, Niti Aayog, Ministry of Petroleum and Natural Gas, Government of India.

Chapter No. 9: Energy saving techniques during jaggery making

S.I. Anwar
Principal Scientist
Division of Agricultural Engineering, ICAR-Indian Institute of Sugarcane Research,
Raebareli Road, Lucknow - 226002 (U.P.)
e-mail: sianwar@yahoo.co.in

Sugar, jaggery and *khandsari* are the main products of sugarcane in India. Out of these, sugar and *khandsari* are merely sweeteners whereas jaggery is a food material as well due to presence of important constituents of human diet. The major states involved in jaggery production are; Uttar Pradesh, Maharashtra, Madhya Pradesh & Chhattisgarh, Bihar, Karnataka, Andhra Pradesh and Tamil Nadu. Apart from handling of sugarcane, major unit operations involved in jaggery production are; sugarcane crushing (juice extraction), juice filtration, juice heating, juice clarification, juice boiling and concentration, cooling/puddling of concentrated mass, moulding and packaging. All these operations involves consumption of energy. An efficient jaggery plant should produce more jaggery per unit of energy consumed.

Sugarcane crushing

Sugarcane crushing is normally done in sugarcane crushers, which are animal or power driven. Nowadays mostly power driven crushers are used, which are either run by diesel engine or by electric power. Here also, emphasis is given to extract maximum juice from sugarcane per unit of power and therefore, efficient sugarcane crushers are needed. These crushers are further classified as vertical or horizontal roller crushers. Vertical crushers have limitations of cane feeding whereas more canes can be accommodated in horizontal crushers. Juice extraction and power requirement depend upon crop and machine factors. Amongst crop factors, type of sugarcane variety, fibre content and hardness/softness of cane play an important role. Hard canes require more energy. A crusher giving more than or equal to 65 per cent extraction (cane basis) may be considered as an efficient one. In order to have uniformity in comparison a formula for reduced juice extraction has been developed by Baboo and Anwar (1994)

$$RE = \frac{12.5}{FC}[JE - 100] + 100$$

where,

RE = Reduced juice extraction, % cane
FC = Fibre content, % cane
JE = Actual juice extraction, % cane

Machine factors involve gap between rollers, roller grooving, orientation and roller diameter. Speed of rollers should be such that juice should get minimum time for re-absorption by the bagasse. Use of ball bearing and efficient bushes could reduce power requirement to a great extent.

Sugarcane juice heating, boiling and concentration

This is the most energy intensive unit operation of jaggery production. At most of the jaggery units, this unit operation is done in open pan furnaces. Different types of jaggery making furnaces have been developed in India (Roy, 1951). These furnaces are not so efficient. However, lots of design modifications have been incorporated leading to development of many kind of furnaces. These furnaces may vary from single removable pan to multiple fixed pan where size and number of pans depend upon capacity of jaggery plant. Bagasse is the main fuel of these furnaces and a jaggery plant is said to be self reliant if bagasse produced from crushing of canes is sufficient enough to process the juice extracted from the same quantity of sugarcane. But in many cases shortage of fuel is experienced. Therefore, there is always a need for energy-efficient furnace, which not only process sugarcane juice in shorter period towards improvement in jaggery productivity but at the same time would be useful in saving of bagasse. This saved bagasse may be a source of extra revenue generation for jaggery manufacturer as it is an excellent source of fibre.

Modified pans having fins

Juice boiling/concentrating pan is the integral part of any furnace. Size and number of pans, shape of pan (hemispherical/flat bottom) vary from furnace to furnace. ICAR-Indian Institute of Sugarcane Research, Lucknow has developed 2-pan and 3-pan furnaces. 2-pan furnace has flat bottom whereas 3-pan furnace has hemispherical bottom pans. It was thought of providing fins to the pan bottom with the objective of increasing area of heat receiving surface. The hypothesis is; more the heat receiving area, more will be the heat energy received. This heat will be transferred to the lesser area *i.e.* the area on which the juice is processed (the other side of pan bottom). By this way, more heat will be supplied to the juice and the furnace efficiency will be improved.

For fins, parallel (PF), flame spreader (FSF) and radial (RF) configurations were considered (**Anwar,** 2017). These were compared with conventional plain bottom. These configurations are shown in Fig.1.

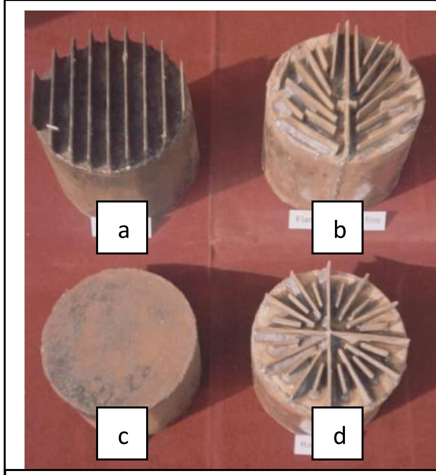


Fig.1. Fin configurations
(a) PF (b) FSF (c) Plain pan
(d) RF

Mild steel flats (25 x 3 mm) were welded to each of the three finned pans. The total length of flats in all the cases was kept equal. Therefore, per cent increase in area was same in all the cases. All these configurations were tested through water boiling test and the results are summarized below:

Table 1. Performance of different fin configuration

Sl No.	Parameters	Fin configuration/geometry				
		Plain	PF	FSF	RF	Avg. (fins)
1	Water evaporated (kg)	1.720	2.273	2.180	2.143	2.199
2	Thermal efficiency (%)	9.93	12.47	12.06	11.90	12.14
3	Heat utilization efficiency (%)	7.52	9.94	9.53	9.37	9.62
4	% increase in thermal efficiency as compared to plain pan	---	25.58	21.45	19.84	22.29
5	% increase in heat utilization efficiency as compared to plain pan	---	32.18	26.73	24.60	27.93

It can be seen that pans having fins performed better as compared to unfinned (plain) pan in terms of water evaporation and thermal/heat utilization efficiency. Amongst three fins configurations tested, parallel fins gave best results followed by plain spreader and radial fins.

The pans (circular main and rectangular gutter) of 2-pan IISR furnace were modified by providing fins (Anon. 2005-06). Parallel fins were provided to main and gutter pans of IISR 2-pan furnace. Modified pans are shown in Fig. 2.

Fig. 2. Modified main and gutter pan of IISR 2-pan furnace

Due to fins, per cent increase in area of heat receiving surface is given below:

Main Pan

Conventional : 12667.69 cm^2

Modified : 27561.29 cm^2

Increase in area : 118%

Gutter pan

Conventional : 7442 cm^2

Modified : 17202 cm^2

Increase in area : 131%

Performance of furnace was evaluated by water boiling test and actual juice processing for jaggery making. Advancement in time of boiling in the main pan in modified system was observed. Modified system was found to be capable of evaporating about 15 kg more water that too with 75 kg bagasse in 90 minutes only as against with 100 kg bagasse in 120 minutes with unfinned system. Therefore, 0.71 kg more water per kilogram of bagasse was evaporated with modified system. In another way, 0.21 kg less bagasse was consumed per kilogram of water evaporated with finned system. The heat utilization efficiency improved by 9.44%. Now it is evident that heat utilization efficiency of IISR 2-pan furnace increased considerably due to finned pans. Bagasse saving was also observed to the tune of more than 30% and 25% per unit weight of water evaporated and jaggery made respectively. Jaggery production was observed to be increased by 20% with about 17% saving in time (Anwar, 2010[a]; Anwar and Singh, 2010).

Optimization of parallel fins

Work on optimization of parallel fins was also carried out. Smaller mild steel pans were fabricated in which area of heat receiving surface was increased up to 311 per cent by using varying number of fins. In second set of experiment, size of fin was varied by keeping increase in area as constant. The performance of pans was evaluated through water boiling test. It was found that performance of pan improves with increase in number of fins i.e. area of heat receiving surface. However for a particular increase in area of heat receiving surface, it is better to provide more number of smaller fins than less number of larger fins (Anwar, 2010[b]).

Waste heat recovery system (WHRS) for open pan jaggery furnace

There are many design parameters affecting furnace efficiency like size of combustion chamber, size and geometry of flue gas channel, height of chimney *etc*. It was observed that despite many improvements, still lots of energy goes as waste with the flue gases. This is a shear wastage of valuable heat energy. There are two solutions for *i.e.* either to further improve furnace efficiency or to recover part of this energy to be used for other useful purposes like bagasse/jaggery drying or space heating.

Bagasse is the main fuel used in jaggery/*khandsari* furnaces. Due to poor heat utilization/thermal efficiency of these furnaces, many a times situation comes that bagasse, generated in the process of juice extraction, is not sufficient for juice concentration and requirement for addition fuel is faced. It has been calculated that if bagasse generated from some quantity of sugarcane is to be used for processing of juice obtained from same quantity of sugarcane, the minimum heat utilization efficiency of furnace should be 35%, which is very difficult to achieve.

For recovering part of waste heat, 100 mm mild steel pipe was fixed in the flue gas channel in the form of counter current type of heat exchanger. One end of pipe is exposed to open atmosphere for sucking fresh and clean air. A blower is attached to it via flow regulating valve for sucking air through the pipe. Heating of air is done through convective mode of heat transfer (Fig.3).

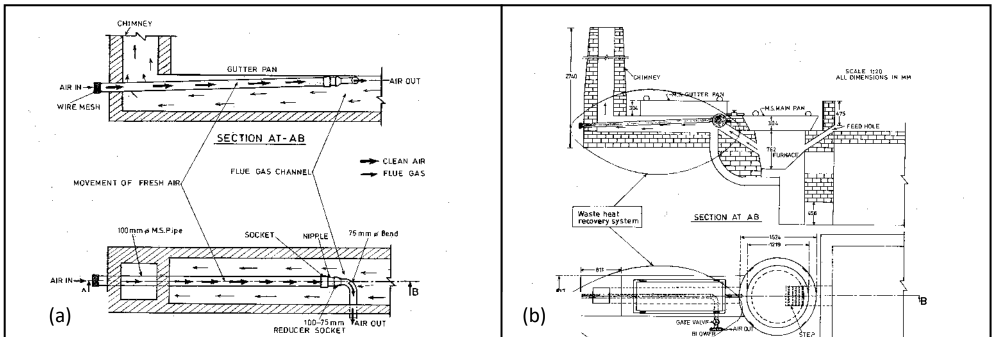


Fig. 3. (a) Counter-current type heat exchanging unit and (b) installation of WHRS in IISR 2-pan furnace

Working of WHRS

When the furnace is operated, blower is also run for sucking fresh air through the pipe. The whole pipe is surrounded by hot flue gases. The air on its run in the pipe gets heated. The bend, which is purposely kept at such a position that flue gases coming out of combustion chamber will strike it first and therefore it becomes the hottest part. The air takes a sharp turn at bend where maximum heat transfer takes place. As a result, clean heated air is obtained. Temperature profile of air heated through WHRS is shown in Fig.4.

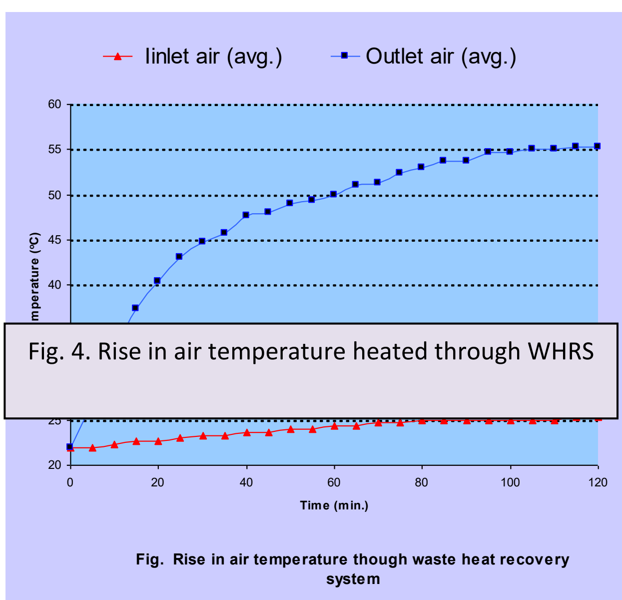


Fig. 4. Rise in air temperature heated through WHRS

Rise in air temperature was achieved right from the beginning. Almost steady state condition was achieved after about 105 minutes of operation and the temperature of air reached as high as 56^{o}C (a temperature rise of abut 30^{o}C) at full blower speed. This heated air can effectively be used for bagasse/jaggery drying and/or space conditioning.

Efficiency Boosting Device (EBD)

It has been observed that flames, which are formed during bagasse combustion in jaggery furnaces, drift towards flue gas opening and many of these flames do not even touch pan bottom. Therefore, a device, which can direct flame towards pan bottom and make more turbulence for increased heat transfer may overcome this problem to some extent. Therefore, a device for forcing flames towards pan bottom has been conceptualized. The air supplied through this would also help in complete combustion of unburnt gases, which would have otherwise gone as waste.

A miniature model of efficiency boosting device (EBD) was designed and fabricated (Anwar, 2015). It consisted of G.I. nipples, sockets, tee, cross tee and bends (Fig.5 & 6). Holes (4 mm dia.) were drilled at specific locations. The size of efficiency booster was kept matching with a pan of 203 mm diameter. This was installed on a wood stove at such a height that it does not affect normal fuel feeding and was connected to a hand blower with suitable attachments. This was kept close to the pan bottom so that air coming out of holes would be able to strike pan bottom.

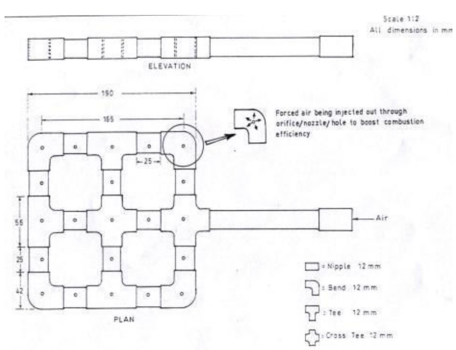


Fig.5. Line diagram of miniature model of EBD

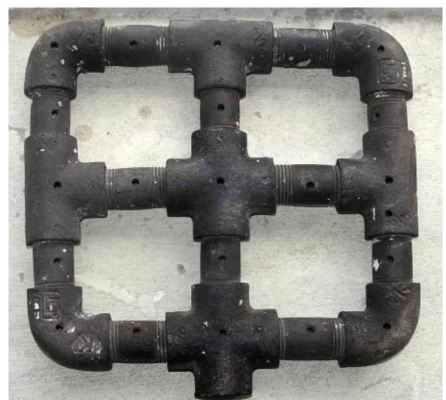


Fig.6. Miniature model of EBD

During water boiling test **i**t required considerably less time to reach boiling point. More turbulence in flames was also observed, which helped in more heat transfer. Lesser quantity of fuel was consumed with EBD and it had positive effect on all the performance parameters of the furnace.

Although performance was improved with EBD with 4 mm holes but venturi effect was noticed and flames were not able to touch pan bottom. Hence, it was thought of providing nipples on EBD instead of providing simple holes. The final design of EBD thus was provided nipples for directing flames and hot air towards pan bottom for more heat transfer. Nipples of 20 mm length and 4 mm diameter were provided on EBD. The unit was tested and compared against the unit with simple holes of 4 mm diameter and the results are summarized in table 2:

Table 2. Comparison of EBD with simple 4 mm holes and nipples

Parameter	EBD with only 4 mm holes	EBD with nipples	Per cent increase/decrease
Water evaporated, kg	1.96	2.16	10.20 (increase)
Evaporation/kg fuel, kg	0.75	0.82	9.33 (increase)
Fuel consumed/kg water evaporated, kg	1.33	1.22	8.27 (decrease)
Time requirement/kg water evaporation, hours	0.36	0.34	5.56 (decrease)

It may be seen that performance of EBD further improved with nipples of 4 mm diameter and 20 mm length. This resulted in more water evaporation and saving in fuel and time. Based on above results, scale-up model of efficiency boosting device suitable for IISR 2-pan furnace has been fabricated and installed.

References

Baboo, B. and **Anwar, S.I.** 1994. Recent Developments in Jaggery (Gur) Research. Tech. Bull. No. IISR/JKS/94/9.

Roy SC. Monograph on the *gur* industry of India. New Delhi: ICSC, 1951.

Anwar, S.I. 2017. Experimental identification of best fin configuration for pans of jaggery making furnace. *E-Souvenir-cum-Proc.* SOLARIS-2017:410-414.

Anonymous. Annual Report of Indian Institute of Sugarcane Research, Lucknow, 2005-06: 54.

Anwar, S.I. 2010[a]. Fuel and energy saving in open pan furnace used in jaggery making through modified juice boiling/concentrating pans. *Energy Conversion and Management*, 51: 360-364.

Anwar, S.I. and Singh, J. 2010. Modified pans for open pan jaggery furnace. Operation manual no. AE/10/01.

Anwar, S.I. 2010[b]. An experimental study for optimizing fins provided to jaggery pan for improved efficiency. In: Energy Conversion and Management. S.K. Shukla and J.V. Tirkey (Eds). Narosa Publishing House, New Delhi: 191-196.

Anwar, S.I. 2008. Waste Heat Recovery from Open Pan Heating System. In: Processing, Handling and Storage of Sugarcane Jaggery. IISR, Lucknow, pp 76-78.

Anwar, S.I. 2015. Improving thermal efficiency of open pan jaggery furnaces – A novel concept. *Indian J of Sugarcane Technology*, 29(1):32-34.

Chapter No. 10: Varietal Development Approaches for High Sugar Varieties and Improving Sugar Recovery

J Singh and Sanjeev Kumar
Principal Scientist
ICAR-Indian Institute of Sugarcane Research, Lucknow

Sugarcane is the most important agro industrial crop in the country next to cotton, being cultivated in around 4.96 million hectares and producing 336 million tonnes of cane at a national average yield of approximately 68 tonnes per hectare. It produces invaluable commodities for food - white sugar, gur, khandsari, fodder, fuel and fibre for all sectors of society. Varieties have important role to play in this context and we may reiterate to breed for sugarcane varieties that suits to diverse farming systems and situations, with least damage to the environment. We have to look for varieties that either befit into a sugarcane-based cropping system or other cropping system where sugarcane can be a component. Our country is next to Brazil in sugarcane and sugar production. There is a wide gap in the cane productivity of tropical and sub-tropical zones in the country.

Sugarcane raw material accounts for nearly 70% of the cost of production of sugar. Therefore, sugar industry is primarily dependent upon the availability of good quality cane in sufficient quantity for a maximum possible period giving economic recovery of sugar with high return, Horizontal expansion; in terms of area with respect to cane cultivation in future does not appear feasible. With an assumption of 60% per capita consumption as white sugar the country may require the production of about 27.39 million tons of sugar corresponding nearly 415 million tons of sugarcane with an average sugar recovery of about 11% by 2020. The area needed would be 4.15 million hectares expecting 100 tonnes cane / ha (Anonymous 1997). In the last sixty years, progress has been there in the country with respect to productivity of sugarcane but on the % sugar recovery front the gain has been so marginal until 2010 that it does not figure out substantially. The harsh climate of subtropics has contributed much more to this low gain. Increase in sugar content of cane is more difficult than increase in yield of cane. In the subtropical region of our country there is an average potential of about 75 t/ha cane yield and 11% sugar recovery where as in tropical region it is about 120 t/ha cane yield and 11.5 to 12% sugar recovery (Naidu 1991). Proper planning of the available cane farming resources their execution with technical know- how and on-going efforts to improve the varietal potential for the subtropics can help in achievement of the future target.

Input cost, Yield and price received for the produce are the three components of the profit equation. If the suitable sugarcane varieties can be grown to their economic level of cane yield in the given environment(s) fetching better price and higher sucrose content, the profit equation will favour both the growers and millers.

Ratoon crops giving favourable annualized average value of net returns form the basis of a cultivar's merit. Variety by environment interactions for both plant and ratoon crops are high, thus the optimal choice of variety may vary according to environment. The trend of decline has generally been found to be less between plant-cane and first ratoon than between the first and the second ratoon. However, differences exist among varieties in yield potential of the plant crop and the rate at which the yield decline in successive ratoon crops. Variety which produces high ratoon crop yield or many economically rewarding ratoon crops should be preferred (Srivastava and Kapur, 1997).

India has diverse agroecosystem and so diverse are sugarcane related problems. Different sugarcane growing areas have different biotic and abiotic problems. North India faces sever water logging problem during monsoon drought during summer. The sugarcane crop faces chill winter condition during winter which leads to poor sprouting of ratoon. Table 3, 4 depict different biotic and abiotic stresses prevailing in different states of sub-tropical and tropical India.

Table 3: Biotic and Abiotic Constraints in Sugarcane Production in Sub-Tropical India

	Assam	Bihar	Haryana	Punjab	Rajasthan	W. Bengal	U. P.
Abiotic							
waterlogging	✓	✓	-	-	-	✓	✓
Salinity/alkalinity	-	✓	✓	✓	-	-	-
Extreme low / high temperature	-	✓	✓	✓	✓	-	-
Biotic Constraints							
Red rot	✓	✓	✓	✓	-	✓	✓
Wilt	-	✓	-	-	-	✓	
Cane borers	✓	✓	✓	✓	✓	✓	✓
Pyrilla	-	✓	✓	✓	✓	-	✓

Table 4: Biotic and Abiotic Constraints in Sugarcane Production in Tropical India

	A. P.	Gujarat	Karnataka	Kerala	Maharashtra	Tamil Nadu
Abiotic						
Drought	✓	✓	✓	-	✓	✓
Water-logging	✓	-	✓	✓	✓	✓
Salinity / alkalanity	✓	✓	✓	✓	✓	✓
Biotic Constraints						
Red rot	✓	✓	-	✓	✓	✓
Smut	✓	✓	✓	-	✓	✓
Top borers	✓	✓	✓	✓	✓	✓
Wilt	✓	✓	✓	-	✓	✓
Woolly aphid	-	✓	✓	✓	✓	✓

An ideal variety is one which gives most profitable yield under the given environment with maximum stability. The commencement of harvest is determined by the sugar content of the canes, Thus the range of variation in the CCS% based on the ripening patterns of varieties (differences for rising sucrose curves) become the critical point to facilitate harvesting. Further minimum period of crushing (cut to crush) of a particular variety during the peak maturity has definitely an advantage in increasing the recovery but this period can be expanded to both sides only till the recovery is desirable. Hence varietal planning and harvesting schedule together for the target area may help in sustaining the sugar production to a great extent. Harvesting of immature canes in the early part of crushing season and those undergoing considerable inversion during hot summer months result in huge losses in sugar recovery (Solomon *et al.* 1997).

The increasing requirement of sugar has to be met mostly through increased production per hectare since there is no possibility of further increase in the area under sugarcane due to competition from other crops, urbanization etc. Several improved varieties have been developed through varietal improvement programmes for tropical as well as subtropical part of India.Second decade of 22 century has witnessed significant increase in area, productivity and sugar recovery (Table1).

Table 1: Area, production, productivity and sugar recovery in U.P.

Items	Unit	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22
Cane Area	Lakh/ha	20.54	22.99	27.94	26.79	27.4	27.6
Average Y	Tons/ ha	72.38	79.19	80.5	81.1	81.5	82.31
Cane Production	Lakh Tons	1486.57	1820.75	2249.2	2172.53	2232.82	2272.19
Cane Crushed	Lakh Tons	827.16	1111.9	1031.67	1118.02	1027.5	1016.26
Sugar Production	Lakh Tons	87.73	120.5	118.22	126.37	110.59	101.98
Rec with B heavy	%	10.61	10.84	11.46	11.3	10.76	10.03
Rec without B heavy	%			11.49	11.73	11.46	11.4

Source: Sugar Industries and Cane Development Department of Uttar Pradesh

Not with standing the extreme and adverse conditions of cane growing in sub-tropical region of the country where availability of limited irrigation (inadequate irrigation) intermittent drought, waterlogging followed byheavy rain, significant progress have been made due to development of high yielding and high sugar varieties like Co 0238, Co 0118, CoLk94184. Spread of Co 0238 was very fast as this variety occupies more than 86% area in U.P. table 2

Table 2. Area and percentage of major sugarcane varieties in Uttar Pradesh during last five years

Variety	**2017-2018**		**2018-2019**		**2019-2020**		**2020-2021**		**2021-2022**	
	Area (lakh ha)	Percent age	Area (lakh ha)	Percent age	Area (lakh ha)	Percent age	Area (lakh ha)	Perce ntage	Area (lakh ha)	Perce ntage
Early Group										
Co 0238	12.08	52.55	19.28	69.02	22.02	82.21	23.75	86.70	22.55	81.68
Co 0118	0.41	1.79	0.69	2.48	0.57	2.15	0.86	3.14	2.06	7.46
CoLk 94184	1.44	6.27	1.88	6.74	1.49	5.56	1.18	4.30	1.40	5.06
Co 98014	0.65	2.81	0.54	1.93	0.40	1.49	0.33	1.21	0.40	1.46
CoS 8436	0.34	1.48	0.23	0.83	0.11	0.44	0.08	0.29	0.08	0.31
Others	1.28	5.56	1.37	4.86	0.72	2.63	0.50	1.81	0.54	1.95
Total	**16.20**	**70.46**	**23.99**	**85.86**	**25.31**	**94.48**	**26.70**	**97.45**	**27.03**	**97.92**
Midlate Group										
CoS 767	1.16	5.03	0.42	1.52	0.10	0.36	0.04	0.13	0.02	0.07
CoSe 01434	1.07	4.64	0.70	2.49	0.27	1.03	0.16	0.57	0.09	0.33
CoS 97264	0.41	1.77	0.20	0.72	0.06	0.21	0.02	0.06	0.01	0.02
CoS 97261	0.24	1.05	0.13	0.46	0.02	0.09	0.01	0.02	0.00	0.00
CoS 99259	0.15	0.64	0.10	0.35	0.01	0.02	0.00	0.00	0.00	0.00
Others	2.58	11.27	1.90	6.80	0.88	3.30	0.31	1.56	0.43	1.59
Total	**5.61**	**24.40**	**3.45**	**12.34**	**1.34**	**5.01**	**0.54**	**2.34**	**0.55**	**2.01**
Unsuitable Varieties	**1.18**	**5.14**	**0.50**	**1.80**	**0.14**	**0.51**	**0.06**	**0.21**	**0.02**	**0.07**
Total Area	**22.99**	**100.00**	**27.94**	**100.00**	**26.79**	**100.00**	**27.30**	**100.0 0**	**27.60**	**100.0 0**

(Source: Cane Department, Government of Uttar Pradesh)

Vulnerability to new pests or new races of an established disease like red rot makes variety diversification the best insurance against large economic losses. While planting the large percentages of the land to the most productive variety, small acreages of other varieties should be maintained by the growers in case their major varieties suffer de4cvastating losses due to pests.

Indeed, it is extremely difficult to develop a variety encompassing all the desired attributes. Hence, the breeder has to have a compromise for attributes most essential and possible. In essence, the varietal planning deals with the complementation of characteristics of different tested varieties suitable for the given area. It aims at making the crop more remunerative to both the borrower and the miller.

Available evidence indicates that selection of parents for sugar content should be successful, but progeny testing would seem to be necessary for yield of cane. Some success will be achieved by selecting parents for yield of cane because there is substantial additive genetic variance but, in view of the magnitude of non-additive genetic variance, predictions based on the yields of parental varieties will not be very good. Consequently, it would seem to be desirable to test a large range of crosses for specific combining ability for yield of cane. When elite crosses are identified, large populations of these crosses should be planted to maximize the chance of selecting superior varieties.Transgressive segregants that would result from coming together of useful gene complexes are obtained when widely different parents are involved in hybridisation. Thus, needless to say, genetic diversity lays the foundation for effective crop improvement. One of the frequently used procedures is to choose parents that complement each other for different agronomic traits. However, the purpose would be better served when importance is given to traits with higher levels of coefficient of genetic determination. In addition, parents that are known for higher general combining ability should be given preference. As explained earlier, the degree of ancestral relationship (coefficient of co ancestry) should form the bed rock for deciding the cross combinations.

Several improved varieties have been developed through varictal improvement programmes for the subtropics of India by the Sugarcane Breeding Institute, Coimbatore; Indian Institute of Sugarcane Research, Lucknow; U.P. Council of Sugarcane Research, Shahjahanpur &Seorahi; Sugarcane Research stations/Centres like Pantnagar and Jalandhar; Pusa (Bihar), Uchani (Karnal) and at other centres.A list of major improved varieties is presented in Table 3.

Table3: Sugarcane varieties (attributes and potential)

S. N	Variety	Adaptability	Yield (t/ha)	Sucrose %	Duration	Special feature
1	Co 85004 (Prabha)	Peninsular	90.5	19.5	Early	R to smut
2	Co 94008 (Shyama)	Peninsular	119.8	18.3	Early	MR to red rot & R to smut
3	Co 8371 (Bhima)	Peninsular	117.7	18.6	Mid Late	R to red rot
4	**Co 86032 (Nayana)**	**Peninsular**	**102.0**	**20.1**	**Mid Late**	**R to smut & drought tolerant**
5	Co 87025 (Kalyani)	Peninsular	98.2	18.3	Mid Late	R to smut & drought tolerant
6	Co 87044 (Uttara)	Peninsular	101.0	18.3	Mid Late	R to smut
7	Co 91010 (Dhanush)	Peninsular	116.0	19.1	Mid Late	R to smut
8	CoM 88121 (Krishna)	Peninsular	88.7	18.6	Mid Late	R to smut,drought
9	Co 99004 (Damodar)	Peninsular	116.69	18.76	Mid Late	Tol. to drought, salinity
10	Co 2001-13 (Sulabh)	Peninsular	108.6	19.03	Mid Late	R to red rot, smut
11	Co 2001-15 (Mangal)	Peninsular	113.0	19.37	Mid Late	R to red rot, smut
12	CoC 01061	East Coast	110.8	17.4	Early	R to red rot
13	Co 86249 (Bhavani)	East Coast	104.2	18.7	Mid Late	R to red rot & smut
14	CoSe 95422 (Rasbhari)	NC&E Zone	67.8	17.7	Early	MR to red rot
15	CoSe 96234 (Rashmi)	NC&E Zone	64.10	17.9	Early	MR to red rot
16	CoSe 96436 (Jalpari)	NC&E Zone	80	17.13	Midlate	Waterlogging tolerant
17	CoLk 94184 (Birendra)	NC&E Zone	80.0	17.5	Early	Early & good ratooning
18	Co 98014 (Karan-1)	NW zone	76.3	17.6	Early	R to red rot
19	CoH 92201	NW zone	70.0	18.2	Early	R to red rot
20	Co 0237	NW Zone	71.33	18.78	Early	MR to red rot
21	Co 0238	NW zone	81.08	17.99	Early	R to red rot, wilt
22	Co 0118	NW zone	78.2	18.45	Early	R to red rot, smut & wilt
23	CoS 96268 (Mithas)	NW zone	81-98	16.50	Early	R to red rot
24	CoS 95255 (Rachna)	NW zone	70.5	17.5	Early	R to red rot
25	CoPant 90223	NW zone	73.3	18.5	Mid late	R to red rot, smut
26	CoS 91230	NW zone	68.2	18.8	Mid late	R to red rot
27	CoS 96275 (Sweety)	NW zone	80.8	17.3	Mid late	R to red rot
28	CoH 119	NW zone	82.8	17.5	Mid late	R to red rot
29	CoPant 97222	NW zone	88.2	18.2	Mid late	R to red rot
30	Co 99004 (Damodar)	Peninsular	115.5	19.8	Mid late	MR to redrot
31	Co 10026 (Upahar)	Peninsular	109.01	19.18	Early	MR to red rot
32	Co 09004 (Amrita)	Peninsular	109.85	18.94	Early	MR to red rot

Table 4: Recommended varieties for Uttar Pradesh (2022)

S. No.	Name of the Area	Districts of the Area	Early Maturing Varieties	Mid/ Late Maturing Varieties
1	All Areas	All cane growing districts	CoS 8436, CoS88230 ,CoS 95255, CoS 96268, CoSe 03234, UP 05125 (UP 09453), CoSe 98231,CoS 08272,CoSe95422, Co 0238, Co 0118, Co 98014, CoS 13231, CoS 13235, CoLk 14201 and CoS 17231	CoS 767, CoS 8432, CoS 97264 CoS 96275, CoS 97261,CoS98259, CoS 99259, CoSe 01434, UP 0097,CoS08279, CoS 08276, CoS 12232, CoSe 11453, Co 05011, CoS 09232, CoSe13452 and CoS 14233
2	Western region	Meerut, Ghaziabad,HapurBulandshahar, BagpatSaharanpur, Muzzafarnagar and Shamali	Varieties for all cane growing District and CoJ 64, CoS 03251,CoLk 9709, Co 0237, Co 5009, CoLk 11203 and Co 15023	Varieties for all cane growing District and CoS 94257, CoS96269, UP 39, CoPant 84212, CoS07250, CoH119, CoPant 97222, CoJ 20193,Co 0124, CoH 128,CoLk09204, CoLk 11206, Co 09022, Co 12029 and CoPk 05191
3		Lucknow, Lakhimpur Sitapur,Hardoi, Raibarely, Kanpur, Kanpur Dehat, Farukkhabad, UnnaoBarielly,Pilibhit,Shahjahanpur, Badaun,Aligarh, Etah, Mathura, Moradabad, Sabhal, Amroha, Rampur and Bijnor	Varieties for all cane growing District and CoJ 64, CoSe 01235, CoLk 9709, Co 0237, Co 05009, CoLk 11203 and Co 15023	Varieties for all cane growing District and CoS 94257, CoS 96269, UP 39, CoPant 84212, CoH 119, CoPant 97222, CoJ 20193, Co 0124, CoH 0128, CoLk 09204, CoLk 11206, Co 09022, Co 12029 and CoPk 05191
4	Meerut & Saharanpur	Gonda,Balrampur, Shravasti,Baharaich, Deoria, Kushinagar, Gorakhpur, Maharajganj, Basti, Jaunpur, Siddharthanagar, Sant Kabir Nagar,Azamgarh, Mau, Balia,Ayodhya Ghazipur, Varanasi, Bhadohi, Prayagraj, Barabanki, Ambedkar Nagar, Amethi,Mirzapur & Sultanpur	Varieties for all cane growing District and CoSe 01235, Co87263, Co 87268, Co 89029, CoLk 94184, Co 0232, Co 01421, and CoLk12207	Varieties for all cane growing District and CoSe96436, CoSe 08452, CoLk 12209
5.	Water Logged Areas	All Places Affected	UP 9530CoS 10239, UP 14234&CoSe 96436	

Chapter No. 11: Micropropagation for multiplication of disease-free and genetically uniform sugarcane plantlets

Sanjiv Gupta, Mamata Kumari, Alok Singh, Komal Yadav, Nandita Banerjee and Sanjeev Kumar[1]*
Division of Crop Improvement, ICAR-Indian Institute of Sugarcane Research,
Raibareli Road, P.O. Dilkusha, Lucknow
*Corresponding author, Email: Sanjeev.Kumar7@icar.gov.in

Introduction

In vitro culture of plant cells/tissues is now a routine technique using a range of explant types from many important crop plants. Successful technologies include isolation, culture of tissues, cells, protoplasts, organs, embryos, ovules, anthers, and microspores and regeneration from them of complete plantlets. The development of plant tissue culture technology represents one of the most exciting advances in plant sciences. For example, the prospect of being able to introduce, develop, produce, transfer, and conserve the existing gene pool of plant species by using tissue culture methods opens up new opportunities for researchers and entrepreneurs. Strictly speaking, the term "plant tissue culture" should denote in vitro cultivation of plant cells or tissues in an unorganized mass, i.e., callus culture. But in general, this term is applied to in vitro culture of plant cells, tissues, and organs. The number of published reports on plant tissue culture technology, especially micropropagation and its utilization in commercial multiplication of a wide range of species, has increased dramatically in the past 20–25 years. Another related term is cell culture, which means in vitro culture of plant cells, e.g., suspension cultures. When an organized structure (e.g., root tip, shoot tip, embryo) is cultured in vitro to obtain an organized structure, it is called organ culture. Micropropagation is a powerful tool, which represents "the production of multiple plantlets from somatic explants of a single plant or plants of a single genotype using in vitro culture of the explants".

Sugarcane is a crop which has enormous industrial value. It is widely cultivated in tropical and subtropical regions of India primarily for white sugar and jaggery production. Sugarcane, being a multiproduct crop, has immense potential for diversification: the green top of sugarcane is used as fodder; similarly, molasses, a by-product of sugar processing is also used as a cattle feed. The fuel potential of sugarcane is utilized by both sugar mills and jaggery processing units. High ploidy level, low fertility, large genome, and complex environmental interactions make conventional breeding and genetic studies tough for this crop. Sugarcane is a vegetatively propagated crop and is cultivated through stem cuttings termed as "sett." Sustained production and supply of quality seed is an important factor for the stability of agricultural production, since it is the most important basic input and is solely responsible for increasing the crop production by 15%–20%. The sustained high production of sugar per unit area depends primarily on continuous supply of adequate quantity of good-quality seed cane which has to be genetically pure, free from diseases and pests, and with no nutritional disorders. This can effectively be achieved by applying tissue culture techniques, since the raised plants are free from infections and the original vigor of the newly bred variety is maintained. Traditionally, sugarcane is multiplied through stem cuttings using three-budded sett. Diseases like red rot, leaf scald, ratoon stunting, grassy shoot, and mosaic are carried to successive crops through infected seeds. Thus, heavy financial losses occur annually on account of reduction in cane yield and sucrose recovery.

In this context, use of healthy seed of recommended varieties through hot air treatment and tissue culture technique becomes exceedingly important. The conventional mode of seed multiplication has a multiplication rate of 1:8–10, due to which a new variety takes 7–8 years to get cultivated in large areas at farmers' fields. However, the micropropagation technique is well recognized in sugarcane and has offered a thousandfold rate of multiplication; presently, it is one of the quickest available methods for seed production which provides a rapid technique of generating healthy seed of new varieties and rejuvenates old run-down varieties. The technology is not only economically viable but profitable as well.

The emergence of theory of totipotency led to the development of different *in vitro* techniques. Totipotency may be defined as 'the ability of a single differentiated mature cell to develop in to a complete plant', preferably *via* formation of an embryo. Clonal propagation via tissue culture, *i.e.*, micropropagation as a concept was first presented to the scientific community in 1960. Though the role of growth promoters in plants and tissue cultures was observed since 1950's and it was not until early 1960s that a generalized culture medium for plant tissue culture was established. Haberlandt was the first to culture, in 1902, fully differentiated cells isolated from leaves of several plant species.

Micropropagation

A related terminology is "meristem culture," which describes the culture of explants bearing intact apical/axillary shoot meristem with a view to obtain complete plantlets. The apical meristem (i.e., growing shoot tip) could be cultured in vitro resulting in continued and organized growth; this is sometimes known as meristem-tip culture, which gives enhanced axillary branching that minimizes the risk of somaclonal variations. Meristem-tip culture is of practical significance, and can be utilized to produce virus/disease-free plants since shoot meristems are generally free from viruses; to achieve this, the apical meristem of 100–200 μm needs to be cultured. However, for micropropagation, longer shoot tips of 2–5 mm can be cultured.

The apical dome (i.e., growing point) could be cultured, resulting in continued and organized growth. This method is known as meristem-tip culture, which gives enhanced axillary proliferation ensuring clean and variably stable culture with high purity and reliability. These shoot apices finally give rise to small shoots, which can be rooted. The technique can be utilized to produce disease-free plants. Since shoot primordial are closed structure and generally they are free from bacteria, viruses, etc., they could be cultured to obtain virus-free plant. Thus, the extreme tip of the shoot (0.5–2.0 mm in length) can be cultured. The technique involves manipulation of culture conditions so that the meristem can be organized to form shoot/root leading to plantlet formation.

To begin with, a range of culture conditions (including nutrients) are tested with sufficient explants to obtain aseptic cultures. Getting an organized structure such as a bud into an aseptic culture is a time-consuming process, and initially contamination is a hurdle. The multiplication rate is also slow at first, but later on, if the culture conditions are satisfactory, a much higher multiplication rate can be achieved. If the growth regulators are appropriately balanced, the shoot tip will elongate. Later on, the lateral bud break and adventitious shoots are also produced on the stem piece. This rapid proliferation of shoot results in masses of shoots being produced from a single shoot tip. This multiplication process is of commercial value, where the elite stock, hybrid lines, seedless line, male sterile line, etc., could be multiplied. Several hundred shoots can be produced within 12 weeks (4–6 subcultures). The multiplication rate varies with genotypes and species. Shoots are removed at regular interval and a portion of the mass is replaced on a fresh medium to continue proliferation. The small shoots which are removed from the cultures are then rooted on a separate medium. The resulting rooted shoot is referred to as a "plantlet" because of its miniature size, which are later hardened in green house and finally transferred to open field.

Stem/node culture

The term "stem/node culture" refers to "culture of explant bearing intact shoot meristem/ nodal portions." Hence, the main purpose is to produce a large number of shoots with repeated formation of axillary branches. Thus, the newly developed shoots serve as stock culture and are used as explants for repeated proliferation. The usual size of the explant is 10–20 mm in length compared to meristem culture. This technique is very much preferred to produce virus-free stocks at commercial scale. The most favorable feature of this technique is high multiplication frequency with genetic uniformity. The growth is generally promoted by the addition of growth regulators (cytokinins) into the growth medium. The primary explant is derived from an apical or nodal segment having a meristematic stem/few leaf primordia. Developing the meristem, shoot tip, or nodal portion will result in development of small shoots. After the appropriate treatment in stages I, II, III, and IV, the original cultures give rise root to finally develop as plantlets. At the same time, these auxiliary buds can be induced (at stage II) to develop multiple shoots or shoot clusters.

The first step in micropropagation is to establish contamination-free cultures of the meristem explants. This can be particularly problematic if the explants are taken from field-grown plants. This can be a time-consuming process and initially contamination is a hurdle. In addition, adventitious shoots are also produced as a consequence of the cytokinin used in the culture medium. This results in a mass of shoots being produced from a single shoot tip. The newly developed shoots serve as explants for further subcultures to support repeated cycles of shoot proliferation. If we assume that each culture yields an average of five shoots in 5 weeks, we can get 510 shoots in 1 year from a single explant; we have assumed here that all the shoots produced during the year are subcultured and all the subcultures survive and remain contamination-free. In practice, shoots are excised from the cultures at regular intervals, and a proportion of these are used for subculturing on a fresh medium to continue proliferation, while the rest of the shoots are rooted either in vitro or directly in peat moss. Rooting may or may not require an auxin like IBA or NAA.

The general technique

The different techniques of *in vitro* culture must solve two basic problems. *Firstly*, the cultured cells/organs must be maintained in a sterile or aseptic condition, *i.e.*, free from microbes. *Secondly*, the proliferation and proper development of the cultured cells/ organs must be ensured by providing the necessary nutrients, growth regulators and the other growth conditions. In general, a small piece of the plant to be cultured (referred to as the 'explant') is removed from a healthy, well-maintained stock/ mother plant. The source of tissue will vary from species to species, but shoot-tips, leaves, stems, lateral buds, and flower tissues are the most commonly used explants. The type of explant chosen depends mainly on the objective of the research worker and the species with which the work is being carried out.

The selected explant is rinsed with a dilute detergent (*e.g.*, Tween) solution, followed by surface sterilization using a suitable chemical treatment, *e.g.*, with 0.1% mercuric chloride. After this, the explant is rinsed 4-6 times with sterile distilled water, and placed in a vessel containing the selected culture medium; all these operations are carried out under aseptic conditions. The pattern of growth of the cultures is principally determined by the plant growth regulators (mainly the types and the concentrations of auxin and cytokinin) supplemented in the tissue culture medium.

Most cultures are established and begin to proliferate within 4-12 weeks of culture initiation, depending mainly on the plant species and, in some cases, even the particular genotype of the given species. A shoot proliferating culture can be subdivided (sub-cultured) to produce few to several subcultures each of which will continue shoot multiplication. Sub-culturing is a process in which a part of the cultured tissue is transferred onto a fresh medium; this becomes necessary mainly because of nutrient depletion and medium drying.

The laboratory setup

Cleanliness is the major consideration when planning a tissue culture laboratory as the losses from contamination are reported to be up to 50%. Thus, when we consider high valued product (commercial production), losses from contamination are unacceptable. The traffic pattern and workflow must be considered in order to maximize cleanliness. The cleanest rooms/areas are the culture room/primary growth room and ascetic transfer area; thus, it is the best to keep these areas separate so that they are not entered directly from outside.

Media preparation area

A wide variety of equipment are used in tissue culture experiments; these equipments are generally located in the media preparation area. This room has the facility for media preparation and sterilization (autoclaving). It also has a separate facility for cleaning of glassware and storage of the chemicals. The basic equipment in this area are a precision balance (for weighing of chemicals), a pH meter (to measure and adjust media pH), a refrigerator (for storage of chemicals/ stock solutions), a water purification system (for obtaining distilled water), a magnetic stirrer (for mixing of solutions) and a hot plate (for heating of media/ solutions).

Aseptic transfer area

The aseptic transfer room is an area where any operation requiring sterile condition is performed. The aseptic transfer area needs to be as clean as possible to avoid chances of contamination. It is preferable to have a separate room for aseptic transfer; this decreases spore circulation. This area has the laminar air flow workstation to be used for all aseptic works. The aseptic transfer area also has a burner, forceps, scalpel, balance, microscopes.

Culture room

The growth room or culture room is the area where cultures are kept, following inoculation, to enable their maintenance and to support the desired growth and development of the cultures. Generally, this area is separated from rest of the laboratory and is well cleaned. The most important facility in the culture room is the culture racks fitted with tube lights and a photoperiod regulator. Temperature is another important concern in the culture room so that the culture room has the facility for temperature control. Usually, a temperature of 25 ± 2^0C is maintained through air conditioners and heaters. Continuous power supply is a must since a failure of electricity will ruin the experiments.

Acclimatization area

The plants regenerated under *in vitro* conditions are not hardy enough to withstand the rigors of the environment if they are directly planted in the open field. Thus, an area is needed where plantlets are first conditioned to make them ready for field transfer; this area is called acclimatization area. The acclimatization area is a high humidity area with sprinkling irrigation facility. It may be in the form of greenhouse/ polyhouse facility.

Sterilization

Suitable sterilization procedures should be employed to minimize, as much as possible, the risk of microbial contamination of the cultures. To achieve this, all the materials, *e.g.*, culture vessels, instruments, medium, plant materials, etc., as well as the working area should be freed from microbes. This can be achieved by the following approaches of sterilization, *e.g.*, dry heat, flame sterilization, autoclaving, filter sterilization, surface sterilization, etc.; each of these procedures is suited for some but not other items of the culture system.

Nutrient medium

All the nutritional requirements for the normal growth and of plant cells and tissues are met by the nutrient or culture medium, which is often simply referred to as medium. A culture medium generally contains organic and inorganic nutrients, certain vitamins, needed growth regulators as per need and sometimes certain amino acids. Mineral elements play a vital role in the development of a plant as many of the elements form a part of important biomolecules. The media contain six macronutrients (N, P, K, Ca, Mg and S) and six micronutrients (Fe, Mn, Cu, Zn, B and Mo). All these elements are added in the form of their salts (*e.g.*, N as NH_4NO_3, K as KI, Ca and Mg as their sulfate salts, etc.). The iron is added in the form of $FeSO_4$-EDTA; this increases the availability and stability of the complex, particularly at the lower pH values. In addition, vitamins like nicotinic acid, pyridoxine HCl, thiamine HCl, and *m*-inositol; folic acid may also be added in some cases. For preparation of the media, double distilled water and analytical grade chemicals should be used.

In most of the experiments, sucrose is used as the carbon and energy source; glucose or maltose is used rarely. Solidified media provide a substratum to the growing static tissue. For gelling/solidification of the medium, agar is added to the medium at 8-10 g l^{-1}. Gelrite and phytagel serve as a good substitute of the agar; they are used at a lower concentration (~0.2%). Since there is a remarkable variation in the nutritional requirement of plant species, researchers have devised more than hundred different media. The most utilized media are MS (Murashige and Skoog) and B5 media; both these media were announced in 1962.

Growth regulators, which are used to supplement the medium, are divided into six major groups, *viz*., auxins, cytokinins, gibberellins, abscisic acid, ethylene and polyamines. In the auxin group, the main growth regulators are, naphthalene acetic acid (NAA), indole 3-butyric acid (IBA), indole 3-acetic acid (IAA), 2,4-dichlorophynoxy acetic acid (2,4-D), and *p*-chlorophenoxy acetic acid (PCPA). The cytokinin group is dominated by 6-benzyl adenine (BA) and Kinetin; and thidiazuron (TDZ), Zeatin and 2-ip (isopentenyl adenine) are also used occasionally. GA_3 is perhaps the sole gibberellin to be used in tissue cultures.

Stages in micropropagation

Stage I: Establishment of aseptic cultures

This stage consists of selection of the mother plants (source of the explant), and harvesting, surface sterilization and inoculation of the explants. Generally, choice of the explant depends on the species to be micropropagated, and the path of micropropagation to be followed. The season and growth stage of explant may affect the ease of culture establishment. In most cases, actively growing plant parts give good response in culture. In case of tree species, it is desirable to select about 1 yr old branches growing from as close to the base of the tree as possible. It may often be necessary to cut off some old branches from close to the main trunk to force the growth of such young branches. This stage primarily requires transfer of explants to the culture environment contaminant-free state, followed often by growth initiation. Initially, several batches need to be cultured, and the contaminated cultures are discarded. This stage completes with the aseptic culture establishment with a fairly large number of explants.

Stage II: Growth and differentiation of shoots

Micropropagation is generally based on induced multiplication of the axillary Meristem so that each meristem that is either present in the explant or develops in the culture subsequently becomes a potential plant. In addition to (a) an existing apical/axillary meristem, (b) the shoot buds may arise from *de novo* regeneration of adventitious meristems (organogenesis), or (c) plantlets may be obtained via somatic embryos. In commercial practice, the four most commonly used methods of micropropagation are, enhanced axillary branching (i) in shoot-tip and (ii) nodal cultures, and (iii) regeneration of adventitious shoots and (iv) somatic embryogenesis. The propagules produced in stage II (particularly shoots) are ordinarily used for repeated cycles of multiplication, *i.e.*, they are sub-cultured repeatedly to increase their number. For axillary shoot proliferation and adventitious shoot regeneration usually suitable concentration of a cytokinin (generally BA or Kinetin) is used; in some cases, a combination of a cytokinin and a low concentration of an auxin (2,4-D should be avoided) may be superior to cytokinin alone. Somatic embryogenesis is generally induced by a relatively high concentration of an auxin (2,4-D is preferred). But once embryogenic cultures are obtained they are maintained on a medium containing a relatively low auxin level.

Stage III: Root induction in the shoots

In most commercial operations, the preferred method in this stage is non-sterile rooting. Micro-cuttings are harvested (usually under non-sterile conditions) and stuck in a clean (but non-sterile) mixture of vermiculite or in a peat moss plug. If required, the cut ends of shoots may be treated with a suitable rooting mix or a suitable concentration of an auxin like IBA or NAA. These plugs are then placed in mist/fog chamber or polyhouse. However, in laboratory, the root induction is achieved in a suitable culture medium and the rooted explants are then transferred into pots filled with soilrite. Rooting stage is very important part of a commercial multiplication system. On a small scale, shoots are usually rooted on suitable rooting medium containing a lower salt concentration than the normal tissue culture medium. Some species root easily in the culture, but for most species a suitable rooting treatment (usually, a low concentration of IBA or NAA) is needed. Sometimes it may be necessary to allow the shoots to elongate prior to rooting.

Stage IV: Preparation for growth in natural environment (hardening)

The shoots/ micro-cuttings/ plants, derived in stage III are very small and are not capable of self-supporting growth in soil. So, in this stage the efforts are made to condition the plantlets, so that they can grow in external environment and carry out the photosynthesis. After this the transfer of plantlets to soil is also very important step, as any mistake in this critical phase can lead to significant loss of propagules. Shoots developed in culture are grown under high humidity and low light intensity leading to less cellular wax. This is the reason the tissue-cultured plants therefore, lose water rapidly in external environments. In practice the rooted plants are removed from vessels and their agar is washed thoroughly, now the small plants are transferred to sterile rooting medium (vermiculite/ Peat + Sand) and are kept in high humidity and less light for several days. Then plants are gradually shifted to light, hardened and transferred to soil.

Quality assurance for disease-free and genetically uniform seed cane

Seed quality is a very intriguing phenomenon. It is normally judged by morphological, cytological and biochemical data. However, the parameters generally being used are not stable markers; hence it is possible that plantlets raised through tissue culture may contain variants, which ultimately affect overall quality as well as revenue from such varieties. Therefore, it is essential to look for DNA based detection of somaclonal variants. DNA marker techniques like RFLP, RAPD, AFLP, SSR, ISSR, etc. have been extensively utilized in several crops for a variety of purposes including diversity estimation, cultivar identification, detection of somaclones, etc. In the case of sugarcane too, marker systems like RAPD, SSR have been used, however, the standard guidelines for sugarcane tissue culture developed from Department of Biotechnology, Government of India advocated use of ISSR markers.

Quality planting materials are a pre-requisite for raising a good crop. The tissue culture raise plant batches should be uniform, true-to-the type in all aspects with respect to mother plants, and also should be free from viruses. Department of Biotechnology, Government of India has set up the quality standards for tissue culture sugarcane, which necessitates the freedom of tissue cultured plantlets from *sugarcane yellow leaf virus* (*SCYLV*), *sugarcane mosaic virus* (*SCMV*), *sugarcane bacilliform virus* (*SCBV*), and phytoplasma. Thus, the mother stock as well as the batches of tissue culture plantlets are tested for these viruses. Previously, these tests were done by growing the plantlets in field and then recording the disease/virus symptoms, such open field tests were not only time-consuming abut also expensive. Now, these tests are done in the laboratory using highly sensitive techniques, e.g., PCR which uses DNA, and ELISA in which proteins are used. Similarly, the uniformity and test of true-to-type is performed using DNA based tests. These techniques are quick, relatively cheaper and provide very reliable results.

The Department of Biotechnology (DBT), Government of India is acting as a certification agency under the National Certification System for Tissue Culture-raised Plants (NCS-TCP). The aim of NCS-TCP is to enhance the production of tissue culture-raised genetically uniform and virus-free planting materials to the farmers. In the year 2020-21, a total of 93 NCS-TCP recognized Tissue Culture Production Units were under operation in India. DBT through NCS-TCP and its five Accredited Test Laboratories (ATL) spread across India is ensuring the quality certification of tissue culture raised plants of those tissue culture production units which follow its guidelines and are registered with them. ATLs play the most crucial role in testing of tissue culture-raised plants for virus indexing and genetic fidelity testing for certification. In this way, the NCS-TCP is facilitating certification of sugarcane tissue culture plantlets from recognized Tissue Culture Production Units which would ultimately help farmers to improve sugarcane production and productivity.

Expected benefits of tissue culture-raised sugarcane

- Relatively high multiplication rates can be achieved as compared to the conventional vegetative propagation procedures. For example, annual rates of multiplication in sugarcane in generally <10, whereas, micropropagation by adventitious shoot formation can give multiplication rates of 100 to 1000 per annum.
- Tissue cultures are also useful for maintaining special genotypes used in breeding.

- In addition, *in vitro* propagation alone or together with heat therapy can be used to produce disease-free plant materials, which is preferred for international germplasm exchange.
- Round the year propagation is possible without environmental effects.
- Parental clones could be multiplied easily for breeding purposes.
- The technique is also useful for maintaining elite genotypes used in breeding.
- With high rate of multiplication new variety may reach to the end users in limited time.

Limitations of *in vitro* propagation

- The cost of production per unit of propagule can be non-competitive with conventionally propagated material because of the elaborate facilities required, and the maintenance and labor cost.
- At time, some variation may be observed in the plants obtained through *in vitro* techniques as compared to the original mother plant. These variations may arise from (a) epigenetic changes, which are short-lived (usually only one generation), but many of the variations may result from (b) stable genetic changes, *i.e.*, somaclonal variations.
- Thus, in order to realize the full potential of the system, there is an urgent need to develop efficient culture maintenance procedures and techniques for rapid and reliable monitoring of genetic stability.

Conclusions

Tissue culture techniques have a variety of application in agriculture. Among the tissue culture techniques, micropropagation allows rapid multiplication of new or elite genotypes. Since the emergence of the concept of meristem/shoot-tip culture, almost 50 years ago, the technology has advanced to an extent that it is now possible to culture almost all the crop species. Micropropagation has become a standard method in nursery crop industry much as it has in the foliage plants. The global biotech business is estimated about 50 billion US dollars out of which 10% is the contribution of plant tissue culture products. Advances made in commercialization of plant tissue culture and the acceptance of tissue culture-derived plantlets by commercial nursery traders globally has led to the growth of this industry.

Suggested further readings

Bhojwani SS and Rajdan MK. 2004. Studies in Plant Science-5, Plant Tissue Culture: Theory and Practice: A Revised Edition. Elsvier Science BV, The Netherlands.

Cassells AC and Bajaj YPS. 1991. Setting up a commercial micropropagation laboratory. Biotechnology in Agriculture and Forestry vol. 17. Springer-Verlag; Berlin, Germany.

DeFossard RA and deFossard H. 1988. Coping with microbial contaminants and other matters in a small commercial micropropagation laboratory. Acta Hort. 225: 167-176.

Dixon A and Gonzalez RA. 1994. Plant Cell Culture: A practical manual. IRS Press, Oxford, UK.

George EF. 1993. Plant Propagation by Tissue Culture, Part I & II. Exgetics Limited, Edington, UK.

Murashige T and Skoog F. 1962. A revised medium for rapid growth and bioassays with tobacco tissue cultures. Physiol. Plant. 15:473–497

Narayanaswamy S. (1994). Plant Cell and Tissue Culture. Tata McGraw Hill Company Limited, New Delhi, India

Singh, BD 2005. Plant Biotechnology. Kalyani Publishers, New Delhi.

Chapter No. 12: Identification of different varieties of sugarcane

Sanjeev Kumar*, J. Singh* and Aalok Shiv#
*Principal Scientist and #Scientist
ICAR-Indian Institute of Sugarcane Research, Lucknow

Sugarcane varieties are the lifeblood of the Indian sugarcane industry. Varietal diversification is essential in the survival of the sugarcane industry in India. Variety identification is very important. An important aspect of the varietal identification is to associate the variety with the cultural practices needed to maximize its production. In the absence of a single agency for seed cane multiplication and distribution among the sugarcane farmers for commercial cultivation, a number of agencies/individuals such as State departments of sugarcane/agriculture, sugar factories, progressive farmers engage themselves in this stupendous task. Though, the maintenance of purity of purity of the seed material is an essential prerequisite for improving sugarcane and sugar productivity in the country. Multiagency involvement in the seed multiplication programme leads to unintentional mix up of varieties. Such a situation at commercial cultivation stage may result in decrease in cane yield and sugar yield as well as the quality of jaggery. In addition to this, experience has also shown that admixture of variety which is highly susceptible to a particular pest/disease may result in the large scale occurrence of that pest or disease in that area leading to huge economic losses to the farmers. Hence, it would be highly essential that the extension personnel serving in State departments and sugar mills should be able to distinguish a particular sugarcane variety from the other varieties and by their best in maintaining purity at various stages of seed multiplication.

The importance of varietal purity through seed production necessitates observation and identification of varieties by the workers at field level. This distinctiveness of any variety can be established either through molecular or morphological characterization. Out of these, morphological characterization is easier and cheaper and can be practiced on large scale without any additional cost.

Sugarcane varietal identification

To identify a sugarcane variety, the observations should be recorded on main stalk. The crop growing conditions should be normal and recommended package of practices should have been followed. The cane should be sampled from inside the plot and cane should be visibly healthy and free from pests and diseases. In general very first character considered for observation is the leaf curvature. The next important characters which can be observed easily in field are internode and size, shape of bud and presence or absence of bud furrow. The observation should be recorded at 10 months of the crop age.

The plant characters observed most commonly relates to gross morphology and features readily observed and distinguished by examination with naked eyes. Since molecular studies require laboratory facilities and trained personnel, these continued to be limited to research organization. Hence, the characters broadly considered for identification are morphological and vegetative characters only. Presence or absence of flowering in a particular location over the season will also help in identifying varieties, familiarity with the varieties and practical knowledge aid in varietal identification. Varietal diversification, as an essential component of sustainable sugarcane cultivation, will bring about more strain on persons engaged in seed supply and invite him constant attention and vigil in keeping up varietal purity.

Sugarcane plant comprises of stalk and leaf in general, sugarcane stalk is composed of nodes and internodes. Very important stalk characters are distributed on node and internode of stalk. Colour is considered identifiable and important character for cane but proper care should be taken while recording observations as colour might change after some times. The leaves are alternatively placed on stalk. The leaf has three main components, leaf blade, leaf sheath and flexing part called dewlap. Various characters which are used for identification of sugarcane variety are given in details.

Sugarcane descriptors for varietal identification

Based on the DUS testing guidelines 27 morphological characters can be used for the identification of sugarcane varieties. These characters are given in details.

1. Plant growth habit

There are two types of plant growth habit i.e. erect plant growth and semi-erect plant growth. This is one of the grouping characters used in the distinguishing the different sugarcane varieties. The sugarcane varieties may be categorized very easily into two groups i.e. erect as well as semi-erect growing.

2. Leaf sheath hairiness

The presence and absence of hairiness or spines on the back of sheath is the character of use in the varietal identification. When hairs are present, their distribution also is an additional character for identification. When the leaf sheath does not have hairs, it is called glabrous, when the spine fall from older sheath, the spines are deciduous. There are three patterns of leaf sheath hairiness are found in most of the sugarcane varieties i.e. (1) absent, (2) sparse and (3) dense.

3. Shape of ligules

This is small membranous flap like structure on the inside and is an extension of the sheath. it varies in length, shape, symmetry and position and is often a character of considerable importance and one on which reliance can be placed for identification. There are four shape of ligules found in most of the varieties (1) Strap-shaped (2) Deltoid (3) Crescent (4) Arch shaped.

4.Shape of inner auricle

It is also called as ligular process or auricle. These are out growth or lateral extension of the leaf sheath. The length varies with the different leaves of the same cane. they may be present or absent, long or short and of various shapes (1) Incipient (2) Deltoid (3) Dentoid (4) Unciform (5) Calcariform (6) Lanceolate (7) Falcate.

5. Colour of dewlap

The leaf is divisible into two portions *viz.,* the lamina or leaf blade and the sheath. The portion connecting these two is called 'Transverse Mark' or dewlap. The colour of dewlap can be used for the identification of different sugarcane varieties. The dewlap colour may be observed as (1) Green (2) Greenish yellow (3) yellow (4) Yellowish green (5) Brown purple.

6. Leaf blade curvature

Arrangement and general position of leaves is a character of considerable importance in the identification of different sugarcane varieties and often aids identification in the field without the necessity for minute and close examination. Leaf blade curvature is used for the grouping of the sugarcane varieties. The leaf carriage or leaf blade curvature can be of three types (1) erect (2) curved tip (3) arched or spreading type.

7. leaf blade width

The width of the leaf, at its broadest, is often a diagnostic character of importance. Below 3 cm it is regarded as narrow, between 3 and 5 cm it is regarded as medium and above 5 cm as broad.

8.Adherence of leaf sheath

Adherence of leaf sheath is very important character for the identification of sugarcane varieties. This is a grouping character. Leaf sheath adherence may be grouped as weak (self detrashing), medium (semi-clasping type) and strong (tight clasping). Observations can be recorded by pulling dry leaves and grouped as weak, if leaf sheath is removed completely and very easily, medium, if small part of the leaf sheath remains attached with stem and strong, if leaf sheath is strongly and completely attached with stem. The self detrashing is desirable trait helps during harvesting.

9. Internode colour (not exposed to sun)

Unexposed colour can be recorded by removing two lower most green leaves of the stem (after removing the wax with moist cotton) in the middle of the plot. For the assessment of all colour characteristics the latest RHS (Royal Horticultural Society) colour chart can be used. The internode colour may be grouped as (1) Green (2) Green yellow (3) Green white (4) Yellow (5) Yellow green (6) Yellow white (7) Orange white (8) Grayed green (9) Grayed yellow.

10. Internode colour (exposed to sun)

Colour of the stem can be recorded at fifth internode from the base two months after detrashing and removing the wax with moist cotton. Exposed internode may grouped as (1) Green yeloow (2) Yellow green (3) Yellow (4) Grey (5) Brown (6) Purple.

11. Internode diameter

Diameter can be recorded with Vernier Calipers. The measurement can be taken at the middle of cane at the middle of the internode on the axis passes through the bud. Internode diameter may be measured as thin (<2.2 cm), medium (2.2 to 3 cm) and thick (>3 cm).

12.Internode shape

The shape of internode is as important character for varietal identification. There are six major shapes of internode i.e. (1) Cylindrical (2) Tumescent (3) Bobbin shaped (4) Conoidal (5) Obconidal (6) Curved.

13. Internode zigzag alignment

Alignment of internode in the stalk either zigzag or straight and the character may be marked as zigzag alignment is present or absent.

14. Internode growth cracks (Splits)

These are cracks in the epidermis which extends deep into the rind region. These are often reliable for varietal identification. They may be long or short. deep or shallow. For the varietal identification. For the varietal identification this trait can be marked as present or absent.

15. Internode rind surface appearance

The surface of the internode is often characterized by markings which aid in the identification of those varieties wherein they are profuse. These are split in the epidermis and occur as short or long thin lines known as Ivory Markings. Sometime grayish patches develop on the internode owing to the reactions of the weather. These are known as weather marking or corky patches. Based on this important character, the sugarcane varieties may be grouped as having (1) smooth appearance (2) Corky patches only (3) Ivory marking only (4) corky patches and ivory marking both.

16. Internode waxiness

This is the region immediately below the leaf scar and with a heavy deposit of wax. The amount of wax varies and the band may be prominent or not. The region may be even with other portions of the internode constricted or swollen. The presence of waxiness in different sugarcane varieties can be grouped as (1) Light (2) Medium (3) Heavy.

17. Shape of bud

The shape of bud differs among the varieties. This characteristics may be observed on the bud at top most node whose leaf had fully dried and was most reliable. There are total 9 shape of bud which can be used for the identification of different sugarcane varieties (1) Ovate (2) Obovate (3) Oval (4) Round (5) Pentagonal (6) Rhomboids (7) Rectangular (8) Triangular pointed (9) Beaked.

18. Size of bud

The size of bud differs among the different sugarcane varieties. It is measured from the base of bud to the tip. The size of bud can be grouped as small (< 6 mm), medium (6-9 mm) and large (>9 mm).

19. Bud groove
Often depression are noticed on the internode just above the bud and thse are known as bud groove. They may be long or short, deep or shallow. Bud grooves may be classified in the different sugarcane varieties as (1) Absent (2) Shallow (3) Deep.

20. Bud Cushion
in some varieties, there is space between the bud and the leaf scar which is referred to as bud cushion. When the bud cushion is present it is often a fairly reliable character. Bud cushin may be present or absent.

21. Bud tip in relation to growth ring
Position of the bud tip in relation to the growth ring may be observed. it can be marked as distinctive character i.e. bud tip remains below the growth ring or touching the growth ring or surpassing the growth ring.

22. Prominence of the growth ring
This is a region just above the root zone and can be observed at a location opposite to the bud in the middle of the cane. It varies among the varieties in width, colour and nature. The width varies from 2 mm to 5 mm. Below 3 mm the growth ring has been referred to as narrow, between 3 to 4 mm as medium and above 4 mm as wide. The colour of growth ring is either different from that of the other portion of the inernode or the same when it is spoken off as concolourous. The growth ring may be either even with the other portions of the internode, depressed or swollen. The prominence of the growth ring can be marked as either weak (not swollen) or strong (swollen).

23. Width of root band
This is the region just above the leaf scar. It has rows of dormant root primordia or initials which develop in to roots when planted. The root band varies among varieties in width, colour and shape i.e. whether even depressed or swollen. The root band is referred to as narrow when the width is below 6 mm, medium when it is between 6 mm and 8 mm and broad when above 8 mm. The root band may differs in colour from the rest of internodes may be concolorous. It may be even with rest of the internodes depressed or swollen. The number of rows of of root eyes also differ among the varieties. The root eyes may be regular or staggered rows.

24. Internode cross-section
The shape of the cross-section of the cane can be observed after a cut made across it. It may be grouped as round or oval.

25. Pithiness
Pithiness is a condition that occurs in sugarcane stalk that causes dry cavity with no sugarcane juice. Pithiness is of an economic concern because it can result in reduced sucrose extraction during milling. Sugarcane varieties can be identified as pithiness is either present or absent in it.

26. Number of millable canes (NMC) per stool
Fully developed one with a minimum height of one meter can be considered as millable cane. Varieties may be classified as having NMC low (<3.0), medium (3.0 - 5.0), high (5.1 - 7.0) and very high (>7.0).

27. Cane height
Cane height of the cane may be recorded between ground level and base of TVD leaf. Sugarcane varieties may be grouped as short (<1.75 m), medium (1.75-2.5 m), tall (2.6-3.25 m) and very tall (>3.25 m).

In addition to the above, few other characters may also help in the identification of varieties. Venation and position of the germpore on the bud are also important in this context. The number and arrangement of the nerve on the bud is also important character of help in identification of varieies. The germpore is the point of origin of the shoot which sprout from the bud. This pore may be situated either at upper most end of the bud when it is termed as apical, slightly below the top when it is known as sub-apical or about the middle of the bud when it is referred to as dorsal.

Characteristics of recently released sugarcane varieties of ICAR-Indian Institute of Sugarcane Research, Lucknow

Character	CoLk 09204	CoLk 11203	CoLk 11206	CoLk 12207
Parentage	CoLk 8102 x CoJ 64	CoLk 8102 x Co 1148	CoPant 90223 x Co 62198	CoLk 8002 GC
Maturity group	Midlate	Early	Midlate	Early
Plant growth habit	Semi-Erect	Erect	Erect	Erect
Leaf sheath hairiness	Absent	Absent	Absent	Absent
Shape of ligule	Crescent	Crescent	Crescent	Crescent
Shape of inner auricle	Deltoid	Incipient	Incipient	Dentoid
Colour of dewlap	Green	Green Yellow	Brown	Yellowish green
Leaf blade curvature	Arched	Erect	Curved tip	Erect
Leaf blade Width	Medium	Medium	Medium	Medium
Plant: Adherence of leaf sheath	Weak	Semi clasping	Weak	Weak
Internode: colour (Unexposed)	Green	Green Yellow	Green yellow	Yellow green
Internode colour: (exposed)	Purple	Purple	Yellow green group	Yellow green
Internode diameter	Medium	Medium	Medium	Medium
Internode shape	Conoidal	Bobbin	Cylindrical	Conoidal
Zig zag alignment	Present	Absent	Present	Present
Growth crack (Split)	Present	Absent	Absent	Absent
Rind surface appearance	Smooth	Smooth	Smooth	Corky patches only
Waxiness	Medium	Light	Medium	Light
Shape of bud	Round	Ovate	Ovate	Round
Size of bud	Medium	Large	Large	Small
Bud groove	Absent	Absent	Shallow	Absent
Bud cushion	Absent	Present	Absent	Absent
Bud tip in relation to growth ring	Below growth ring	Touching the growth ring	Touching the ring	Below growth ring
Prominence of growth ring	Weak	Weak	Weak	Strong
Width of root band	Broad	Broad	Medium	Narrow
Internode Cross section	Oval	Oval	Oval	Round
Internode: Pithiness	Present	Absent	Absent	Absent
Number of millable canesl	High	Medium	Medium	Medium
Cane height	Medium	Medium	Medium	Medium

Character	CoLk 12209	CoLk 14201	CoLk 14204	CoLk 15201
Parentage	LG 95053 x CoPant 90223	Co 0238 GC	CoLk 8002 x CoSe 92423	CoS 8436 GC
Maturity group	Midlate	Early	Midlate	Early
Plant growth habit	Erect	Erect	Erect	Erect
Leaf sheath hairiness	Absent	Sparse	Absent	Absent
Shape of ligule	Crescent	Deltoid	Crescent	Deltoid
Shape of inner auricle	Deltoid	Deltoid	Lanceolate	Incipient
Colour of dewlap	Yellowish-green	Green	Yellowish green	Yellowish Green
Leaf blade curvature	Curved tip	Erect	Arched	Erect
Leaf blade Width	Medium	Medium	Medium	Medium
Plant: Adherence of leaf sheath	Medium	Medium	Medium	Semi clasping

Internode: colour (Unexposed)	Green white	Yellow white	Yellow white	Green yellow
Internode colour: (exposed)	Purple Group	Purple	Yellow white	Purple
Internode diameter	Medium	Medium	Medium	Medium
Internode shape	Cylindrical	Cylindrical	Cylindrical	Cylindrical
Zig zag alignment	Absent	Absent	Absent	Present
Growth crack (Split)	Absent	Absent	Present	Absent
Rind surface appearance	Smooth	Smooth	Corky patches	Smooth
Waxiness	Light	Medium	Medium	Light
Shape of bud	Oval	Oval	Ovate	Ovate
Size of bud	Small	Medium	Medium	Medium
Bud groove	Absent	Shallow	Shallow	Shallow
Bud cushion	Absent	Present	Present	Absent
Bud tip in relation to growth ring	Touching the growth ring	Touching growth ring	Touching the ring	Above the growth ring
Prominence of growth ring	Weak	Strong	Weak	Swollen
Width of root band	Narrow	Narrow	Medium	Medium
Internode Cross section	Round	Round	Round	Round
Internode: Pithiness	Absent	Absent	Present	Present
Number of millable canes	Medium	High	High	Medium
Cane height	Medium	Mediun	Medium	Tall

Character	CoLk 15207	CoLk 15466	CoLk 15206	CoLk 16466
Parentage	Co 88039 GC	CoS 8436 GC	LG 95053	BO 91 x Co 86002
Maturity group	Midlate	Early	Midlate	Early
Plant growth habit	Erect	Erect	Erect	Erect
Leaf sheath hairiness	Absent	Sparse	Absent	Absent
Shape of ligule	Crescent	Crescent	Crescent	Deltoid
Shape of inner auricle	Deltoid	Incipient	Incipient	Incipient
Colour of dewlap	Purple	Purple	Green	Yellowish green
Leaf blade curvature	Arched	Curved Tip	Curved Tip	Arched
Leaf blade Width	Medium	Medium	Broad	Broad
Plant: Adherence of leaf sheath	Weak	Medium	Strong	Weak
Internode: colour (Unexposed)	Yellow Green	Yellow Green	Yellow	Yellow Green
Internode colour: (exposed)	Purple	Purple	Purple	Grey group
Internode diameter	Medium	Medium	Medium	Medium
Internode shape	Cylindrical	Cylindrical	Bobbin	Bobbin
Zig zag alignment	Present	Present	Present	Present
Growth crack (Split)	Absent	Absent	Absent	Absent
Rind surface appearance	Smooth	Smooth	Ivory marks only	Ivory marks only
Waxiness	Medium	Light	Light	Medium
Shape of bud	Ovate	Oval	Oval	Pentagonal
Size of bud	Large	Medium	Medium	Medium
Bud groove	Deep	Absent	Absent	Shallow
Bud cushion	Absent	Absent	Absent	Absent
Bud tip in relation to growth ring	Above growth ring	Touching growth ring	Below the growth ring	Touching the ring
Prominence of growth ring	Swollen	Weak	Strong	Weak
Width of root band	Medium	Narrow	Medium	Medium
Internode Cross section	Oval	Round	Round	Round
Internode: Pithiness	Absent	Present	Absent	Present
Number of millable canes	Medium	High	Medium	Medium
Cane height	Medium	Medium	Medium	Medium

Suggested Readings

1. Artschwagar, E. (1940). Morphology of the vegetative organs of sugarcane. J.Agric. Res. 60:503-549.
2. Forte C. and Dematte, J A M (2006). Discrimination of sugarcane varieties using Landsat 7 ETM + spectral data. International Journal of Sugarcane Varieties, 27: 7, 13951412, DOI: 10.1080/01431160500383863.
3. P.K. Singh, A. Siraree, Sanjeev Kumar, R. Kewal Singh, D.K Pandey and J. Singh. (2012). Characterization of sub-tropical sugarcane varieties based on Distinctiveness, Uniformity and Stability testing guidelines of India. *International Sugar Journal*, 114 : 423-33.
4. Siraree A. Banerjee N. Sanjeev Kumar, M S Khan, P K Singh, Sanjeev Kumar, Swati Sharma, R K Singh and J Singh (2017).Identification of marker-trait associations for morphological descriptors and yield component traits in sugarcane. *Physiology and Molecular Biology of Plants.* 23 :185-196.
5. Sugarcane (Saccharum L.) Guidelines for the conduct of tests for DUS (2005) TG/188/1, UPOV, Geneva.
6. Van Dillewijn C. (1952). *Botany of Sugarcane.* The Chronica Botanica Co., Waltham, Mass., USA and Wm. Dawson & Sons, Ltd., London.

Chapter No. 13: Sugar beet Germplasm: Ex-Situ conservation, evaluation and utilisation in India

A.K. Mall, Varucha Misra, A.D. Pathak and Ankur Tripathi*
ICAR-IISR, Lucknow
*Ph.D. Scholar, ANDUAT, Ayodhya
Email: Ashutosh.Mall@icar.gov.in

Sugarbeet (Beta vulgaris) provides about 20 % of the global demand for sugar. Sugar beet is one of the main sugar crops in the world contributing to 20% of global needs of sugar consumption. The Russian Federation is the world's leading producer of sugar beets. In the year 2020, sugar beet production in the Russian Federation was 33.9 million tonnes accounting for 13.73% of global sugar beet production. The top five countries (Russian Federation, United States of America, Germany, France, and Turkey) contribute to 57.59% of it. In 2020, global sugar beet production is expected to hit 246 million tonnes. In the Indian scenario, the price increase in gas and diesel has caused problems in people's livelihoods, hence biofuel has gained attention as a substitute. Sugar beets are a good source of ethanol, thus Indian sugar companies in Andhra Pradesh, Maharashtra, Karnataka, and Punjab are interested in fair trials that have been proven to be agronomically feasible through in-house crop development. Multinational sugar beet seed companies such as Syngenta, SES Vanderhave, and KWS are interested in growing this crop in India to market it. These companies are especially active in sharing information on sugar beet seed, such as how to cultivate and treat it. This crop is also intensively promoted by IISR in Lucknow (Uttar Pradesh) and VSI in Pune (Maharashtra). The Seed Development Foundation is also contributing financially to the design and construction of a prototype plant for sugar beet processing at Samarth Sahakari Sakhar Karkhana Ltd. in Jalna (Maharashtra). In addition, a sugar beet-based ethanol production unit has been developed in Hameshwar (Maharashtra), however, response from these enterprises is needed. Many other government and corporate groups are also working in demonstrating the crop's economic potential. The positive response to these works in the future could serve as a model for others looking to promote this crop.

For almost seven decades, the Indian Institute of Sugarcane Research has been researching on this crop, and researchers have produced evidence for sugar beet growth and development in India's tropical and subtropical climates. With the introduction of several commercial cultivars for Indian agro-climatic conditions, as well as the development of agro-technologies for crop production, protection, and machinery. The multinational company Syngenta India Ltd. had developed thermo-insensitive varieties such as HI0064, Dorotea, and Posada, and were grown on experimental basis in 38 sugar factories in Maharashtra. Based on experimental trials conducted at various locations, sugar beet cultivation was started in Sri Ganganagar, Rajasthan for sugar production and in Sundarbans, West Bengal for alcohol/ ethanol production. A Network Project to develop agronomical techniques for the cultivation of sugar beet in India was initiated by ICAR during 2004-07, with centres at VSI, Pune, RRS, Sangli, IISR, Lucknow, and Sriganganagar. The experimental findings revealed that the productivity of sugar beet grown in the winter season was 60-75 t/ha. However, the sugar beet productivity was 30-35 t/ha at farmers' field. Amongst the variety, HI0064 was the best followed by the IISR, Lucknow varieties, i.e., LS 6 and IISR Comp. 1.

Varietal development in sugar beet in India: Seed Production Perspective

As a biennial crop, the sugar beet generally takes two years to generate a seed. The first year, mother beets or stecklings are grown from seed and, after storing over winter, are used to grow the seed crop the following year. Epigeal germination results in the formation of a rosette of glabrous, dark green, glossy leaves with germinant mid ribs and string petioles in the first year. Leaf production continues throughout the first season, while the root grows and accumulates sugar. The leaves are straightforward, with a broad blade and petiole. Root harvests are often harvested before the first frost of the season. In the second year, the sugar is needed to build the flowering stalk, flowers, and seed. Seed can be gathered by

July from plantings made the previous fall in locations where winters are reasonably mild, with some light cold conditions to stop vegetative growth.

Bolting: Bolting refers to the growth of seed stalks by plants. Although low temperatures are required to induce full and uniform bolting, frost damage must be kept to a minimal. The length of freezing temperatures has an effect on the proportion of blossoming plants. Bolting times varied amongst cultivars; some bolted 52 days after planting, while others bolted 41 days after planting. More bolters emerge in plants that have been exposed to lower temperatures for a longer period of time, and the first bolters appear sooner after cold treatment. Because resistance cultivars require higher induction than susceptible cultivars, the minimum duration of the cold period varies by cultivar. A longer vernalization period (5 weeks at 5°C) causes bolting to begin earlier at each photoperiod and a larger final proportion of bolters. Bolting plants can be obtained in a variety of ways, including longer freezing and shorter photoperiod and *vice-versa*.

Bolting is not a desirable trait in sugar beets produced for sugar production. If bolting occurs early in the growing season, the roots remain relatively short and become fibrous or woody, making slicing at the factory for sugar processing problematic.

Flowering: Sugar beet bolting and blooming requires a cool temperature of 3-8°C. During the blossoming season, air humidity should not be too low. Vernalisation is necessary for flowering. The seed stem appears at the end of April (25 days after replanting depending on temperature), and flowering occurs around 20 days later. The flowers are complete but imperfect. They have a five-part calyx but lack corolla. They grow on a panicle-like spike.

Seed Production: *In-situ* and transplanting methods are two seed production methods used practically all over the world. The suitability of a given approach is heavily influenced by the temperature, rainfall, and microclimatic variables of the location. Ramonskaya 06 (R-06), a Russian variety, was the first variety whose seeds were successfully produced in India. With the advance in sugar beet research in India, the development and production of indigenous varieties were also initiated with achievements.

***In-situ* method (or Direct Method):** The technique is appropriate for commercial seed production. The direct method of seed production is more easily mechanized than the indirect method, resulting in lower labour costs. In India, the seed is planted in June at high altitudes (Kashmir valley and Himanchal Pradesh) with snowfalls. The chosen area meets the climatic requirements for seed production. The crop is produced from seed to seed in one field without being disturbed in this way. It gives improved seed output due to enhanced plant establishment in the early phases, with no further interruption. Under Indian agro-climatic conditions, particularly where temperatures do not fall below freezing, resulting in root mortality, the *in-situ* approach will be preferable for commercial seed production. Winter temperatures ranging from 1.66°C to 7.22°C for two to three months are ideal for allowing beets to overwinter in the field without causing root death. The *in-situ* technique, on the other hand, has the flaw of no prior selection of steckling for phenotypic characteristics or illnesses.

***Transplanting* Method (or Indirect Method):** Small plants known as stecklings are created in the first stage of vegetative growth in this type of method, and these are grown to produce seeds in the second stage. The steckling crop is sown on plains in India using the transplanting method during the first week of October. In December, selected roots are transplanted or placed in terraces for overwintering before being replanted in March. This method allows for the removal of off kinds/unwanted types by observing roots that are not true to the types. Before shifting for vernalization, the little roots are scrutinized for morphological characteristics in order to protect the genetic purity of the parent for seed production.

Hybrid Seed Production: The production of the hybrid seed occurs in two ways. The majority of commercial seed is created by combining a male-sterile F1 line as the dominant female parent with seed from a multi-germ pollinator in a 10:1 ratio. The seed-bearing parent must be monogerm, whereas the pollinator parent is normally multigerm to give enough pollen. The seed ball generated is monogerm (maternal parent fruit), but the real seed is genotypically multigerm, which alleviates the pleiotropic effect on vegetative plant growth that is frequently linked with the monogerm state. The resulting crop contains a small percentage of non-hybrid seed. However, because they are larger and different in shape, they can be easily separated from the small flattish monogerm seed during conditioning. The second approach is more expensive, but it produces a fully hybrid crop. It is generally used to preserve parent stock seed for use in three-way or double-cross hybrids. The multi-germ pollinator is grown in four independent rows separated by a skip-row of 16 to 20 female male-sterile rows. After pollination and before harvesting the hybrid seed generated on the male-sterile parent, the male rows are removed. Backcrossing with their type "O" equivalent keeps the male-sterile lines alive for future use. This procedure ensures that the offspring are male sterile. When crossed with male-sterile lines, male fertile lines do not restore pollen production in the offspring. They are comparable to the maintenance lines used in hybrid corn production. Hybrids may be either diploid (2n = 18) or triploid (2n = 27). Triploids are created when autotetraploid (2n = 36) pollinators, where colchicine was applied, are utilized to double the chromosomal number of a diploid plant.

Male sterility is an influential factor for hybrid seed production. Male sterility in sugar beet is of two types, genetic male sterility (inherited on the nuclear chromosomes in a Mendelian fashion) and genetic-cytoplasmic male sterility (CMS) (controlled by an interaction of nuclear and mitochondrial genomes). The CMS line maintainer (with sterile cytoplasm and recessive restorer genes—xxzz) is referred regarded as a 'O-type.' The CMS system enables hybrid cultivar production.

Sugar beet Seed: Sugar beet seeds are woody fruits that are frequently referred to as seed balls. By the first week of September, the seed begins to mature on the older branches beginning at the base, followed by younger branches until the first week of October. Because of the uneven maturity, the seed-bearing branches are harvested twice, the first in the mid-September and the second in the first week of October. One (monogerm) or up to five (multigerm) kidney-shaped seeds are securely enclosed in a woody pericarp made up of impermeable sclerenchyma cells inside each seed ball. The inner dense layer of the pericarp prevents water and oxygen uptake by the contained seeds, whereas the basal aperture at the bottom of the pericarp is made up of loose cells that allow water and oxygen to enter.

Monogerm Seed: A monogerm refers to a single seed. The seeds are round and very uniform. The monogerm character appeared constant and invariable. The seedlings developed from these seeds give birth to ordinary seedlings. These seeds mostly show non-bolting tendency.

Multigerm Seed: A multi-germ "seed ball," refers to a cluster of two to five achenes generated by the uniting of numerous floral units. This was the original natural sugar beet seed unit. Each of the achenes germinated when planted, resulting in three to five plants. The resulting plant stand was far too dense for optimal root and sugar production, necessitating manual thinning at substantial expense to the grower.

Development of Indian commercial sugar beet varieties by IISR:

LS 6: A higher yielder with moderate sugar variety was identified for both tropical and sub-tropical regions of India. This genotype was open-pollinated and developed through mass selection. It is tolerant to high temperatures and equally suitable for sub-tropical and tropical agro-climates. The variety has less incidence of Sclerotium root rot. It is multigerm and hardy. The seed cost is much less than the pelleted monogerm seed of exotic varieties. A methodology has also been developed for producing good-quality seeds of this variety. LS 6 has been bred for Indian conditions and is well adapted to a wide range of growing conditions.

Variety	Root yield (t/ha)	Sucrose (%)	Gross sugar (t/ha)
LS 6	70.42	16.22	11.484

IISR Comp 1: It is open pollinated diploid and has four diploid varieties in its parentage, namely Ramonskaya 06, Dobrovicka C, AJ 3 and US 75. It is a diploid variety with a chromosome number of 2n=18, multigerm and self-fertile. It has very good germination in normal as well as cold climate. It has been tested in farmers' field conditions at Sriganganagar (Rajasthan) and Zira (Punjab). It was identified as a superior variety in 7th All India Coordinated Research Workshop held at Kolkata in 1984. The variety was recommended for release in 1986. It is suitable for cultivation in the states of Uttar Pradesh, Rajasthan, Punjab, and West Bengal. This variety is superior in root yield and gross sugar to Ramonskaya 06 the only variety under commercial cultivation in India. It has other additional characteristics like better tolerance to diseases, higher purity, and tolerance to temperature.

Variety	Root yield (t/ha)	Sucrose (%)	Gross sugar (t/ha)
IISR Comp 1	71.42	15.82	11.29

Germplasm maintenance and conservation

The conservation of sugar beet genetics includes the collection, reproduction, and storing of seed samples under cold storage conditions ex-situ. Germplasm collection is the most efficient technique to harvest. Indigenous variety' germplasm is being collected, maintained, and evaluated. 80 sugar beet germplasm has been imported from various sugar beet companies around the world (SASVanderhave, JK Seeds, KWS SAAT SE & Co. KGaA), with 40 indigenous germplasm being generated. As previously indicated, seed production places in India at higher elevations of 5000 amsl have shown to be appropriate for this crop's seed production. The IISR Sugar beet Outpost Mukteshwar in Uttarakhand uses the steckling procedure to preserve these germplasms.

In addition, medium-term storage (temperatures of 0–10°C, relative humidity (RH) of 25–30%, and seed moisture of 6–8%) has been maintained at IISR Lucknow, where seeds are held in cold storage for a period of 2-3 years to preserve genetic resources. Seed storage also includes a database with information such as the date and number of packets of each type. In addition, every other year, a set of indigenous and exogenous sugar beet types is freshened up to maintain seed viability.

Germplasm evaluation is being performed at the farm area of the Institute and many indigenous varieties have been identified for different conditions like LKC LB, LKC 2007, LKC 2006, LKC 2010, LKS 10, LK 4 for water-deficit stress condition, LKC 2020 for better ethanol recovery under irrigated and drought conditions, LKC LB and LKC 2000 for good juice quality under post-harvest deterioration conditions, LKC LB for fodder purposes, LKC 2000, LKC 2007, LKC HB for high Brix and sucrose content, LKC 2020-1 for *Spodoptera litura* resistant. The seeds of these varieties are now being produced on a larger basis for commercializing and spreading sugar beet technologies developed by IISR due to the sudden interest of farmers and millers in terms of ethanol production. Seeds are being supplied to many governments and the private sector like S. Nijiligappa Sugar Institute, Belgavi; NSI, Kanpur; Parle Pvt. Ltd. Bahraich; Neoko Private industries, Bengaluru.

Conclusion

Varietal development of sugar beet is the talk of the time. With the issues of sudden and abrupt climatic conditions, favorable varieties are required for coping with such situations. Besides, high sugar and ethanol-yielding varieties are also needed to be developed as per the current ethanol blending program initiative along with disease and insect pest resistance. Sugar beets are generally allogamous (cross-pollinating), with a complicated gametophytic self-incompatibility mechanism that prevents self-pollination but permits practically any two plants to cross-pollinate. A dominant self-incompatibility suppressor gene controls self-compatibility, resulting in nearly full self-fertility. In population improvement initiatives based on selfed-progeny performance and the development of inbred lines for hybrids, self-fertility may be employed in conjunction with hereditary male sterility. Sugar beet hybrid seed production is dependent on CMS. Because identifying maintainer lines requires time-consuming and arduous test crossings using a CMS tester, the development of a marker-assisted selection approach for the rf gene (the non-restoring allele of the restorer-of-fertility locus) is extremely desirable for sugar beet breeding. Strict selection for the maintainer genotype allows for the discovery of maintainer lines capable of producing stable CMS lines.

Plant breeding can even significantly enhance the economics of sugar beet production by changing the typical form of the sugar beet root. Public pre-breeding initiatives use breeding plans to improve germplasm while at the prevailing time, discovering molecular markers in the populations with which they deal are equally important. More markers are being discovered on the hybrid from the exotic source and sugar beet parent. Sugar beet is a highly outcrossing crop because it is wind pollinated. As a result, plant breeders today may benefit from exotic germplasm that was accidentally or purposefully introduced into the sugar beet breeding pool. Characterizing and comprehending the genetic diversity of sugar beet germplasm is critical. In this run, molecular markers are a good tool to supplement morphological features and disease response characterization.

REFERENCES

Mall AK, Misra V, Santeshwari, Pathak AD, Srivastava S (2021) Sugar beet cultivation in India: Prospects for bioethanol production and value added co products. Sugar Tech 23:1218-1234

Pathak AD and Kapur R (2013) Current status of sugar beet research in India. In: Kumar S, Singh PK, Swapna M and Pathak AD (eds) Souvenir, IISR-Industry Interface on Research and Development Initiatives for Sugar beet in India 28 & 29th May, 2013 (Sugarbeet Breeding Outpost of IISR-IVRI Campus, Mukteswar-263138, Nainital. pp 8-14.

Pathak AD, Kapur R, Solomon S, Kumar R, Srivastava S and Singh PR (2014) Sugar Beet: A Historical Perspective in Indian Context. Sugar Tech 16(2): 125-132. DOI 10.1007/s12355-014-0304-7.

Misra Varucha, Srivastava AK (2022) Understanding the sugar beet crop and its physiology. In Misra V., Srivastava S. and Mall AK (eds) Sugar beet Cultivation, Management, and Processing. Springer Publisher, Singapore pp 11-25

Mall AK, Misra Varucha, Srivastava S, Pathak AD (2022) India's Sugar beet Seed technology and production. In Misra V., Srivastava S. and Mall AK (eds) Sugar beet Cultivation, Management, and Processing. Springer Publisher, Singapore pp 121-129.

Mall AK, Misra Varucha, Srivastava Sangeeta and Pathak Ashwini Dutt (2020) Sugarbeet: as an alternative crop for bio-ethanol production in India. Indian farming 70(06):34-37

Chapter No. 14: Sugarcane quality improvement through molecular approaches

Sangeeta Srivastava
Principal Scientist, DivisionofCropImprovement,
ICAR-Indian Institute of Sugarcane Research, Lucknow
E-mail: Sangeeta.Srivastava@icar.gov.in; sangeeta_iisr@yahoo.co.in

1. Introduction

Sugarcane with its exceptional ability to convert light and nutrients into chemical harvestable energyis the main sugar crop of many countries for extracting sucrose, along with other by-products such as bagasse, molasses, press mud, ashes and vinasse having diversified uses through value addition. The recent alternative conversion of sugarcane biomass to produce second-generation ethanol has led to increasing demand of sugarcane bagasse as a valuable feedstock source. Sugar industry is now a biomass-based industry which can, on the one hand develop high nutritive and industrial value products for the food sector and on the other, bio-product diversification and value-added biofuels, energy, and chemical production for the non-food sector.

2. Taxonomy and genetic constitution

2.1 *Saccharum* complex

Sugarcane is a perennial C_4 grass belonging to the family Poaceae, the tribe *Andropogoneae*, the subtribe *Saccharinae* and the genus *Saccharum* which has a high degree of polyploidy and aneuploidy (Naidu and Sreenivasan 1987; Roach 1989). Mukherjee (1957) coined the term **"*Saccharum complex*"** for large closely related interbreeding pool consisting of *Saccharum, Erianthus, Sclerostachya* and *Narenga* and identified Indo-Burma, China border region, as the centre of origin of *Saccharum* complex because the maximum numbers of all species occurred in this region. Daniel and Roach(1987)added *Miscanthus* sec. Diandra to "*Saccharum Complex*" as a few characters present in the complex were not present in the previous four genera. Thus, according to present day concept, the *Saccharum* complex has five genera: *Saccharum, Erianthus*Michx. sect. *Ripidium*Henrard, *Sclerostachya* (Hack.) A. Camus, *Narenga* Bor. and *Miscanthus*Anderss. sect. Diandra Keng. Of these five genera, *Erianthus*and*Miscanthus* are presumed to be the most primitive forms (Daniels *et al.* 1975).

2.2 Species of genus *Saccharum*

Dutt and Rao (1951) identified five speciesof *Saccharum*; *S. officinarum*(2n=80), *S. spontaneum*(main cytotypes of 2n = 48, 64, 80, 96, 112, or 128), *S. barberi* (2n=81-124) which comprises of Mungo (2n=82), Saretha(2n=90-92), Sunnabile (2n=82-116), and Nargori (2n=107-124), *S. sinense* (the Pansahi group; 2n=111-120) *and S. robustum (*with two most common numbers of 2n=60 and 80), to which *S. edule* (a minor group of sterile canes with aborted inflorescencewith chromosome numbers 2n=60 and 80) was added later. Of the six species (*S. officinarum, S. spontaneum, S. sinense, S. robustum, S. edule, S. barberi*), two species *viz. S. spontaneum* and *S. robustum* are considered as wild species and rest four species are cultivated species (Daniels and Roach, 1987;D'Hont *et al.* 1995;Sreenivasan *et al.* 1987).

3. The present-day sugarcane cultivars

The modern sugarcane (*Saccharum* spp. hybrid*)*is thought to have one of the most complex plant genomes because of its multi-species origin and chromosome mosaicism (generally 2n=100-130) with a commensurately large nuclear DNA content of about 3000-mega bases (D'Hont and Glaszmann, 2001, Tomkins *et al.*, 1999). Thecommercial sugarcane varieties are derived from interspecific hybridization between *S. officinarum* and *S. spontaneum* pioneered in Java 100years ago using *S. officinarum* as the maternal parent(Price, 1963; Pérez *et al.*, 1997; Sreenivasan *et al.*, 1987) and are considered allopolyploid hybrids, with most exhibiting a 2n + n constitution, representing two copies of the *S. officinarum* genome plus one copy of the *S. spontaneum* genome (Daniels and Roach 1987; Cesnik and Miocque 2004). Sugarcane breeders have been improving the sugarcane genotypes through the selection and breeding for desirable characteristics improved yield, disease and insect pest resistance, tolerance to abiotic stresses such as drought and waterlogging and to improve the sucrose content. Developments in sugarcane breeding have contributed significantly to the improvement of agronomic traits and crop productivity for last more than hundred years, and have resulted in many elite varieties that have been used in commercial cultivation. Still, the ever-increasing worldwide demand for sugar and biofuel under the current climate change framework necessitates further improvements in cane and sugar yields.

4. Genetic improvement of sugarcane by conventional breeding: Constraints

Sugarcane breeding programs are mainly focused on developing cultivars with improved yield and biotic/abiotic stress resistance/tolerance.One cycle of conventional sugarcane variety improvement programs takes on an average 12 years from hybridization to the release of cultivars.Compared to other crops, it is extremely difficult to make high quality sugarcane crosses because sugarcane has irregular meiosis as well as unusual inheritance of quantitative traits and also difficult to hybridize due to tiny size of flower. The combination of genes for sugar with other agronomic traits is difficult to attain and time taking in conventional breeding programme due to linkage and complex polyploidy which creates hindrance in the inheritance of desired combination of sugar and disease resistance. Besides, conventional methods involve selection of individual plants based on morphological or measurable traits to achieve the targets. Further, accomplishment the desired genetic enhancement of sugarcane by conventional breeding methods is a difficult task due to its large genome size (10 Gb), being a highly heterozygous polyploid hybrid and genetically complex polygenic nature of important agronomic traits with each gene exerting small effects causing limitations to breeders and slowing down the genome-based breeding efforts.

Despite the genetic limitations in sugarcane, many superior agronomic traits/genes for higher cane yield, sugar production, and disease/pest resistance have been identified through the mapping of quantitative trait loci, genome-wide association studies, and transcriptome approaches.Improvement in sugar content is more desirable because much amount of sucrose in less biomass can be produced which would result the less cost of sugar production (Singh *et al.*, 2005).Commercial sugarcane which is predominantly interspecies cross of *S. officinarum* and *S. spontaneum* (Bakker, 1999), would significantly aid bioengineering advances owing to its unique polyploid genome, sensitivity to several pathogens, and the a long sustained period required for the development of elite cultivars.

5. Sugarcane quality improvement

Quality in terms of sucrose content is one of the most important commercial aspects along with yield improvement. Sucrose production/accumulation is a determinant of the maturation/ ripening phase condition and sugar yield. A mature cane stalk consists of high amounts of sucrose along with a reduced level of glucose and fructose (Botha and Black 2000; Rohwer and Botha 2001). Moore (1995) demonstrated that this crop has high potential and ability for sucrose production and accumulation in its stalk which can go up to a level of 0.7 M in mature internodes. Use of conventional breeding approaches has been the main mode for increasing sucrose content in sugarcane, however, annual nature of crop, its complex genetics and time taken for breeding of elite canes are certain constraints to this process. There is a need to understand the sucrose production and accumulation cyclein order to get enhanced sucrose content in sugarcane.Sucrose is a photosynthetic product that after being synthesized in leaves moves to storage tissues. This involves metabolizing enzymes and transporters for their smooth processing. Sucrose synthase (SS), sucrose phosphate synthase (SPS), sucrose phosphate phosphatase (SPP), and invertase enzymes are the sugar metabolizing enzymes in sugarcanewhich help in sucrose production and hydrolysis. Sugar transporters play an effective function in glucose and fructose transportation to sink tissues.

6. What are molecular markers?

A molecular marker is a DNA sequence in the genome which can be located and identified. As a result of genetic alterations (mutations, insertions, deletions), the base composition at a particular location of the genome may be different in different plants.These differences, collectively called as polymorphisms can be mapped and identified. Plant breeders always prefer to detect the gene as the molecular marker, although this is not always possible. The alternative is to have markers which are closely associated with genes and inherited together.

The molecular markers are highly reliable and advantageous in plant breeding programmes:

i. Molecular markers provide a true representation of the genetic makeup at the DNA level.
ii. They are consistent and not affected by environmental factors.
iii. Molecular markers can be detected much before development of plants occur.
iv. A large number of markers can be generated as per the needs.

6.1 Characteristics of an ideal molecular marker

An ideal molecular marker must have all or at least some of the following characteristics:

- It should occur frequently within genome.
- It should be readily available.
- It must be easy to analyze.
- It should not be time-consuming.
- It must be highly reproducible.
- It must be phenotypically or selectively neutral.
- It can produce interchangeable data.
- It should show polymorphism.
- It should not interact with other markers while using multiple markers at a same time
- It must be non-epistatic.
- Assay for detecting markers should be simple and rapid.

A series of different molecular markers of the system, which was available during the last two decades, can be classified in general into three classes:

- The first-generation molecular markers - RFLPs, the RAPDs, and modifications.
- The second-generation molecular markers -SSR, AFLP, and their modified forms.
- The third-generationmarkers - environmentally sound technologies, SNP, and many more.

6.2 Types of molecular markers

Molecular markers of isoenzymes are used to label proteins. They are designed to identify enzymes that differ in amino acid sequences, but that catalyze the same amino acid reaction.DNA based molecular markers can be classified as PCR based and hybridization based.

6.2.1 Hybridization based genetic markers(non-PCR based approaches)

The DNA piece of targeted gene is digested with restriction enzymes and can be cloned, and allowed to hybridize with the genomic DNA which can be detected e. g.RFLP, VNTRs.Marker-based DNA hybridization is widely used. The major limitation of this approach is that it requires large quantities of DNA and the use of labelled probes.

6.2.2 PCR based genetic markers (PCR-based approaches)

Polymerase chain reaction (PCR) is a valuable technique for the amplification of selected regions of DNA.The advantage with PCR is that even a minute quantity of DNA can be amplified. Thus, PCR-based molecular markers such asRAPD, ISSR, EST-SSR, microsatellite, CAPS etc. require only a small quantity of DNA to start with.

PCR-based markers may be divided into two types:

6.2.2.1 **:**Locus non-specific markers e.g. random amplified polymorphic DNA (RAPD); amplified fragment length polymorphism (AFLP).

6.2.2.2 **:**Locus specific markers e.g. simple sequence repeats (SSR); single nucleotide polymorphism (SNP).

6.2.2.3 Some common types of molecular markers are

- RFLP (or restriction fragment length polymorphism).
- AFLP (or amplifiedfragment length polymorphism).

- RAPD (or random amplification of polymorphic DNA).
- VNTR (or variable number repetition).
- Microsatellite polymorphism.
- SNP (or single nucleotide polymorphism).
- STR (or short repeat).
- SFP (or single-feature polymorphism), DArT (or diversity matrix technology).

6.2.4 Molecular Marker Assisted Selection

Selection of the desired traits and improvement of crops has been a part of the conventional breeding programmes. This is predominantly based on the identification of phenotypes. It is now an accepted fact that the phenotypes do not necessarilyrepresent the genotypes. Many a times the environment may mark the genotype. Thus, the plant's genetic potential is not truly reflected in the phenotypic expression for various reasons.The molecular marker assisted selection is based on the identification of DNA markers that link/ represent the plant traits. These traits include resistance to pathogens and insects, tolerance to abiotic stresses, and various other qualitative and quantitative traits. The advantage with a molecular marker is that a plant breeder can select a suitable marker for the desired trait which can be detected well in advance. Accordingly, breeding programmes can be planned.

7. Why molecular markers tools are required?

Molecular markers represent a valuable DNA toolfor genome analysis, both for basic and applied research and can be used to identify genes associated with the high sugar traits and to find out their role in sucrose accumulation. It becomes more precise and efficient by identifying desirable genes using molecular markers by examining the DNA of a plant. Hence, molecular markers are the very important tools for sugarcane improvement. These techniques would increase the efficiency of indirect and early molecular selection in sugarcane which would be exert a great impact on molecular breeding for high sugar content and could increase the selection precision for early high sugar content. Therefore, the molecular markers only may help to combine the desirable traits to develop ideal varieties.Molecular marker-based approaches were introduced in the last century mainly for the identification of genetic diversity and during the last two decades, these have been used to improve the breeding efficiency in sugarcane, by improving various traits such as increased biomass production, tolerance to biotic & abiotic stresses, sugar content and acceptable fibre content. Nowadays, the markers are being used for marker assisted selection (MAS), QTL mapping, genetic diversity analysis and phylogenetic relationship among cultivated varieties, related species/genera of plants, construction of linkage maps, gene tagging, map-based cloning, germplasm characterization, functional genomics *etc*.

8. Molecular markers and their application in sugarcane

Molecular markers represent a valuable tool for the breeder because they increase the efficiency of indirect and early selection in sugarcane that has a great impact on breeding for high sugar content and could increase the selection precision for early sugar content.Significant attempts to enhance this staple crop using molecular biology techniques have only recently begun. A number of reports on various sugarcane molecular markers are available and include restriction fragment length polymorphism (RFLP) (Besse and Mcintyre, 1996; Besse*et al.*, 1996; Burnquist 1991; D' Hont*et al.*, 1993; Glaszmann*et al.*, 1989, 1990; Ming *et al.*, 1998), Random amplified polymorphic DNA (RAPD) (Burner *et al.*, 1997; Harvey and Botha, 1996; Pan *et al.*, 1997, 2004), Amplified fragment length polymorphism (AFLP) (Besse*et al.*, 1998), and genus -specific polymerase chain reaction) (PCR) markers from the 5S rRNA locus (D' Hont*et al.*, 1995; Pan *et al.*, 2000, 2001; Piperides*et al.*, 2000).

8.1 RFLP(Restriction Fragment Length Polymorphism)

RFLP was the very first technology employed for the detection of polymorphism, based on the DNA sequence differences. RFLP is mainly based on the altered restriction enzyme sites, as a result of mutations and re-combinations of genomic DNA. The procedure basically involves the isolation of genomic DNA, its digestion by restriction enzymes, separation by electrophoresis, and finally hybridization by incubating with cloned and labelled probes.

8.2 RAPD(Random Amplification of Polymorphic DNA)

RAPD is a molecular marker based on PCR amplification. The DNA isolated from the genome is denatured the template molecules are annealed with primers, and amplified by PCR.Single short oligonucleotide primers (usually a 10-base primer) can be arbitrarily selected and used for the amplification DNA segments of the genome (which may be in distributed throughout the genome). The amplified products are separated on electrophoresis and identified.Based on the nucleotide alterations in the genome, the polymorphisms of amplified DNA sequences differ which can be identified as bends on gel electrophoresis.Earlier RAPD technique was used widely in sugarcane for diversity analysis, varietal identification, *etc.*A few RAPD fingerprints also were reported in sugarcane clones (Harvey and Botha 1996; Pan *et al.*, 1997).

8.3 SSR/ STR(Short Repeat)

Simple Sequence Repeats (SSRs) or microsatellites from enriched genomic libraries and EST SSRs emerged as the marker system of choicedue to co-dominant inheritance of multi-allelic loci in a more stable and reproducible manner.Simple sequence repeat (SSRs), or short tandem repeats (STRs) (Weber and May 1989; Edwards *et al.*, 1991) are short DNA fragments that contain various number of tandem repeat units of di, tri- or tetra nucleotide motifs (Edwards *et al.*, 1991; Polymeropoulos*et al.*, 1991). Numerous reports on microsatellite in sugarcane and other crop species are available (Cordeiro *et al.*, 2000,2001; Cordeiro and Henry, 2001; Cordeiro *et al.*, 2000, 2001,2003; Da Silva 2001; Jannoo*et al.*, 2001; Pan *et al.*, 2003; Piperidis*et al.*, 2001).

8.4 EST-SSR (Expressed Sequence Tags derived Simple Sequence Repeats)

EST-SSR markers identify variation in the expressed portion of the genome and are useful for gene tagging. Nearly a total of ~240,000 ESTs, generated from 26 tissues and many developmental stage-specific cDNA libraries, are available in the SUCEST web page (Sugarcane EST project in Brazil). Our laboratory at IISR, Lucknow in collaboration with University of Delhi, South Campus, New Delhi has further enriched the sugarcane EST data by submitting 25,382 EST sequences using various tissue-specific cDNA libraries (root, stem, and leaf tissue) of sugarcane cultivar, CoS 767. These ESTs offer a good genomic resource for the development of EST-SSRs. An expressed sequence tag (EST)-derived restriction fragment length polymorphism (RFLP) marker for sugarcane elite genotypes was identified by da Silva and Bressiani(2005), which can be used for quantitative trait loci (QTL) tagging for sugar content. EST-derived RFLP markers for proteins involved in sucrose metabolism have been used in Southern analysis for mapping and gene tagging in elite sugarcane clones. A single dose marker, obtained from a sucrose synthase EST associated with sugar content at the $\alpha = 0.01$ probability level, is presented for sugarcane breeding. Utilization of EST homologues to known genes for generation of molecular markers accelerated the identification of a QTL controlling an important trait-sugar content. Sugarcane bacterial artificial chromosome (BAC) clones hybridizing to the sucrose synthase EST were identified.

8.5 SSCP-SSR(*Single-stranded conformation polymorphism* ofSimple Sequence Repeats)

SSCP-SSR (Srivastava *et al.*, 2005) is a more efficient way to assay polymorphism due to their ability to convert monomorphic to polymorphic markers.It is defined as a conformational difference of single-stranded nucleotide sequences of identical length as induced by differences in the sequences under certain experimental conditions. This property allows sequences to be distinguished by means of gel electrophoresis, which separates fragments according to their different conformations.

8.6 ISSR(Inter Simple Sequence Repeat markers)

Inter simple sequence repeat (ISSR) technique is PCR based method.It was reported by Ztetikiewicz*et al.* in 1994.The ISSR markers are developed by PCR amplification of DNA segments between 2 similar microsatellites repeat regions by use of single primer consisting of microsatellite core regions.The primers can be usually 16-25 bp long, and unattached or attached at 3′ or 5′ end.

8.7 SCAR(Sequence Characterized Amplified Region)

SCAR is based on PCR-agarose gel electrophoresis.It uses longer primers of 15-30 nucleotides yielding high reproducibility. It needs prior sequence information for primer designing.As PCR is used, it needs only low quantities of template DNA.

8.8 AFLP

AFLP is a novel technique involving a combination of RFLP and RAPD. AFLP is based on the principle of generation of DNA fragments using restriction enzymes and oligonucleotide adaptors (or linkers), and their amplification by PCR. Thus, this technique combines the usefulness of restriction digestion and PCR.AFLP was also successful in detecting large number of polymorphic loci (Lima *et al.*, 2002).

8.9 SNP(Single nucleotide polymorphism)

SNP was invented by Lander in 1996.SNP is formed when any alteration/mutation occurs in single nucleotide (A, T, C, or G).The point mutation as such substitutions, insertions or deletions in single nucleotide it represents SNP.SNPs are based on hybridization of detected DNA fragments with SNP chips (DNA probe arrays) and the SNP allele is named with respect to the hybridization results.With the advent of high throughput sequencing techniques, SNP markers have evolved as a system of choice in sugarcane and are being used to study the copy number of genes and variation in gene sequences of sugarcane metabolic pathway, red rot resistance genes, *etc.* Some of these SNPs have been validated in a segregating population of Indian cultivars (Pride *et al.*, 2016).

8.10 Other markers

Other markers like TRAP, SRAP, CAP, CISP (Srivastava and Gupta, 2008, Alwala*et al.*, 2006, Andru*et al.*, 2008, Khan *et al.,* 2011, Wu *et al.*, 2013), *etc.*, have also been successfully used in this crop to analyze the diversity.

8.11 Genetic transformation

Bower and Birch's (1992) introduction of an effective transformation system was the first substantial step in establishing an integrated modern breeding system for sugarcane. Following this major advance, considerable effort has been expended in engineering agronomically useful traits into various cultivated genotypes (Enriquez-Obregon *et al.*, 1998; Zhang *et al.*, 1999; Setamou*et al.*, 2002; Manickavasagam*et al.*, 2004; Vickers *et al.*, 2005a,b).

8.12 Transcriptomic markers

Transcriptomic markers may serve as the link for understanding carbon partitioning for the regulation of fibre and sucrose enhancement in sugarcane. Extensive studies of transcriptomics in sugarcane are being carried out (Ferreira *et al.* 2016; Xu *et al.* 2018; Hoang *et al.* 2017; Ali *et al.* 2021a). About 18,722 differentially expressed genes in sugarcane have been identified for starch and sucrose accumulation including 563 routine genes in addition to 281 new miRNAs and 311 expressed genes. Besides, several transcription factors essentially function in sugar accumulation in addition to the transporters (Ma *et al.* 2019; Ruan 2014; Stein and Granot 2019; Javed*et al.* 2020).

The cell wall metabolism involves a number of genes that are differentially expressed like expansin (SCCCLR2C02A05.g and SCQGRT1040G03.g) which serve in relaxing the cell wall by bond breaking between cellulose microfibrils and matrix polysaccharides stimulating the cell expansion (Cosgrove *et al.* 2002, McQueenMason and Cosgrove 1994). Papini-Terzi *et al.* (2009) have recorded a gene similar to EXPA23 in sugarcane. The gene exhibits a very expression in Brix sugarcane having an age of seven months and in low Brix sugarcane having an age of more than eleven months. These alterations are probably responsible for conferring the high sucrose accumulation in sugarcane. The identification of xyloglucan endo-b-1,4 glucanase has further verified the result in sugarcane (PapiniTerzi *et al.* 2009).

8.13 miRNA

The association of miRNAs miR172, miR164, miR396, and miR169 as regulators to the sugar metabolism-related AP2/ ERF, NAC, GRF, and bZIP transcription factors members, has been demonstrated for the first time (Wang *et al.* 2021).

8.14 CRISPR CAS

Recently a lot of work has been done on the CRISPR technique in sugarcane (Iqbal *et al.*, 2021) and this technique is also contributing their role to improving the sugarcane crop.

9. Conclusion

Considering the interest in developing sugarcane cultivars with desirable traits especially for sugar content, an amalgamation of fundamental and latest insights on biotechnological approaches should be employed for breeding new sugarcane cultivars. The application of multi-omics interventions is expected to pave the way by aiding marker-assisted breeding for quality traits through identification of several key genes, proteins and metabolic pathways thus reducing the time and expense of producing better sugarcane genotypes with enhanced sugar content. Genomic selection is yet another modern breeding tool that has the potential to significantly increase the rate of genetic gain in sugarcane, mainly by (i) reducing the breeding cycle length, (ii) increasing the prediction accuracy for clonal performance, and (iii) increasing the accuracy of breeding values for parent selection. Recent advancements in genome sequencing have provided opportunities to better apply genomic selection to improve the major traits and for more precise breeding of this complex crop. Utilizing emerging tools of genome editing is a highly challenging but potentially very rewarding job that could bring a revolutionary advance over the conventional approaches to improve an otherwise promising sugarcane variety more quickly and with higher precision, however, increased research efforts are needed to enable the implementation of these technologies.

Selected further reading:

- Grivet, L.; Arruda, P. Sugarcane genomics: depicting the complex genome of an important tropical crop. Curr, Opin. Plant Biol. 2:122-127; 2002.
- Gupta V, Raghuvanshi S, Gupta A, Saini N, Gaur A, Khan MS, Gupta RS, Singh J, Duttamajumder SK, Srivastava S, Suman A, Khurana JP, Kapur R, Tyagi AK (2010) The water-deficit stress- and red-rotrelated genes in sugarcane. FunctIntegr Genomics 10:207-214.
- Ulian, E. (2000). Functional genomics for sugar accumulation gene discovery in sugarcane. Sugarcane Genomics Workshop, Brisbane, Australia.
- Casu, R.E.; Manners J.M.; Bonnet, G.D.; Jackson, P.A.; Meintyre, C.L.; Dunne, R.; Chapman, S.C.; Rae, A. L.; Grof, C.P. Genomic approaches for the identification of genes determining important traits in sugarcane. Field Crop Res. 92:137-147; 2005.
- da Silva J.A. and Bressiani J.A. (2005) Sucrose synthase molecular marker associated with sugar content in elite sugarcane progeny. Genetics and Molecular Biology 28(2): 294-298.

Chapter No. 15: Pre-breeding for sugar content and other traits in sugarcane

Swapna, M.
Principal Scientist, Division of Crop Improvement,
ICAR-Indian Institute of Sugarcane Research, Lucknow
E-mail : swapna.m@icar.gov.in

Introduction

Among the conventional and non-conventional sources of sweeteners like sugarcane, sugar beet, sweet sorghum, palms and Stevia, sugarcane and sugar beet are the well-established and the most exploited sources of sugar at global level. These fully cater to the present day demands of sweeteners with sugarcane accounting for around 75% of the sugar production in the world. In India, sugarcane is the sole sugar producing crop at the commercial level. These crops have been identified as attractive sources for other diversified products like green energy, value added bio-products like bio-chemicals and bio-plastics. Yet, sugar still continues to be the main product from sugarcane.

Sugarcane is grown in both tropical and sub-tropical climatic regions and contributes significantly to the national as well as global economy. India, the second largest sugar producing country, is emerging as a significant sugar exporter in the world markets. Thus the R&D activities related to sugarcane and sugar improvement has a lot of significance in the country. India has a strong network of research organizations engaged in sugarcane improvement, production and management and the innovative technologies developed from these research organizations have helped in enhancing the productivity and profitability of the sugar industry in a sustainable manner.

The cultivated sugarcane plant, unlike other diploid crops like rice, maize or sorghum, is a natural hybrid that has resulted from the natural hybridization of species clones like *Saccharum officinarum* and *Saccahrum spontaneum*. The genome of sugarcane is complex, with a large number of chromosomes present in the cells. The chromosome number in the cultivated varieties ranges from 2n=80 to 2n=120 and the number varies in the different *Saccharum* species accessions (Sreenivasan et al., 1987). Even within the same plant there are reports of occasional variations in the chromosome number. During sexual reproduction phase there can be deviations from the normal segregation pattern leading to *en masse* chromosomal elimination, laggard formation during meiosis etc., to name a few. Inter-specific crosses of *S. officinarum* x *S. spontaneum* and their first backcrosses lead to transmission of double the number of gametes from the *S. officinarum* parents and normal transmission of 'n' set of chromosomes from the *S. spontaneum* parent, referred to as 2n+n transmission (Bremer, 1962, Piperidis et al., 2010). This phenomenon has been reported to be responsible for the quicker transmission of sugar accumulation trait from the *S. officinarum* parent during nobilization. 2n +n transmission of chromosomes have also been reported in crosses involving commercial sugarcane cultivars and *S. spontaneum* (Suganya et al., 2019) and *S. officinarum* (Piperidis et al., 2010).

The sugarcane improvement strategies comprises of conventional tools as well as non-conventional approaches like molecular techniques, functional genomics etc., and these are further being supplemented by techniques involving artificial intelligence. The conventional sugarcane improvement mainly consists of hybridization and selection for developing improved sugarcane varieties for cane and sugar yield, biomass, enhanced stress resistance, better water and nutrient use efficiency. This approach has indeed yielded remarkable results, with a substantial improvement in cane productivity (more than 87%) and sugar recovery (3.3%) from 1950-51 to 2020-2021in India. The world sugar production has also recorded significant increase with 171.0 million tons of sugar being produced during 2020-'21. The development of location specific improved sugarcane varieties necessitates variation in the breeding pool. Concerns have been raised regarding the depletion of variability in the present-day breeding pool and the narrow genetic base of the newly developed genotypes/varieties. This has been attributed to a great extent, to the limited number of parents that are being utilized in the hybridization programmes all over the world (Berding and Roach, 1987, Nair, 2011). Broadening of genetic base of the parental population is necessary for enhancing the genetic variability present in these populations. Utilization of diverse parents can be a solution to this concern. This can lead to the identification of parents with novel genetic background. The use of such parents in hybridization programmes can facilitate introgression of new gene combinations into the existing gene pool, thereby resulting in the development of improved parental genotypes.

Pre-breeding in sugarcane

Pre-breeding, an inherent component of the crop improvement programmes all over the world, facilitates the development of novel parental genotypes and genetic/breeding stocks for specific traits that can be used as parents in commercial hybridization programmes. This will also help in base broadening and in introgression of new genes into the pool. Sugarcane varietal improvement programmes for different traits go hand-in-hand with pre-breeding, so as to ensure a continuous supply of improved parental genetic stocks for quality traits like sugar content, stress resistance/tolerance, drought tolerance and for other economically important traits.

(i) Sugar content

Sugar being an important product from sugarcane, the crop improvement efforts in this crop mostly target sugar content/yield. In India, especially in the sub-tropical zone, an improvement in sugar yield has been achieved through an increase in cane yield, even though the sugar content *per se* has not been compromised. The increment in sucrose % in the recent years has not been very substantial (Jackson, 2005, Kapur et al., 2015) even though rigorous improvement programmes have resulted in promising clones with more than 21 % sucrose in juice (Hemaprabha et al., 2015, Ram et al., 2022). An improvement in sugar content being more economical, there need to be more high sugar genotypes with higher sugar accumulation potential, that can be used as parents in breeding programmes.

The strategy of convergent breeding using the method of recurrent selection has been proved to be efficient for development of high sugar genetic stocks (Shanthi and Alarmelu, 2012, Kapur et al., 2015) and the same is the case with other traits like stress resistance. At ICAR-Indian Institute of Sugarcane Research (ICAR-IISR), Lucknow in sub-tropical India, a long term pre-breeding programme was initiated during the early 1990s and till 2016 three cycles of mating and selection were completed (Kapur et al., 2015, Swapna et al., 2020). This involved the identification of high sugar parents from the existing germplasm, intercrossing among these genotypes in all possible combinations, screening and evaluation of the progeny clones in the seedling generation and in the subsequent clonal stages and selection of promising high sugar genotypes from these progenies. This completes one cycle of mating and selection. The selected genotypes are again sent back to the National Hybridization Garden (NHG) at ICAR-Sugarcane Breeding Institute (ICAR-SBI), Coimbatore, to initiate the next cycle in which, these genotypes, after quarantine procedures, are included in NHG. These are used as parents for intermating among themselves and /or in crosses with other promising clones/varieties. The screening and evaluation in the seedling and clonal stages are repeated in the subsequent election cycles too.

The programme has been very productive in terms of genetic stocks as well as improved high sugar sugarcane varieties for commercial cultivation. More than 60 high sugar parental genotypes were developed and these have been included in the NHG at ICAR-Sugarcane Breeding Institute, Coimbatore in the tropical India. A few of these high sugar genotypes have species/ISH/exotic clones in their parentage (Kapur and Swapna, 2014). These parents are regularly being used by the sugarcane breeders of the country in their hybridization programmes. This also helps in studying the progeny behaviour of these high sugar accumulating clones and to get an idea about their combining ability. LG 95053 (INGR 09054) is one high sugar sugarcane genotype that has been registered with the ICAR-National Bureau of plant Genetic Resources (ICAR-NBPGR), New Delhi. Some of the high sugar stocks like LG 08422 and LG 01118 have given rise to many progenies that are potential varietal candidates, thereby proving their mettle as high sugar parental clones. Preliminary estimates indicate that after three cycles of mating and selection, the newly developed high sugar sugarcane genetic stocks show an improvement of 8-10% in sucrose% in juice values, compared to the parents used in the first cycle of mating and selection (Swapna et al., 2020). Three improved high sugar, high yielding red rot resistant sugarcane varieties viz., CoLk 94184, CoLk 12209 and CoLk 15206 have also emanated from this programme and these are recommended for commercial cultivation in the north-west and north-central and eastern sugarcane growing zones of the country.

Introgression of new genes for base broadening and developing high sugar genetic stocks has yielded good results, as reported from investigations at ICAR-SBI, Coimbatore. Pre-breeding for sugar content reported an improvement of more than 10% in sugar content in the newly developed clones, compared to the base population with variability in the different selection cycles (Shanthi and Alarmelu, 2012, Alarmelu et al., 2015).Intra-specific/inter-generic improvement of species clones was attempted and the improved clones have been used as parents in commercial crossing programmes (Nair et al., 2006, Nair et al., 2017). Utilization of improved *Saccharum* spp. clones like *S. officinarum* and *S. robustum* crosses has resulted in an increase in sucrose content up to more than 25% in the progenies (Karuppaiyyan et al., 2020, Alarmelu et al., 2014, 2017). These have the potential to be used as parents in commercial breeding programmes. Studies on the use of commercial hybrid clones and species accessions in inter-specific crosses have indicated an improvement in sucrose content (sucrose% in juice), even up to more than 40% in the first stage hybrids and up to 24 % in the second stage hybrids (reviewed in Kapur and Swapna, 2014). Of late, a novel parent specific for sugar-related traits, viz., OH-44 an interspecific hybrid, has been identified from introgression studies using species clones (Hemaprabha et al., 2020).

Other sugar producing countries also have such robust pre-breeding programmes for sugar and other traits (Heinz, 1967). Utilization of species clones and identification of high sugar accumulating clones for use as parents have been reported from several countries like Australia, Mauritius, Caribbean countries and United States (Badaloo and Ramdoyal, 2004, Santchurn et al., 2019a,b, Hale et al., 2022, Hemaprabha et al., 2022, Kennedy, 2022, Luzaran et al., 2022, Santchurn et al., 2022, Wei et al., 2022).

(ii) Pre-breeding for other traits

Apart from sugar content other important traits also have their prebreeding programmes associated with varietal breeding. Attempts have been made for population improvement with respect to red rot resistance in sugarcane at ICAR-IISR, Lucknow (Pandey et al., 2012, 2015). Here also, along with cultivated varieties, interspecific hybrids were used as parents to develop promising red rot resistant genotypes. Two sugarcane clones LG 05817 and LG 05823 have durable resistance to red rot pathotypes CF 01, CF 08, CF 09, and CF 011. Of these, the clone LG 05817 (INGR 18035) has been registered with ICAR-NBPGR, New Delhi as a red rot resistant parental genetic stock with durable resistance for four prevalent races of *Colletotrichum falcatum*, the causal organism of red rot disease in sugarcane. Approximately 10 red rot genetic stocks with red rot resistance have been included in NHG during the last decade and these are being used as parents in commercial breeding programmes.

Other traits are also being studied and promising parental clones are being identified in India and in other countries (Lakshmanan et al., 2022). The introgression studies mentioned before have resulted in genotypes with good cane yield and other traits, which can be putative parents for varietal development in this crop. For example, the Lousiana sugar industry has reported continuous genetic gains in economically important traits due to the introgression programmes and this has resulted in promising clones with increased tolerance to biotic and abiotic stresses and also improved yield (reviewed in Hale et al., 2022).

Use of molecular tools for population improvement and pre-breeding

As in varietal breeding programmes, the conventional pre-breeding strategies also need to be supplemented with the use of molecular tools like molecular markers for diversity studies, identification of superior clones using trait-specific markers, functional genomics to characterize the populations, genomic selection for predicting the most promising parents and for related applications. Genomic selection can be applied to characterization of field gene banks, core collections, prediction of suitable parental combinations for higher genetic gains, progeny evaluation and clonal selections, recurrent selection for pre-breeding, base broadening, introgression of genes for sucrose content, yield and stress related traits. The initiatives to sequence the sugarcane genome (Garsmeur et al., 2018, Zhang et al., 2018, Souza et al., 2019, Trujillo-Montenegro et al., 2021) has led to the development of draft reference genome for cultivated as well as species clones and the information from these sequencing efforts can facilitate applications including genetic and genomic studies in this crop. The voluminous data that will be derived from the advanced genomics investigations has necessitated the rapid development of bioinformatics in sugarcane and the research reports from all over the world suggests that bioinformatics also has advanced a lot in sugarcane, even with the inherent challenges peculiar to this crop (Casu, 2010, Thirugnanasambadam et al, 2018).

Conclusion :

In the current scenario of climate change, breakdown of stress resistance and other challenges, demand driven varietal development is the need with enough variability present in the breeding pool. Choice of parents is very important in this context. A constant availability of superior parents for specific traits need to be ensured along with enhancing the variability available in the genetic pool. Novel genes need to introgressed into the existing genetic background and the available variability need to be exploited to the maximum. Pre-breeding as an inherent component of the sugarcane varietal development programmes aids towards meeting these goals. A robust, dynamic and resilient pre-breeding programme that responds to the changing needs of the stakeholders will be an asset to the productivity, profitability and sustainability of the sugar industry across the world.

References :

Alarmelu,S., Nagarajan, R., Shanthi, RM., Hemaprabha, G. And Nair NV. 2014. Development and evaluation of backcross progenies of improve*d Saccharu*m spp. for yield and quality traits. J. Sugarcane Res. 4(1) : 19-32.

Alarmelu, S., Hemaprabha, G., and Shanthi, R.M. 2015. Potential hybrids through recurrent selection for yield and quality in sugarcane. Proceedings Joint Convention of the Sugar Technologists Association of India and the Deccan Sugar Technologists Association 11: 248–258.

Alarmelu,S., Pazhany, AS., Jayabose, C. and Manjunatha, T. 2017. Pre-breeding utilizing the improved intra specific clones of *Saccharum* spp. In : (Eds.)

Hemaprabha, G., Viswanathan, R., Ramasubramaniam, T. Bhaskaran, A. Mohanraj. K, Bakshi Ram Proc. International Symp. *Sugarcane Research since Co 205 : 100 years and beyond (SucroSym 2017)*. ICAR-Sugarcane Breeding Institute, Coimbatore. 7-10.

Badaloo, MHG and Ramdoyal, K. 2004. Variation and inheritance of quantitative traits in Commercial x *Saccharum spontaneum* L. Crosses. In. (ed.) Lalouette, JA, Bachraz, DY and Bheenick, KJ. Proc. 6th AnnualMeeting of Agricultural Scientists Reduit : Food and Agricultural Council. 169-178.

Bremer G. 1962. Problems in breeding and cytology of sugarcane. V. Chromosome increase in *Saccharum* hybrids in relation to interspecific and intergeneric hybrids in other genera. Euphytica.. 1962;**11**: 65-80

Berding, N. and Roach, BT. 1987. Germplasm collection, maintenance and use. In: (Ed.)Heinz, DJ. Sugarcane Improvement through Breeding. Elsevier Science Publishers, The Netherlands. 143-210

Casu, RE. 2010. Role of bioinformatics as a tool for sugarcane research. In : (Eds.). Henry, RJ and Kole, C. Genetics, Genomics and Breeding of Sugarcane.Science Publishers, USA. 229-248.

Garsmeur, O., Droc, G, Antonaise, R et al. 2018. A mosaic monoploid reference sequence for the highly complex genome of sugarcane. Nat. Comm. 9: 2638. DOI: 10.1038/s41467-018-05051-5

Hale, AL, Todd, JR., Gravios, KA., Mollov, D. et al. 2022. Sugarcane breeding programs in USA. Sugar Tech 24 (1) : 97-111. https://doi.org/10.1007/s12355-021- 01018-x

Heinz, D.J. 1967. Wild *Saccharum* species for breeding in Hawaii. Proc. ISSCT, 12, 1037-1043.

Hemaprabha G., Alarmelu S and Shanthi RM. 2015. Genetic improvement of sugarcane varieties developed over decades. In: Proceedings of 11th Joint Convention of STAI and DSTA, 219-227.

Hemaprabha,G., Mohanraj,K. Alarmelu,S. and Ram, B. 2020. Assessment of breeding methods and parental value of Co canes developed during 1918 – 2017. J. Sugarcane Res. 10: 24-31 https://doi.org/10.37580/JSR.2020.1.10.24-31

Hemaprabha, G, Mohanraj,K, Jackson PA, Lakshmanan, P., Ali, GS, Li, AM, Huang, DL and Ram,B. 2022. Sugarcane genetic diversity and major germplasm collections. Sugar Tech 24(1) : 279-297.

Jackson PA 2005 Breeding for improved sugar content in sugarcane. Field Crops Res92: 277-290.

Kapur R and Swapna M. 2014. Sugarcane In: ed. Chopra, VL Breeding Field Crops II : Advances. Studium Press, LLc, USA. 111-129.

Kapur R, Duttamajumder SK Ramkumar. 2015. Identifying parents conferring high sugar accumulation potential to the progeny. Proc 11th Joint Conv STAI & DSTA : 163- 169

Karuppaiyyan, R. Nair, NV., Ram, B., Mohanraj, K., Durai, AA. And Amudha, P. 2020. Evaluation of intra-specific hybrids of *Saccharum robustum* for yield, quality and yellow leaf disease incidence. Indian J. Sugar Technol. 35(1) : 28-32.

Kennedy, AJ. 2022. Sugarcane variety development in the Caribbean. Sugar Tech 24 (1) : 64-72. https://doi.org/10.1007/s12355-020-00936-6

Lakshmanan, P. Jackson, PA, Hemaprabha, G. And Li, YR (Eds). 2022. Special Issue : History of Sugarcane Breeding, Germplasm Development and Molecular Biology. Sugar Tech 24 (1) : p.385

Luzaran, RT., Engle, LM.,Villariez, HP. And Oquias, GB. 2022. Sugarcane breeding and germplasm development in Philippines. Sugar Tech 24 (1):210-221. https://doi.org/10.1007/s12355-021-00979-3

Nair NV. 2011. Sugarcane Varietal development programmes in India: An overview.Sugar Tech. 13, 275-280.

Nair NV, Selvi A, Sreenivasan TV, Pushpalatha KN, Mary S. 2006. Characterization of inter-generic hybrids of *Saccharum* using molecular markers. Genet Resour. Crop Evol. 53: 163-169

Nair, NV, Mohanraj, K, Sunadaravelpandian, K. Suganya, A., Selvi, A. And Appunu, C. 2017. Characterization of an intergeneric hybrid of *Erianthus procerus x Saccharum officinarum* and its backcross progenies. Euphytica. 213 (12): 267.

Pandey, DK., Lal, S., Singh, PK, Sanjeev Kumar, Singh, J. and Singh, RK. 2012. Screening of progenies of sugarcane crosses for durable resistance to red rot (*Colletotrichum falcatum*). Proc. ISNPSR 15-18 October, 2012. ICAR-Sugarcane Breeding Institute, Coimbatore. 120.

Pandey, DK., Lal,S., Singh, PK, Singh,J. and Sanjeev Kumar. 2015. Early generation selection for resistance to red rot (*Colletotrichum falcatum*) and sucrose content in sugarcane (*Saccharum* spp. Hybrids). Indian J. Sugarcane Technol. 30 (22): 59-62.

Piperidis G, Piperidis N, D'Hont A. 2010. Molecular cytogenetic investigation of chromosome composition and transmission in sugarcane. Mol. Genet. Genomics 284: 65-73.

Ram B, Hemaprabha, G, Singh, BD and Appunu, C. 2022. History and current sugarcane breeding, germplasm development and molecular biology in India. Sugar Tech 24(1) 4-29.

Santchurn, D, Badaloo, MGH, Zhou, M. and Labuschagne, MT. 2019a. Contribution of sugarcane crop wild relatives in the creation of improved varieties in Mauritius. *Cambridge Core: Plant Genetic Resources (PGRCU)* 17: 151– 163.

Santchurn, D, Badaloo, MGH, Zhou, M. and Labuschagne, MT. 2019b. Genetic studies on sugar and *fibre* accumulation patterns among different types of energy canes in Mauritius. *Sugar Tech* 21: 879–890.

Santchurn D, Badaloo MGH, Koonjah S, Dookun-Saumtally A. 2022. Sugarcane breeding and supporting genetic research in Mauritius. Sugar Tech 24 (1) :48- 65. https://doi.org/10.1007/s12355-021-00960-0

Shanthi RM, Alarmelu S. 2012. Genetic stocks for high sugar content generated over two selection cycles in sugarcane. Indian J. Genet. 72 (3) : 336-342.

Souza, GM, Sluys, MV., Lembke, CG et al. 2019. Assembly of the 373k gene space of the polyploid sugarcane genome reveals reservoirs of functional diversity in the world's leading biomass crop. Gigascience. 8(12):giz129. https://doi.org/10.1093/gigascience/giz129

Sreenivasan, TV, Ahloowalia, BS , Heinz DJ. 1987. Cytogenetics. In: Heinz, DJ (ed) Sugarcane Improvement through Breeding. Elseveir Science Publishers, the Netherlands. pp 211-254.

Suganya, A. Arulmathi,R. Govindaraj, P. and Selvi, A.2019. A rare occurrence of 2*n* gametes functioning in interspecific crosses involving commercial cultivar of sugarcane (Co 89029) and *Saccharum spontaneum* L. Curr. Sci. 116 (6) : 887

Swapna M, Pandey DK, Kapur R. 2020. Recurrent selection cycles for pre-breeding in sugarcane: enhancing the sugar-accumulation potential in selection cycles. Int Sugar J 122 (1459) : 496-502

Thirugnanasambadam, PP, Hoang, NV and Henry, RJ. 2018. The Challenge of analyzing the sugarcane genome. Frontiers in Plant Sci. 9: 616. doi: 10.3389/fpls.2018.00616

Trujillo-Montenegro JH, Rodríguez Cubillos MJ, Loaiza CD, Quintero M, Espitia-Navarro HF, Salazar Villareal FA, Viveros Valens CA, González Barrios AF, De Vega J, Duitama J and Riascos JJ. 2021. Unraveling the Genome of a High Yielding Colombian Sugarcane Hybrid. Front. Plant Sci.12:694859.doi: 10.3389/fpls.2021.694859

Wei, X. Eglinton, J. Piperidis, G. Atkin,F., Morgan, T., Parfitt and Hu, F. 2022. Sugarcane breeding in Australia. Sugar Tech 24 (1) : 151-165. https://doi.org/10.1007/s12355-021-00969-5

Zhang, J., Zhang, X. Tang, H. Zhang, Q., Hua,X. et al., 2018. Allele-defined genome of the autopolyploid sugarcane *Saccharum spontaneum* L. Nat. Genet. 50 : 1565-1573 https://doi.org/10.1038/s41588-018- 0237-2

Chapter No. 16: Genomic approaches for development of red rot resistant varieties in sugarcane

R K Singh* and Renu**
*ADG(CC) and **Principal Scientist; Commercial Crops Section, Crop Science Division
Indian Council of Agricultural Research
Krishi Bhawan, New Delhi

Cultivated sugarcane (*Saccharum* spp. inter-specific hybrids) is a major food and industrial crop grown in more than 110 countries in the tropics and sub-tropics and is regarded as one of the essential cash crops because it improves the socio-economic livelihood of many sugarcane growers (FAO, 2020). Globally, it is the fifth most valuable crop economically, providing >80% of the sugar and ~35% of the bioethanol in the world. Brazil and India combined account for more than 50% of sugarcane production in the world. Other major sugarcane producing countries are Thailand, Pakistan, China, Mexico, United States of America and Australia

In India sugarcane accounts for 3.0%, 3.2% and 2.2% of the total arable land, net sown and gross cropped area, respectively, during 2016–17 (Anonymous 2021a). During 2021-22, India exported 110 LMT sugar and became second largest exporter of sugar in the world and earned about Rs. 40,000 crore worth of foreign exchange for the country (https://pib.gov.in/PressRelease). India ranked second after Brazil in terms of area (4.86 m ha) and production (399.25 MT)of sugarcane (Directorate of Economics & Statistics, DA&FW 2021-22 * 4th Advance Estimates). Decades of sugarcane varietal improvement has provided a strong technological base for this impressive growth (Anonymous 2017), which has benefitted both, the farmers and the sugar industry. Ever increasing demand for sweeteners, electricity cogeneration in sugar mills and targets for fuel-ethanol blending open new vistas of growth for the sugarcane sector. Since 1950–51, the cane area consistently increased by 184.2% (1.71 m ha in 1950–51 to 4.86 m ha in 2020–21) (Fig. 1) but the acreage under the sugarcane crop has been almost static over the last two decades ranging from 4.32 m ha in 1999–2000 to 4.86 m ha during 2021–22, an increase of only 12.5 % which necessitates continuous efforts to increase sugarcane yield and sugar recovery (Chauhan et al., 2022).

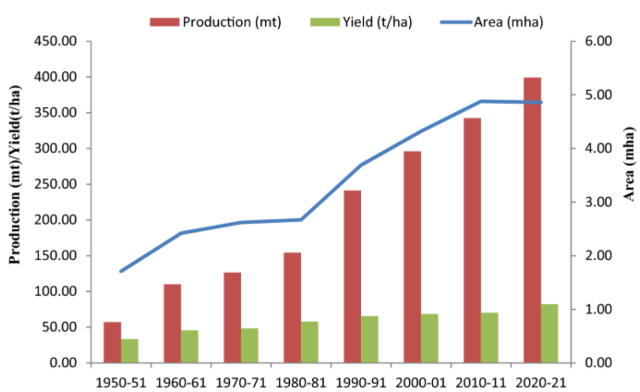


Figure 1: Area production and yield of sugarcane in India. (source : Chauhan et al., 2022)

Red Rot of Sugarcane

Currently, various biotic and abiotic factorshave been implicated as constraint in sugarcane production including extreme heat, drought, typhoons, flooding, frost and poor soil fertility as well as several fungi, bacteria, nematodes and viruses (reviewed in Hossain et al 2020). Out of the many biotic stresses of the sugarcane, the *Colletotrichum falcatum* Went [Perfect stage *Glomerellatucumanensis* (Speg.) Arx & Muller] causes significant reduction in the quality and yield of susceptible sugarcane cultivars [Smith et al., 1990]. The disease has been reported in 77 countries and is the most damaging sugarcane disease in India, Pakistan, Thailand, Nepal, Myanmar and Vietnam

(Viswanathan et al., 2018). The disease causes rotting of sugarcane stalk tissue, affecting cane yield and sugar quality. Inversion of stored sucrose by the pathogen affects sugar juice quality, causing reduced sugar recovery in sugar mills. This disease decreases sugarcane yield by 5–50% and under epiphytotic conditions, may lead to total crop failure (Duttamajumder, 2008). Red rot disease is the major disease due to the destructive effects of the disease as the main cause for the withdrawal of the many sugarcane varieties in the sugarcane cultivation worldwide (Malathi et al., 2002). In the Indian sub-continent red rot is considered as a major threat to profitable cultivation of sugarcane. The first documented epidemic in the Godavari delta of India in 1895–1900 caused enormous damage to sugarcane cultivation. In sub-tropical India, especially states of Uttar Pradesh and Bihar (1938–1939 and 1946–1947) red rot impacted severely resulting in that decimation of popular hybrid variety Co 213 which resulted in enormous loss to the sugar industry of this region.

Pathogen

Red rot of sugarcane disease is caused by *Colletotrichum falcatum* Went, the perfect stage of which is *Glomerellatucumanensis* (Spegazzini) von Arx& Muller[Phylum: Ascomycota, Subphylum: Pezizomycotina, Class: Sordariomycetes and Family: Glomerellaceae]. Went (1983) for the first time described the disease in detail with the symptoms and demonstrated the parasitism of the fungus he isolated from the diseased tissues, calling it Colletotrichum falcatum Went. The pathogen is a facultative parasite. It occurs in anamorphic and teleomorphic forms but the amorphic stage which infects standing canes is the most important stage.

Virulence diversity

The pathogen undergoes adaptive changes in relation to the host varieties cultivated, which subsequently leads to alterations in the virulence pattern of the fungus (Satyavir, 2003; Duttamajumdar, 2008). Development of light isolates and reduced latent period for symptom expression by repeated inoculations on incompatible hosts indicated the increased virulence or pathogenicity of that pathotype for adaptation on a particular cultivar (Malathi et al., 2006). Cultural studies indicated that *C. falcatum* virulence related factors viz., growth, sporulation and conidial germination had negative correlation with the host resistance and positive correlation with sucrose content in various sugarcane varieties. Production of melanin during host pathogen interaction was found to have a positive relation with virulence when pathogenicity assay was conducted in stalks and leaves (Malathi and Viswanathan, 2012). Variable symptoms on genotypes infected by *C. falcatum*and variation may be related to development of new races. The least virulent strains were Cf03 and Cf11, infecting only 3 varieties and widely spreading nature of the pathotype Cf08 in northern area. It may also be concluded that the isolate Cf 08 is more harmful for newly developed varieties. The analysis clearly indicated the genetic diversity of the *C.falcatum* isolates collected from the different regions of the Uttar Pradesh (Saksena et al., 2013). Presently there are 13 designated pathotypesfrom4agro-climaticzonesinthecountrytill date and used for screening of sugarcane progenies in the respective zones. *C. falcatum* “CF13” is the new virulent isolate from Co 0238 based on detailed characterization for pathogenicity (Viswanathan et al., 2022)

Red Rot resistance

To understand and elucidate mechanism of host pathogen interaction it is important to identify the targets in sugarcane in interaction with pathogen *C. falcatum.*

Molecular basis: To investigate the mechanism of red rot resistance, both genomic and proteomic tools were adopted and standardized for sugarcane [Viswanathan, 2012, Viswanathan et al., 2014]. A stalk specific proteome was reported by Sundar et al 2010 for the first time. The 2D-based core proteome analysis classification was performed during the interaction in sugarcane with *C.falcatum*[Ganesh Kumaret al, 2020).Expression pattern of transcription factors (TFs) in sugarcane in incompatible interaction and systemic acquired resistance (SAR) inducer priming revealedthat eight TFs are highlyinduced in both the cases. (Muthaiah et al 2013). A temporal expression of 22 putative defence-related genes by reverse transcription (RT)-PCR inredrot–susceptible cvCoC 671 with response to priming using various SAR inducers and *C .falcatum*elicitor, was studied and upregulatedgenes were identified which are likely to play a potential role in SAR induction and might contribute to defence against *C. falcatum* (Selvaraj et al., 2014).Through put genomic approaches like differential display, subtractive libraries and next-generation sequencing platforms were employed to unravelredrot resistance in sugarcane. In differential display, reverse transcription polymerase chain reaction (DD-RT-PCR) identified altered expression of genes in response to *C. falcatum*infection in red rot resistant cv Co 93009 (Prathima et al., 2013). Transcrip to me analysis in *in vitro* system of using sugarcane suspension cells and crude elicitor of *C. falcatum* identifying defence-related genes in sugarcane and revealed upregulation of many potential defence-related transcripts. Further, by adopting RACE-PCR approach, complete gene sequences of 14-3-3-like protein and xylanase inhibitor were identified and the genes were characterized (Rahul et al., 2016). Atotalof 139 ESTs were obtained through suppression subtractive hybridization (SSH) of libraries from sugarcane stalk samples to understand sugarcane defence responses during the initial phaseof*C.falcatum*pathogenesis which were functionally categorized. Also for the first time, a set of differentially expressed EST clusters in redrot–resistant sugarcane variety was identified in response to *C.falcatum* infection (Sathyabhama et al. 2015; Sathyabhama et al., 2016). Subsequently, the next-general sequencing (NGS) approach was combined with SSH and large transcriptomic data specific to red rot resistant and susceptible libraries were obtained (Viswanathan et al., 2016)

Management

Selection and deployment of resistant varieties is the most common strategy used to manage red rot in affected sugarcane industries (Viswanathan et al., 2018). However, breakdown of red rot resistance is common (Viswanathan, 2021). Unlike other sugarcane pathogens, new *C. falcatum* pathotypes with varying degrees of virulence are frequently formed through mutations and parasexual recombination, causing resistance breakdown (Viswanathan et al., 2020). In India no variety is released for commercial production unless it has resistance to red rot.

Genomic approaches

Breeding for red rot resistance is complicated by the existence of several races of the pathogen. The genetic manipulation of sugarcane for red rot resistance using traditional breeding has been cumbersome due to its heterozygous complex polyploid genome which does not permit an easy and predictable gene introgression. The success of traditional sugarcane breeding rests squarely on high variability of F_1 progeny for red rot resistance and their clonal propagation. Under these circumstances, modern genomic tools could very well aid conventional breeding in overcoming genetic bottlenecks and thereby enhancing breeding efficiency for red rot resistance.

The commercially cultivated sugarcane varieties are inter-specific hybrid derivatives having genome contributions primarily from *S. officinarum* L. ($2n = 80$) and *S. spontaneum* ($2n = 40$–128), indicating a ploidy between 5 and 16 (D'Hont et al. 1998), and the phenomenon of female restitution ($2n + n$ transmission) has contributed to large and varying numbers of somatic chromosomes in the commercial varieties with chromosome numbers ranging around $2n = 112$.Over the years, numerous research groups have enriched the linkage maps of sugarcane (reviewed in Singh et al., 2016). However, these are mostly based on low frequency marker alleles resulting in biased genome sampling. In the case of sugarcane, family-based mapping has mostly utilized F_1 populations and thus yielded only modest results due to several factors including quantitative, multigenic and/or multiallelic nature of the genes, and limited internal contrasts between the genes. Thudi et al. (2014) in case of chickpea reported that family-based mapping has a limitation of low resolution mainly due to non-utilization of available genetic diversity. Since, sugarcane crop possess a narrow genetic base, family-based mapping would further aggravate the problem of low marker resolution.

Candidate genes (CGs) refer either to cloned genes affecting a given trait (functional CGs) or genes located near trait-controlling loci on linkage maps (positional CGs; Pflieger et al. 2001). In the case of sugarcane, Gupta et al. (2010) for the first time identified 85 unique EST clusters using real-time reverse transcription PCR that were preferentially expressed in response to *C. falcatum* infection. Later, Prathima et al. (2013) also identified 112 differentially expressed sequence tags/candidate genes related to *C. falcatum*-mediated gene regulation using differential display real-time (DDRT)-PCR. Despite this success, functional CGs identification in these cases suffered from a fundamental limitation that differential genomic expression within a single genotype was studied without any reference to segregation pattern of the genes and their epistatic interactions. Such shortcoming could be overcome by identification of positional candidate genes through marker-trait association study using a panel of diverse genotypes. Such an approach also known as association mapping (AM) is able to capture a wide range of allelic diversity and account for historical breakdown of linkage during the evolutionary history so as to identify markers in linkage disequilibrium (LD) with the trait of interest (Gupta et al., 2005). Association mapping is preferred over traditional linkage mapping as it offers simultaneous detection of markers associated with comparatively larger number of traits that show variation in the panel of the accessions under study (Roy et al. 2010). In addition, AM also allows using historically available phenotypic data for mapping (Breseghello and Sorrells 2006; Selvi and Nair 2010; Banerjee et al. 2015). Most association studies either employ genome-wide association studies (GWAS) or candidate gene approaches, but in the case of chickpea, a combination of the two was reported to be more efficient (Thudi et al. 2014). To date, a limited number of AM studies in sugarcane have been attempted for traits like stalk fibre content (Mosomi and Botha 1994), resistance to smut, eldana and sugarcane mosaic virus (Barnes et al. 1997), root rot, leaf scald and Fiji leaf diseases (Wei et al. 2006), cane yield and sugar content traits (Banerjee et al. 2015), and resistance to sugarcane yellow leaf virus (Debibakas et al. 2014). Our group conducted study based on a panel of 119 sugarcane genotypes fingerprinted for 944 SSR alleles was undertaken with an aim to identify marker-trait associations (MTAs) for resistance to red rot and mining of putative positional candidate genes using comparative genomics approachSingh et al. (2016).

The disease screening for each genotype of the association panel against the three (*Cf*01, *Cf*08, *Cf*09) races of red rot pathogen revealed highly significant differential responses.Although, the majority of genotypes fell in the moderately resistant (MR) category against each of the three races of red rot pathogen, a range of susceptibility was noted; few genotypes did show consistent resistance against red rot. Results revealed a break-down of resistance against red rot pathogen in three of the most popular sugarcane genotypes, viz., CoJ 64, Co 1158 and Co 419 that have been under cultivation in sub-tropical India. The four genotypes, viz., CoP 9702, BO 91, BO 128 and Co 6811 that were resistant to all the three races of red rot could be used as sources of resistance in breeding programmes.

Information on DNA markers associated with red rot resistance in present day varieties and advanced breeding lines has potential to accelerate sugarcane breeding programmes. Although, well-established procedures for molecular marker based studies are available for diploid species, there is a dearth of proper statistical and analytical tools to study marker-trait associations in complex polyploid crops such as sugarcane. A limited number of MTAs has been reported in the case of sugarcane (Debibakas et al. 2014; Banerjee et al. 2015; Guoy et al. 2015). In our study the 98 EST-SSR primers generated a total of 733 alleles, while 17 g-SSRs generated 211 alleles; thus, in total 944 dominant alleles were generated by the 115 SSR primer pairs across the 119 sugarcane genotypes. The g-SSR markers showed a comparatively higher degree of polymorphism than the EST-SSR markers which is in agreement to the reports of Banerjee et al. (2015).Marker trait associations with red rot resistance could explain 10–17 % of the total trait variation. These results on effect size are in agreement to those of Wei et al. (2006) for leaf scald parenchyma root and Fiji diseases, and of Debibakas et al. (2014) yellow leaf virus diseases in sugarcane.To find markers showing significant association with resistance to the three races of red rot pathogen, association mapping was carried out using TASSEL based on the GLM and MLM, including Bonferroni's correction factor and a Benjamini Hochberg false discovery rate (FDR) of 0.05. Model comparison revealed that MLM model was more powerful and accurate as it was able to screen out both type I and type II errors. The MLM was able to detect four markers, two each associated with reaction to pathotypes *Cf*01(IISR_298a_140, IISR_256_240) and *Cf*09(IISR_46b_170, IISR_137_240) (Table 1), but this model could not detect any MTA with *Cf*08 (Singh et al., 2016). This could be due the fact that ancestral alleles associated with *Cf*08 and *Cf*09 were able to survive the population bottleneck and those associated with *Cf*08 were not. Moreover, *Cf*08 is wide-spread in the sub-tropical Indian conditions as a result of which the presence of resistant genotypes against *Cf*08 in association panel was very limited. These 4 markers might be potential markers in marker-assisted selection (MAS) and were used for further investigations to identify candidate genes involved in plant-pathogen interaction.

Table 1 Significant marker-trait associations (MTAs) identified for resistance to three races of red rot pathogen *C. falcatum*

Red rot pathotype	Marker	GLM −Log *P* value	Variation explained in the trait	−Log *P* value	MLM Variation explained in the trait
*Cf*01					
	IISR_298a_140	4.55**	0.168	4.12*	0.166
	IISR_256_240	4.12*	0.118	3.97*	0.107
	IISR_90_360	3.95*	0.101	–	–
*Cf*08	IISR_198_170	4.00*	0.105	–	–
*Cf*09	IISR_46b_170	4.85**	0.174	4.07*	0.145
	IISR_148_200	3.92*	0.118	–	–
	SCB10_410	4.25**	0.133	–	–
	ESTA69_400	3.85*	0.113	–	–
	IISR_137_240	–	–	3.95*	0.117

1. *GLM* general linear model, *MLM* mixed linear model
2. ** −Log *P* value that satisfy Bonferroni correction factor (cut-off 4.17)
3. * −Log *P* value that satisfy Benjamini Hochberg false discovery rate

Recently, many workers discovered more efficient markers such as SNPs in combination with better statistical tools (Hackett et al. 2013; Garcia et al. 2013). These systems of analysis have the capacity to employ allelic dosage data with better statistical tools which may account for the genotypic ambiguities of the sugarcane genome in a more efficient manner.

Related species often have conserved organization of their genome (Pflieger et al. 2001). In view of this, the synteny between sorghum and sugarcane genome was exploited to identify putative candidate genes involved in red rot resistance, as both these genomes share ~80 % similarity (Singh et al. 2013). Use of the candidate gene approach to identify genes involved in pathogen recognition, signal transduction and defence has been reported by many workers (Lamb et al. 1989; Hammond-Kosack and Jones 1996; Bent 1996; Debibakas et al. 2014). In the case sugarcane, there are only few reports on the identification of candidate genes for resistance to red rot pathogen *C. falcatum* (Gupta et al. 2010; Prathima et al. 2013). These studies were based on the expression profiles of only one of the two genotypes with contrasting disease response to red rot. Sugarcane exhibits both horizontal and vertical resistance components for red rot (Babu et al. 2010), and the susceptibility to this disease has been reported to be race-specific (Duttamajumder and Singh 1999). Singh et al. (2016) utilized a larger panel of genotypes, 119 in numbers, that is able to capture most if not all of the allelic variation for resistance to red rot to identify candidate genes. This study identified a significant number of candidate genes in the 100 kb vicinity of the mapped MTAs that have been previously reported to be directly/indirectly involved in plant defence against a number of biotic stresses. The proteins related to plant defence encoded by such genes against different pathogens are presented in Table 2.

Table 2 Putative defence related candidate genes in the vicinity of associated sugarcane markers on sorghum chromosomes

Associated markers and their position on sorghum genome (Chromosome/bp)	Predicted gene in the vicinity of the associated marker	Pathogen/stress against which functional response of the gene reported

Associated markers and their position on sorghum genome (Chromosome/bp)	Predicted gene in the vicinity of the associated marker	Pathogen/stress against which functional response of the gene reported
IISR_298a/Chromosome 07/4691126 bp	Glycerol-3-phosphate transporter- 1	*Colletotrichum higginsianum*, *Peronospora parasitica*
	Serine/threonine-protein kinase	*Pseudomonas syringae* pv. *tomato Colletotrichum lindemuthianum*, *Cladosporium fulvum*
	MAP Kinase- 4	*Pseudomonas syringae* pv. *tomato*, *Phytophthora sojae*
	RING-finger domain	*Pseudomonas syringae* pv. *tomato*, *Golovinomycescichoracearum*
	UDP-glycosyltransferase 83A1-like	*Pseudomonas syringae* pv. *tomato*, *Fusarium graminearum*, *Phakopsorapachyrhizi*, *potato virus Y*
	Caffeic acid O-methyltransferase	Abioticstress, *Xanthomonasoryzae* pv. *oryzae*, *Mag naporthegrisea*
IISR-256/Chromosome 02/77,551,000 bp	Actin related protein 2	*Pseudomonas syringae* pv. *tomato*, *Botrytis allii*, *Uromycesvignae*, *Erysiphe cichoracearum*
	Lon protease 1,	Heat shock, *Beauveria bassiana*
	Zinc finger (RING-type) domain	As mentioned above
	Pectinesterase	*Blumeriagraminis f.* sp. *tritici*. *Botrytis cinerea*
	26S protease regulatory complex subunit	*Pseudomonas syringae* pv. *tomato*, *Golovinomycescichoracearum*
IISR_46b/Chromosome 02/131,176 bp	Cyclic nucleotide-gated ion channel 18-like	Fungal elicitors, *Cucumber mosaic virus*
	Cytochrome P450	*Colletotrichum sublineolum*, *Alternaria brassicicola*, *Helminthosporiumturcicum*, *Stenocarp ella maydis*
	Legume lectins beta domain with protein precursor	Salt stress, abscisic acid, *Xanthomonasoryzae* pv. *oryzae Pseudomonas syringae*, *Botrytis cinerea*, *Valsa. Mali*, *Erysiphe orontii*, *Magnaporthegrisea*, *Gigasporarosea*; *Toba cco mosaic virus* (TMV), *Tobacco etch virus*
	Laccase 7	*Heterobasidionirregulare*
	Pentatricopeptide repeat (PPR)	Salt stress, *Xanthomonas oryzae* pv. *orzicola*, *Botrytis cinerea*

The marker IISR_256 was mapped on to chromosome 2 of sorghum and an important gene identified in the periphery of this marker coded for a protein homologous to a zinc finger (RING-type) domain; such proteins in *Arabidopsis* have been reported to negatively regulate the cell death pathway (Grant and Loake 2000). Another such gene was 26S protease regulatory complex subunit, which plays a vital role in plant defence (Yao et al. 2012). A simultaneous binding takes place between RING finger domains, ubiquitination enzymes and their substrates, which functions as ligases and ultimately degrade the substrate protein (Freemont 2000). The degradation process is carried out by 26S protease (Vierstra 2003). Such ubiquitin/26S proteasome pathway has shown defense response against pathogen attack in *Vitispseudoreticulata* (Yu et al. 2013), *Arabidopsis thaliana* (Boyes et al. 1998) and many other plant species (Vierstra 2003). In the region around marker IISR_46b on chromosome 2, a gene coding for protein homologous to cytochrome P450 was found. Genes of the cytochrome P450 family have been reported to be involved in plant defence in maize (Niemeyer 1988), *Arabidopsis* (Zhou et al. 1999), cotton (Sun et al. 2014), grapevine (Cheng et al. 2010), oat (Geisler et al. 2013), wheat (Li et al. 2010), and sorghum (Du et al. 2010). It was also demonstrated that seedlings of the sorghum resistant cultivar SC748-5 showed more rapid and elevated accumulation of luteolin than the susceptible cultivar BTx623 after inoculation with the anthracnose pathogen *Colletotrichum sublineolum*. On the other hand, apigenin was the major flavone detected in infected BTx623 seedlings. Luteolin was demonstrated to show stronger inhibition of spore germination of *C. Sublineolum* than apigenin because of their pathogen-inducible and antifungal nature (Du et al. 2010). The region around marker IISR_46 also harbours a gene coding for a protein homologous to cyclic nucleotide-gated ion channel that has been observed in response to fungal elicitors in *Medicago sativa* cell cultures and French bean cells (Bolwell 1992; Cooke et al. 1994). Another important gene in the vicinity was legume lectins β domain. Plant lectins have a vital role in plant defence against viruses, bacteria, Oomycete and fungi (Ang et al. 2014; Dias et al. 2015). Legume-like lectin receptor kinase proved to be a resistant component against *Phytophthora infestans* in transgenic *Arabidopsis* (Bouwmeester et al. 2011), *Nicotiana benthamiana* (Kanzaki et al. 2008) and rice blast resistance (Chen et al. 2006).

In addition, a putative pentatricopeptide repeat (PPR) was also present in the region of marker IISR_46b. Mitochondria-localized PPR proteins provide resistance to necrotrophic fungus *Botrytis cinerea* and tolerance to salt stress (Laluk et al. 2011). A total of 65 PPR genes were upregulated in transgenic rice compare to wild type when exposed to bacterial streak pathogen, *Xanthomonas oryzae* pv. *oryzicola* (Zhou et al. 2010). Another marker, IISR_298a that was mapped on sorghum chromosome 7 harboured in its vicinity a gene coding a RING finger domain protein which was also present in the vicinity of marker IISR_256; such domains simultaneously bind ubiquitination enzymes and function as ligases, and have been identified as defence regulators, especially as essential components of *R*-gene-mediated resistance (Devoto et al. 2003). Two putative kinase genes (serine/threonine-protein kinase and MAP kinase 4) were identified in the region of marker IISR_298a. MAP kinase 4 (MPK4) functions is essential for repression of salicylic acid (SA)-dependent resistance and for activation of jasmonate (JA)-dependent defence mechanism (Innes 2001; Andreasson et al. 2005). When the leaves of parsley are infected with spores from the soybean pathogen *Phytophthora sojae*, it led to activation of an elicitor-responsive mitogen-activated protein (MAP) kinase. The MAP kinase is translocated to the nucleus upon activation, which might induce expression of defence genes (Ligterink et al. 1997). A possible glycerol-3-phosphate transporter gene was also identified in the vicinity, the level of which increases when *Arabidopsis* was inoculate with hemi-biotrophic fungus *Colletotrichum higginsianum* leading to enhanced resistance (Chanda et al. 2008). In another study on *Arabidopsis*, acylation of G3P with oleic acid is one of the important steps for regulation of SA and JA defense-signalling pathway (Kachroo et al. 2004).

The region around IISR_298a also harboured a UDP-glycosyltransferase 83A1 gene. UDP-glucosyltransferase provides non-host resistance to *Arabidopsis* against the Asian soybean rust pathogen *Phakopsorapachyrhizi* (Langenbach et al. 2013). Overexpression of a barley UDP-glucosyltransferase gene in transgenic Arabidopsis provides resistance to a mycotoxin compound from *Fusarium graminearum*, i.e., deoxynivalenol (DON; Shin et al. 2012). The vicinity of marker IISR_298a also harbours important gene, caffeic acid O-methyltransferase, which along with Cinnamoyl CoA-reductase, catalyzes essential steps in the biosynthesis of monolignols, which is building block of plant lignin (Tu et al. 2010). It have been upregulated during PBZ-induced disease resistance in rice against blast and bacterial blight (Lin et al. 2008).

Conclusion

In conclusion, the markers identified may prove to be of high value in marker-assisted selection for red rot resistance in this complex polyploid crop. Three of the four markers in the given table, mapped to locations of the sorghum genome that exhibited the presence of intriguing positional candidate genes related to plant defence. The identification of candidate genes for red rot resistance may contribute to the understanding of biological mechanisms determining the partial and polygenically inherited resistance for this disease. A deeper investigation of the candidate genes given in this chapter that were coding for proteins with LRR and Ring finger as functional domains, Cytochrome P450, MAP kinase-4 and legume lectins and others may contribute to understand the very subjective notion of durability of disease resistance. Knowledge about the functions controlled by resistance loci involved in resistance to red rot will allow breeders to construct novel resistant genotypes by association of complementary mechanisms to develop sugarcane varieties with durable resistance to red rot. The statistical relationship between the candidate genes and the phenotypic variation with respect to different pathotypes of red rot has to be followed by further validation to confirm the actual involvement of the CGs in variation for red rot resistance. Once validated, these CGs are expected to provide highly efficient molecular markers for identification of varieties as well as marker-aided selection (MAS) programmes in sugarcane.

Reference

Andreasson E, Jenkins T, Brodersen P, Thorgrimsen S, Petersen NH, Zhu S, Qiu JL et al (2005) The MAP kinase substrate MKS1 is a regulator of plant defense responses. EMBO J 24:2579–2589

Ang ASW, Cheung RCF, Dan X, Chan YS, Pan W, Ng TB (2014) Purification and characterization of a glucosamine-binding antifungal lectin from *Phaseolus vulgaris* cv. Chinese Pinto Beans with antiproliferative activity towards nasopharyngeal carcinoma cells. ApplBiochemBiotechnol 172:672–686

Anonymous 2021a. Agricultural Statistics at a Glance 2020. Directorate of Economics & Statistics, Department of Agriculture, Cooperation and Farmers Welfare, Ministry of Agriculture & Farmers Welfare, Government of India, New Delhi, p. 318

Anonymous. 2017. Sugarcane - a sweat to sweet commodity. In Report of the Committee for Doubling Farmers' Income Vol. VIII ''Production Enhancement through Productivity Gains''. Committee for Doubling Farmers' Income, Department of Agriculture, Cooperation and Farmers' Welfare, Ministry of Agriculture & Farmers' Welfare, GOI, pp. 73–111

Babu C, Natarajan US, Shanthi RM, Govindaraj P, Sunder AR, Viswanathan R (2010) Inheritance of red rot resistance in sugarcane (Saccharum sp. hybrids). Sugar Tech 12(2):167–171

Banerjee N, Siraree A, Yadav S, Kumar S, Singh J, Kumar S, Pandey DK, Singh RK (2015) Marker-trait associations for sucrose and yield contributing traits in sugarcane (Saccharum spp. Hybrid). Euphytica 205:185–201

Barnes JM, Rutherford RS, Botha FC (1997) The identification of potential genetic markers in sugarcane varieties for the prediction of disease and pest resistance ratings. Proc AnnuCongr S Afr Sugar Technol Assoc 71:57–61

Bent AF (1996) Plant disease resistance genes: function meets structure. Plant Cell 8:1757–1771

Bolwell GP (1992) A role for phosphorylation in the down-regulation of phenylalanine ammonia-lyase in suspension-cultured cells of French bean. Phytochemistry 31:4081–4086

Boyes DC, Nam J, Dangl JL (1998) The *Arabidopsis thaliana* RPM1 disease resistance gene product is a peripheral plasma membrane protein that is degraded coincident with the hypersensitive response. Proc Natl Acad Sci USA 95:15849–15854

Breseghello F, Sorrells ME (2006) Association mapping of kernel size and milling quality in wheat (Triticum aestivum L.) cultivars. Genetics 172:1165–1177

Chanda B, Venugopal SC, Kulshrestha S, Navarre DA, Downie B, Vaillancourt L, Kachroo A, Kachroo P (2008) Glycerol-3-phosphate levels are associated with basal resistance to the hemibiotrophic fungus *Colletotrichum higginsianum* in Arabidopsis. Plant Physiol 147:2017–2029

Chauhan, J.S., Govindaraj, P., Ram, B. *et al.* Growth, Varietal Scenario and Seed Production of Sugarcane in India: Status, Impact and Future Outlook. *Sugar Tech* **24**, 1649–1669 (2022). https://doi.org/10.1007/s12355-022-01148-w

Chen X, Shang J, Chen D, Lei C, Zou Y, Zhai W, Liu G et al (2006) AB-lectin receptor kinase gene conferring rice blast resistance. Plant J 46:794–804

Cheng DW, Lin H, Takahashi Y, Walker MA, Civerolo EL, Stenger DC (2010) Transcriptional regulation of the grape cytochrome P450 monooxygenase gene CYP736B expression in response to *Xylellafastidiosa* infection. BMC Plant Biol 10:135–149

Cooke CJ, Smith CJ, Walton TJ, Newton RP (1994) Evidence that cyclic AMP is involved in the hypersensitive response of *Medicagosativa* to a fungal elicitor. Phytochemistry 35:889–895

D'Hont A, Ison D, Alix K, Roux C, Glaszmann JC (1998) Determination of basic chromosome numbers in the genus *Saccharum* by physical mapping of ribosomal RNA genes. Genome 41(2):221–225

Debibakas S, Rocher S, Garsmeur O, Toubi L, Roques D, D'Hont A, Hoarau JY, Daugrois JH (2014) Prospecting sugarcane resistance to sugarcane yellow leaf virus by genome-wide association. TheorAppl Genet 127(8):1719–1732

Devoto A, Muskett PR, Shirasu K (2003) Role of ubiquitination in the regulation of plant defence against pathogens. CurrOpin Plant Biol 6(4):307–311

Dias RdO, Machado LdS, Migliolo L, Franco OL (2015) Insights into animal and plant lectins with antimicrobial activities. Molecules 20:519–541

Du Y, Chu H, Wang M, Chu IK, Lo C (2010) Identification of flavone phytoalexins and a pathogen-inducible flavone synthase II gene (SbFNSII) in sorghum. J Exp Bot 61(4):983–994

Duttamajumdar, S.K. (2008). Red Rot of Sugarcane. Lucknow, India, Indian Institute of Sugarcane Research. 46p.

Duttamajumder SK, Singh RP (1999) Revised criteria for grading resistance against red rot disease of sugarcane. Indian Phytopath 52:157–159

FAO (2020). *Food and agriculture society of the united nations*. Availableat: https://www.fao.org/faostat/en/#data/QC (Rome, Italy).

Freemont PS (2000) Ubiquitination: RING for destruction? CurrBiol10:R84–R87

Ganesh Kumar V, Viswanathan R, Malathi P, Sundar AR, Prasanth CN, Nandakumar M. Identification of differential expressed proteins and establishing a defense proteome of sugarcane in response to *Colletotrichum falcatum*infection. Journal of Plant Pathology 2020. doi: 10.1007/ s42161-020-00577-4.

Garcia AAF, Mollinari M, Marconi TG, Serang OR, Silva RR et al (2013) SNP genotyping allows an indepth characterisation of the genome of sugarcane and other complex autopolyploids. Sci Rep 3:3399

Geisler K, Hughes RK, Sainsbury F, Lomonossoff GP, Rejzek M, Fairhurst S, Osbourn A (2013) Biochemical analysis of a multifunctional cytochrome P450 (CYP51) enzyme required for synthesis of antimicrobial triterpenes in plants. Proc Natl Acad Sci USA 110(35):3360–3367

Grant JJ, Loake GJ (2000) Role of reactive oxygen intermediates and cognate redox signaling in disease resistance. Plant Physiol 124(1):21–30

Guoy M, Rousselle Y, Chane AT, Anglade A, Royaert S, Nibouche S, Costet L (2015) Genome wide association mapping of agro-morphological and disease resistance traits in sugarcane. Euphytica 202:269–284

Gupta PK, Rustgi S, Kulwal PL (2005) Linkage disequilibrium and association studies in higher plants: present status and future prospects. Plant Mol Biol 57:461–485

Gupta V, Raghuvanshi S, Gupta A, Saini N, Gaur A, Khan MS, Tyagi AK (2010) The water-deficit stress- and red-rot-related genes in sugarcane. FunctIntegrGenom 10(2):207–214

Hackett CA, McLean K, Bryan GJ (2013) Linkage analysis and QTL mapping using SNP dosage data in a tetraploid potato mapping population. PloSOne 8(5):e63939

Hammond-Kosack KE, Jones JDG (1996) Resistance gene dependent plant defense response. Plant Cell 8:1773–1791

Hossain, Md Imam, Khairulmazmi Ahmad, Yasmeen Siddiqui, Norsazilawati Saad, Ziaur Rahman, Ahmed Osumanu Haruna, and Siti KhairunnizaBejo. 2020. "Current and Prospective Strategies on Detecting and Managing *Colletotrichumfalcatum* Causing Red Rot of Sugarcane" *Agronomy* 10, no. 9: 1253. https://doi.org/10.3390/agronomy10091253

Innes RW (2001) Mapping out the roles of MAP kinases in plant defense. Trends Plant Sci 6:392–394

Kachroo A, Venugopal SC, Lapchyk L, Falcone D, Hildebrand D, Kachroo P (2004) Oleic acid levels regulated by glycerolipid metabolism modulate defense gene expression in Arabidopsis. Proc Natl Acad Sci USA 101:5152–5157

Kanzaki H, Saitoh H, Takahashi Y, Berberich T, Ito A, Kamoun S, Terauchi R (2008) NbLRK1, a lectin-like receptor kinase protein of *Nicotiana benthamiana*, interacts with *Phytophthora infestans* INF1 elicitin and mediates INF1-induced cell death. Planta 228:977–987

Laluk K, AbuQamar S, Mengiste T (2011) The Arabidopsis mitochondria-localized pentatricopeptide repeat protein PGN functions in defense against necrotrophic fungi and abiotic stress tolerance. Plant Physiol 156:2053–2068

Lamb CJ, Lawton MA, Dron M, Dixon RA (1989) Signals and transduction mechanisms for activation of plant defense against microbial attack. Cell 56:215–224

Langenbach C, Campe R, Schaffrath U, Goellner K, Conrath U (2013) UDP-glucosyltransferase UGT84A2/BRT1 is required for Arabidopsis nonhost resistance to the Asian soybean rust pathogen *Phakopsorapachyrhizi*. New Phytol 198:536–545

Li X, Zhang JB, Song B, Li HP, Xu HQ, Qu B, Dang FJ, Liao YC (2010) Resistance to Fusarium head blight and seedling blight in wheat is associated with activation of a cytochrome P450 gene. Phytopathology 100(2):183–191

Ligterink W, Kroj T, zurNieden U, Hirt H, Scheel D (1997) Receptor-mediated activation of a MAP kinase in pathogen defense of plants. Science 276:2054–2057

Lin YZ, Chen HY, Kao R, Chang SP, Chang SJ, Lai EM (2008) Proteomic analysis of rice defense response induced by probenazole. Phytochemistry 69:715–728

Malathi, P. and R. Viswanathan (2012). Variation in Colletotrichum falcatum-Red rot pathogen of sugarcane in relation to host resistance. Sugar Tech., 14(2): 181–187

Malathi, P.; Viswanathan, R.; Padmanaban, P.; Mohanraj, D.; Ramesh, A. Compatibility of biocontrol agents with fungicides against red rot disease of sugarcane. Sugar Tech 2002, 4, 131–136.

Malathi, R., R. Viswanathan and R. Jothi (2006). Specific Adaptation of Colletotrichum falcatum Pathotypes to Sugarcane Cultivars. Sugar Tech., 8(l): 54-58.

Mosomi N, Botha FC (1994) Identification of molecular markers linked to fibre using bulk segregant analysis. Proc AnnuCongr S Afr Sugar Technol Assoc 68:41–45

Muthaiah M, Ashwin R, Sundar AR, Malathi P,Viswanathan R. (2013). Expression profiling of transcription factors (TFs) in sugarcane X *Colletotrichum falcatum*interaction. Journal of Plant Biochemistry and Biotechnology; 22:286–94.

Niemeyer HM (1988) Hydroxamic acids (4-hydroxy-1,4-benzoxazin-3-ones), defense chemicals in the Gramineae. Phytochemistry 27:3349–3358

Pflieger S, Lefebvre V, Causse M (2001) The candidate gene approach in plant genetics: a review. Mol Breed 7(4):275–291

Prathima PT, Raveendran M, Kumar KK, Rahul PR, Kumar GV, Viswanathan R, Sundar AR, Malathi P, Sudhakar D, Balasubramaniam P (2013) Differential regulation of defense-related gene expression in response to red rot pathogen Colletotrichum falcatum infection in sugarcane. ApplBiochemBiotechnol 171(2):488–503

Rahul PR, Ganesh Kumar V, Viswanathan R, Sundar AR, Malathi P, Prasanth NC, et al. Defense transcriptome analysis of sugarcane and *Colletotrichum falcatum*interaction using host suspension cells and pathogen c. Sugar Tech2016;18:16–28.
Roy JK, Smith KP, Muehlbauer GJ, Chao S, Close TJ, Steffenson BJ (2010) Association mapping of spot blotch resistance in wild barley. Mol Breed 26:243–256
Sathyabhama M, Viswanathan R, Malathi P, Ramesh Sundar A. (2016) Identification of differentially expressed genes in sugarcane during pathogenesis of *Colletotrichum falcatum*by suppression subtractive hybridization (SSH). Sugar Tech; 18:176–83.
Sathyabhama M, Viswanathan R, Nandakumar M, Malathi P, Sundar RA. (2015) Understanding sugarcane defence responses during the initial phase of *Colletotrichumfalcatum*pathogenesis by suppression subtractive hybridization (SSH). Physiological and Molecular Plant Pathology 91:131–40.
Satyavir (2003). Red rot of sugarcane current scenario. Indian Phytopathology, 56: 245–254
Selvaraj N, Ashwin R, Sundar AR, Malathi P,Viswanathan R. Molecular profiling of systemic acquired resistance (SAR)-responsive transcripts in sugarcane challenged with *Colletotrichum falcatum*. Applied Biochemistry and Biotechnology 2014;174:2839–50.
Selvi A, Nair NV (2010) Molecular breeding in sugarcane. Intl J Agric Environ Biotech 3(1):115–127
Shin S, Torres-Acosta JA, Heinen SJ, McCormick S, Lemmens M, Paris MPK, Berthiller F et al (2012) Transgenic *Arabidopsis thaliana* expressing a barley UDP-glucosyltransferase exhibit resistance to the mycotoxin deoxynivalenol. J Exp Bot 63:4731–4740
Singh RK, Jena SN, Khan MS, Yadav S, Banarjee N, Raghuvanshi S, Bhardwaj V et al (2013) Development, cross-species/genera transferability of novel EST-SSR markers and their utility in revealing population structure and genetic diversity in sugarcane. Gene 524:309–329
Singh, R.K., Banerjee, N., Khan, M.S. *et al.* (2016). Identification of putative candidate genes for red rot resistance in sugarcane (*Saccharum* species hybrid) using LD-based association mapping. *Mol Genet Genomics* **291**, 1363–1377 https://doi.org/10.1007/s00438-016-1190-3
Smith, B.J.; Black, L.L. Morphological, cultural and pathogenic variation among Colletotrichum species isolated from strawberry. Plant Dis. 1990, 74, 69–76. [CrossRef]
Sun L, Zhu L, Xu L, Yuan D, Min L, Zhang X (2014) Cotton cytochrome P450 CYP82D regulates systemic cell death by modulating the octadecanoid pathway. Nat Comm 5:1–12
Thudi M, Upadhyaya HD, Rathore A, Gaur PM, Krishnamurthy L, Roorkiwal M, Nayak SN (2014) Genetic dissection of drought and heat tolerance in chickpea through genome-wide and candidate gene-based association mapping approaches. PLoS ONE 9(5):96758
Tu Y, Rochfort S, Liu Z, Ran Y, Griffith M, Badenhorst P, Louie GV et al (2010) Functional analyses of caffeic acid O-methyltransferase and cinnamoyl-CoA-reductase genes from perennial ryegrass (*Loliumperenne*). Plant Cell 22:3357–3373
Vierstra RD (2003) The ubiquitin/26S proteasome pathway, the complex last chapter in the life of many plant proteins. Trends Plant Sci 8:135–142
Viswanathan R, Sathyabhama M, Malathi P, Sundar AR. Transcriptome analysis of host-pathogeninteraction between sugarcane and *Colletotrichum falcatum*by Suppression Subtractive Hybridization and Illumina sequencing. Proceedings of the International Society of Sugar Cane Technologists 2016; 29:1639–44
Viswanathan, R. (2021). Sustainable sugarcane cultivation in India through threats of red rotby varietal management. *Sugar Tech* 23, 239–253. doi: 10.1007/s12355-020-00882-3
Viswanathan, R., Amalraj, R., Selvakumar, R., Malathi, P. (2018). "Progress in understandingfungal diseases affecting sugarcane: red rot," in *Achieving sustainable cultivation of sugarcane, volume 2: Breeding, pests and diseases*. Ed. Rott, P. (Cambridge: BurleighDodds Science Publishing), 201–219.
Viswanathan, R., Singh, S.P., Selvakumar, R. *et al.* (2022). Varietal Break Down to Red Rot in the Sugarcane Variety Co 0238 Mimics Vertifolia Effect: Characterizing New *Colletotrichum falcatum* Pathotype CF13. *Sugar Tech* **24**, 1479–1496.

Wei X, Phillip AJ, McIntyre CL, Aitken KS, Barry C (2006) Associations between DNA markers and resistance to diseases in sugarcane and effects of population substructure. TheorAppl Genet 114:155–164

Went FAFC. 1983. Het rood snot. Arch. Java-Suikerindus; 1:265–82.

Yao C, Wu Y, Nie H, Tang D (2012) RPN1a, a 26S proteasome subunit is required for innate immunity in Arabidopsis. Plant J 71:1015–1028

Yu Y, Xu W, Wang J, Wang L, Yao W, Yang Y, Xu Y et al (2013) The Chinese wild grapevine (*Vitispseudoreticulata*) E3 ubiquitin ligase Erysiphe necator-induced RING finger protein 1 (EIRP1) activates plant defense responses by inducing proteolysis of the VpWRKY11 transcription factor. New Phytol 200:834–846

Zhou N, Tootle TL, Glazebrook J (1999) Arabidopsis PAD3, a gene required for camalexin biosynthesis, encodes a putative cytochrome P450 monooxygenase. Plant Cell Online 11(12):2419–2428

Zhou YL, Xu MR, Zhao MF, Xie XW, Zhu LH, Fu BY, Li ZK (2010) Genome-wide gene responses in a transgenic rice line carrying the maize resistance gene Rxo1 to the rice bacterial streak pathogen, *Xanthomonas oryzae* pv. oryzicola. BMC Genomics 11:78–89

Chapter No. 17: Varietal planning and seed cane development programme

Sanjeev Kumar*, J. Singh* and Aalok Shiv**
*Principal Scientist and **Scientist
ICAR-Indian Institute of Sugarcane Research, Lucknow

Sugarcane is the second largest commercial crop cultivated in over 5.8 million hectares in the country. Sugarcane research especially varietal improvement programme has revolutionized sugarcane cultivation supporting establishment of the sugar industry on a healthy base in the country. The sugarcane production has scaled to over 431.8 million tonnes during 2021-22 against 36.35 million tonnes during the 1930. The number of sugarmills in the country has grown up to about 521 against 29 in 1930. The net sugar production has expanded to 38.29 million tonnes (without considering the diversion into ethanol) from 0.12 million tonnes during the same period.

Varietal Planning

Varietal planning is the utmost important in sugarcane cultivation as the number of improved sugarcane varieties are being released every year. To harness the maximum potential of newly evolved sugarcane varieties, it is better to deploy them in their suitable niches. There are two groups of sugarcane varieties which are classified based upon the maturity duration i.e. early and midlate groups. The early varieties are those which attain 18 % sucrose in juice and 85 % purity at 10 months of crop age (which is generally considered as the month of January), whereas midlate varieties have to qualify the same standards at the 12 months of crop age which coincides with the month of March. The new Sugar Season is always started from 1st October but most of the sugarmills in north India begun their crushing in the month of November and onwards. Sugar recovery in the early part of the crushing season is always a major concern.

In last two decades, number of improved sugarcane varieties were released through the Central/ State Release Committees. During 2001-2010, area under midlate varieties (dominant varieties CoS 767 and CoSe 92423) was more than 80 %. The main objectives of varietal planning and management during this period was to enhance the area of early maturing sugarcane varieties. During this period, a number of excellent early maturing varieties such as Co 0238, CoLk 94184, Co 0118, CoLk 9709 etc. were recommended for the commercial cultivation through their respective Release Committees. At that period of time, the average sugarcane productivity was around 60 t/ha and sugar recovery hovering around 9 to 9.5 percent. Then, the ruling varieties were CoS 767 and CoSe 92423 which were low yielder and having low sugar content. The major emphasis through varietal planning was to enhance the area of early maturing varieties up to 40 % and to replace the old midlate sugarcane varieties with new ones having high yield and sugar content such as CoPant 97222.

During last decade i.e. 2011-2021, the wider adoption of Co 0238 among the farmers changed the scenario of sugar sector particularly in north India. Co 0238 was released in year 2009 by the Central Sub-Committee on Crop Standards, Notification and Release of Varieties of Agricultural Crops for the commercial cultivation in North West Zone and within short period of time it occupies more than 85 % sugarcane area particularly in Uttar Pradesh. The average sugarcane productivity has increased > 80 t/ha and sugar recovery reached above 11 percent. Due to fast and wide adoption of Co 0238, all other sugarcane varieties whether they were new or old ones had decimated to the negligible one. Sugarcane cultivation particularly in Uttar Pradesh has became a sort of monoculture of this popular variety Co 0238. Although, Co 0238 an excellent variety liked by both farmers and millers, a rare situation, has succumbed to red rot disease with the evolution of new race of pathogen probably because of large area occupied by this single variety. The variety Co 0238 has become susceptible to newly evolved race of red rot pathogen Cf 13. This is a typical case of Vertifolia Effect as historically reported break down of vertical resistance of the variety Vertifolia in the case of potato.

Proper balance of early and midlate maturing varieties

Of the total cane acreage approximately 97.92, 2.01 and 0.07 % area is occupied with early, midlate and unsuitable varieties, respectively in Uttar Pradesh during 2021-2022 (Table 1). Seeing the present scenario of early and midlate maturing varietal spectrum there is fervent need to emphasize a balance under improved early and midlate maturing varieties having high sugar and cane yield. It was emphasized that proper balance of early and midlate sugarcane varieties is very important for better cane productivity, longer crushing period and sugar recovery. To achieve the higher sugar recovery, it has been found that balanced proportion of area under early and midlate maturing variety should be kept to ensure proper supply of cane of desired quality and maturity throughout the crushing period. Required varietal proportion which is lacking in this part of country will not only increase the total sugar recovery but will also maintain it throughout the crushing season. Right varietal balance of early and midlate maturing varieties will increase the sugar recovery *vis-à-vis* sugarcane yield in the north India.

Table 1. Harvesting schedule

Month	Season of planting/ crop/ variety
October/November	Autumn/Spring Ratoon-Early maturing varieties
December	Autumn Plant-Early maturing varieties/ Ratoon-Midlate maturing varieties
January	Ratoon-Midlate maturing varieties/ Spring Plant-Early maturing varieties
February	Spring Ratoon/ Plant-Midlate maturing varieties
March	Spring Plant- Midlate maturing varieties
April and onwards	Late planted- Midlate maturing varieties

There is need to assess the value of balance of area grown under improved early and midlate maturing varieties possessing high sugar content. It is emphasized that a proper balance of early and midlate maturing sugarcane varieties is very important for longer crushing periods with higher sugar recovery. The cost of production of sugar and profitability of the sugar industry besides many other factors depends primarily on the availability of sufficient quantity of good quality sugarcane during the crushing season. For increasing productivity of sugarcane and production of sugar besides use of scientific package of practices, varietal planning and scheduling of harvesting help cane growers and cane personnel in determining allocation of land to different varieties, their plant and ratoon crops and planning the harvesting and crushing schedules during the peak ripening curves of varieties covering the poosible crushing period to provide economic return to both the growers and millers.

A suitable variety is one that provides the most productive yield with maximum stability under the given environment. The start of harvest is determined by the sugar content of the canes, so the variation range in percentage of CCS (Commercial Cane Sugar) based on the maturity pattern of the varieties becomes the critical point to facilitate harvesting. Other minimum crushing period during peak maturity of a particular variety definitely has an advantage in increasing the sugar recovery, but this period can only be extended to both sides until the recovery is desirable. Therefore, proper varietal balance and harvesting schedule will help to a great extent to maintain sugar production

Table 2. Area and percentage of major sugarcane varieties in Uttar Pradesh during last five years

Variety	2017-2018		2018-2019		2019-2020		2020-2021		2021-2022	
	Area (lakh ha)	Percentage	Area (lakh ha)	Percentage	Area (lakh ha)	Percentage	Area (lakh ha)	Percentage	Area (lakh ha)	Percentage
Early Group										
Co 0238	12.08	52.55	19.28	69.02	22.02	82.21	23.75	86.70	22.55	81.68
Co 0118	0.41	1.79	0.69	2.48	0.57	2.15	0.86	3.14	2.06	7.46
CoLk 94184	1.44	6.27	1.88	6.74	1.49	5.56	1.18	4.30	1.40	5.06
Co 98014	0.65	2.81	0.54	1.93	0.40	1.49	0.33	1.21	0.40	1.46
CoS 8436	0.34	1.48	0.23	0.83	0.11	0.44	0.08	0.29	0.08	0.31

Others	1.28	5.56	1.37	4.86	0.72	2.63	0.50	1.81	0.54	1.95
Total	**16.20**	**70.46**	**23.99**	**85.86**	**25.31**	**94.48**	**26.70**	**97.45**	**27.03**	**97.92**
Midlate Group										
CoS 767	1.16	5.03	0.42	1.52	0.10	0.36	0.04	0.13	0.02	0.07
CoSe 01434	1.07	4.64	0.70	2.49	0.27	1.03	0.16	0.57	0.09	0.33
CoS 97264	0.41	1.77	0.20	0.72	0.06	0.21	0.02	0.06	0.01	0.02
CoS 97261	0.24	1.05	0.13	0.46	0.02	0.09	0.01	0.02	0.00	0.00
CoS 99259	0.15	0.64	0.10	0.35	0.01	0.02	0.00	0.00	0.00	0.00
Others	2.58	11.27	1.90	6.80	0.88	3.30	0.31	1.56	0.43	1.59
Total	**5.61**	**24.40**	**3.45**	**12.34**	**1.34**	**5.01**	**0.54**	**2.34**	**0.55**	**2.01**
Unsuitable Varieties	**1.18**	**5.14**	**0.50**	**1.80**	**0.14**	**0.51**	**0.06**	**0.21**	**0.02**	**0.07**
Total Area	**22.99**	**100.00**	**27.94**	**100.00**	**26.79**	**100.00**	**27.30**	**100.00**	**27.60**	**100.00**

Recently, several improved early and midlate maturing varieties of sugarcane have been developed through varietal development programme by the different research institutes in the country. Adoption of high sugar and high yielding varieties resulted in the enhanced sugarcane productivity as well as sugar recovery, however there is still a good scope for adopting the proper balance of these early and midlate maturing varieties and completely discarding the area of unsuitable varieties. Judicious combination of early and midlate maturing varieties and ratoon, staggered planting and planned harvesting will ensure the supply of mature and fresh quality cane for crushing. The new early maturing varieties like CoLk 14201, CoS 13235 (released by the SVRC) and Co 15023 are now becoming pouplar among the farmers and may replace the red rot susceptible variety Co 0238. The varietal diversity is very important and it will provide insurance against the epidemic of pests and diseases which may otherwise threaten to completely wipe out the particular variety.

Table 3. Sugarcane varieties released and notified by the CVRC

Zone	Early	Mid late
Peninsular zone *(Tamilnadu, Kerala, Karnataka, Maharashtra, Gujarat, M.P.)*	Co 85004 (Prabha), Co 94008 (Shyama), Co 0314, Co 0403, CoSnk 05103, Co 09004	Co 8371 (Bhima), Co 86032 (Nayana), Co 87025 (Kalyani), Co 87044 (Uttara), Co 91010 (Dhanush), CoM 88121 (Krishna), Co 99004 (Damodar), Co 0218, CoSnk 05104, Co 06027
East Coast zone *(Andhra Pradesh, Orrisa, Coastal part of Tamilnadu)*	CoC 01061, CoOr 03151	Co 86249 (Bhavani), Co 06030
North central and Eastern zone *(Eastern part of U.P., Bihar, West Bengal, Assam)*	Co 87263 (Sarayu), Co 87268 (Moti), Co 89029 (Gandak), CoSe 95422 (Rasbhari), CoSe 96234 (Rashmi), CoSe 96436 (Jalpari), CoLk 94184 (Birendra), Co 0232 (Kamal), CoLk 12027, CoLk 15466	BO 128 (Pramod), CoSe 92423 (Rajbhog), Co 0233 (Kosi), CoP 06436, CoLk 12209
North west zone *(Central and Western part of U.P., Uttarakhand, Haryana, Punjab, Rajasthan)*	Co 98014 (Karan-1), CoH 92201, Co 0238, Co 0118, Co 0237, Co 0239, CoS 96268 (Mithas), CoS 95255 (Rachna), CoPk 05191, Co 05009, CoLk 11203, Co 15023, CoLk 15201	CoPant 90223, CoS 91230, (Raseelee), CoS 94270 (Shweta), CoS 96275 (Sweety), CoH 119, CoJ 20193, CoPant 97222, Co 05011, CoLk 09204, Co 09022, Co 12029, CoLk 11206, CoLk 14204, CoLk 15207

Seed cane development programme

Commercial crop of sugarcane is propagated vegetatively through setts or cuttings of stems. Setts with two or three buds are used to break apical dominance and assist germination. The advantage lies in the fact that the crop thus raised is true to the type. A good seed cane is one which is free from pests and diseases, high in moisture content and rich in invert sugars and soluble nitrogenous compounds. Hence, young cane of 6-8 months in tropical belt and 8-10 months in subtropical belt, well manured and irrigated is considered ideal seed cane. Top portion of unarrowed cane with immature internodes form good seed material. The seed cane pieces should not have adventitious roots or splits and must be free from mixture. Selection of seed cane conforming to prescribed traits and standards is the key issue for obtaining high germinability and productivity in sugarcane. In order to produce healthy seed cane conforming to the desired parameters, good seed forms a strong base for better crop growth and higher yield. For this, the parameters like health, purity, viability and vigour are taken into consideration. Healthy seed means the seed entirely free from disease. This can be obtained only by careful periodic inspection and through eradication of diseased clumps. Healthy seed cane of absolute genetic purity is obtained either from plant crop raised as nucleus seed or the progeny of nucleus seed grown at research station.

Need for seed cane replacement

Although not taken seriously, sugarcane seed replacement is as important as in any other crop. Many serious diseases such a red rot, smut, GSD, RSD etc, affect sugarcane. The inoculums of most of these diseases are carried through the seed cane. Over the generations, these diseases multiply and accumulate in seed cane resulting in yield decline. In sugarcane seed system, the process of seed production in the seed chain, transportation and exchange or replacement is tedious job because of the vegetative propagation and requirement in bulk amount. There are basically two reasons that force the farmers to change or replace sugarcane seed *viz.*,

- Poor seed quality of the adopted variety – Seed Deterioration
- Poor productivity of the variety- Varietal Decline.

Thus, seed cane replacement process includes two kinds of replacements i.e. replacement of old seed with good quality seed of existing/adopted variety and replacement of old variety with good quality seed of new improved variety (varietal replacement). The replacement of old deteriorated/ de-notified varieties with new varieties require well established seed production chain. The planting materials of these new varieties are small in quantity and thus need techniques of rapid multiplication such as tissue culture, STP, polybag nursery etc. for faster replacement

Formulation of seed production chain for seed cane replacement

Seed cane replacement requires a seed production chain encompassing nucleus, breeder, foundation and primary seeds. As per the present seed policy, the seed replacement rate should be 33 per cent. Based on this policy, estimated requirement of all classes of seeds to replace one third of the total planted sugarcane area can be worked out. The total area under sugarcane crop in India is about 5.8 million hectares. Roughly 50 percent of the total sugarcane area is under the ratoon crop. So, the total area under sugarcane plant crop is about 2.9 million hectares. As per the recommended seed cane replacement rate, 9.67 lakh hectares area of sugarcane needs quality seed for replacement. The recommended seed cane required for planting one hectare area is 60 quintals. Thus, total seed cane required for replacement of 9.67 lakh hectare sugarcane area will be approximately 580 lakh quintals. Seed cane multiplication ratio in sugarcane being 1:10, the requirement of foundation, breeder and nucleus seeds will be approximately 1/10th of each class respectively in order of their production.

The role and responsibility of different organizations engaged in seed cane production programme can be decided on the basis of these requirements and their capacity to produce seed cane. The huge responsibility of producing quality seed cane for farmers rests on the development agencies of the concerned states, sugar mills and progressive farmers. To produce this quality seed cane, foundation seed cane should be provided by the sugar mills and different state departments engaged in the seed cane production programme. The breeder seed production is the responsibility of the research institutions, which have adequate seed cane production facilities. Finally, the purest form of seed cane i.e. nucleus seed cane should be produced by the research organizations under their maintenance breeding programme involving all the scientific principles to maintain the highest genetic purity and quality of the seed cane.

Three- tier seed production of sugarcane

Healthy sugarcane seed is developed in phased multiplication. It is referred as three – tier seed in case of sugarcane. Thermo-therapy is essentially given at the first phase for raising breeder seed followed by multiplication as foundation and primary seed in II and III tier. Degenerated seed is replaced with the healthy seed of improved varieties. Replacement of seed from 3-tier sugarcane production has achieved perceptible increase in productivity of the crop.

Nucleus seed

The nucleus seed is the initial seed obtained from selected individual plants (clumps) of a particular variety / parental line for the purpose of purifying and maintaining that variety

Breeder seed

The seed material to be used for raising breeder seed is obtained from nucleus seed nurseries. The breeder seed is raised at the farms of research stations under the supervision of the Breeders

Foundation seed

Foundation seed shall be raised from seed cane taken from breeder seed nurseries. The foundation seed is grown at the government, sugar factory or progressive grower's farm.

Primary seed

Primary seed should be the progeny of foundation seed and its production should be so handled as to maintain specific genetic purity and identity according to seed cane standards prescribed for certification by any certifying agency.

Factors influencing seed cane germination

The spouting or germination of sugarcane buds depends on several internal and external factors:

Internal factors

Varietal characteristics, bud health, position of the bud on the seed cane, sett moisture, reducing sugars and soluble nitrogen

External factors:

Temperature, soil moisture, surface crusting, depth of planting, placement position of bud in soil, soil aeration, acidity created by inorganic fertilizers and insect pest attack

Seed cane treatment

The treatment of seed cane can be done by Heat-therapy, Chemo-therapy and/or Bio-therapy.

Heat–therapy

The most common and effective method of killing/eliminating pathogens from seed is heat treatment. It is carried out by:

i) Moist Hot-Air Treatment (MHAT) at 54^{o}C for 2.5 hrs, at 95-99% relative humidity.
ii) Hot-Water Treatment (HWT) at 52^{o}C for 18-20 min.

IISR Lucknow has developed heat treatment unit which controls the temperature and humidity through electric gadgets. The heat treated seed is not directly used for commercial cultivation but is first grown in nurseries. *Three-tier seed production programme* initiates with MHAT of genetically pure seed.

Chemo-therapy

The planting material is treated with chemicals especially when used for planting by the growers. The common chemicals are the fungicdes like Thiram and Bavistin (0.1%). These are largely effective in protecting the seed from the pathogens present in the soil. Rarely insecticides are used for seed treatment e.g., setts are dipped in 0.1%, Malathion or 0.06% Dimethoate for 15 minutes as surface disinfectants, when setts are infested with scale insects.

Bio- therapy

Bio-therapy is a recent concept for value addition in seed cane. Seed cane is inoculated with bio-agents, *viz., Trichoderma viride* and *Gluconacetobacter diazotrophicus* culture which impart the growing cane crop with disease resistance inducing characteristics, growth promoting substances and nitrogen fixing mechanisms. The inclusion of *Mycorrhiza* as the component of microbial consortia further equips the plants to solubilize insoluble soil phosphate and taps it from deeper layers as well as inter-row spaces. Several methods of heat treatment *viz.,* hot water, hot air, aerated steam and MHAT were tried but later was established to be highly efficient, effective and economical over hot water, hot air and aerated steam. Penetration of heat in the sett was superior in case of MHAT at 54 ^{0} C for 2:30 h at > 90% RH. MHAT treatment is helpful to develop GSD, RSD, smut, leaf - scald free seed material of sugarcane. Incipient infections of shorter duration of red rot and wilt are also eliminated from cane stalks. Deep seated red rot and wilt infections are partly affected.

Rapid seed cane multiplication

In sugarcane seed multiplication ratio is very low i.e. 1:10. For fast multiplication and spreading of new improved sugarcane varieties, it is essential to adopt rapid seed multiplication technique. Some of the techniques are listed below.

Spaced Transplanting (STP)

The technique developed by IISR, consists of transplanting of nursery raised settlings. Settlings are raised by planting single bud setts in nursery about a month before transplanting in the main field. Approximately 50 m^2 land area and about 2 tonnes seed cane are needed to obtain settlings sufficient for transplanting in one hectare of field.

Polybag nusery

Settlings are raised in polythene bags and these can be put at any place. Post-transplanting mortality is very low because polybag settlings are transplanted with earth ball by removing polythene so root system of young shoots is not disturbed, which helps in quick and better establishment of transplanted settlings in the main field.

Bud chip technology

A substantial saving in seed materials may be obtained by using bud chips as it reduces the seed requirement to less than one tonne per hectare. The bud chips from sugarcane stalk are scooped with a sharp edged knife in such a way that each bud has a little portion of stem. Bud chips should be planted on raised nursery beds with inter-row spacing of 7.5 cm @ 300 buds/m^2 or in polybags. Seedlings are ready in 5-8 weeks for transplanting in field.

Short seed crops

Many growers in south India raise a sugarcane crop for 6-7 months duration for seed purpose which is known as `Short Seed Crop'. In this case crop is fertilized with a high rate and irrigated well to produce a well nurtured crop of good thick cane in short period of time. This crop may also be replanted for raising a short seed cane in a succeeding manner. In Andhra Pradesh, short seed crop is planted in February-March and cut and replanted in August-September at about 6 month age. August-September planted crop is harvested by January-February for planting to main crop. Such a crop gives 6-8 times seed multiplication. The system is particularly useful in multiplying new varieties.

Tissue Culture Raised Plants (TCRPs)

Another alternative technique to solve the chronic problem of low multiplication of seed in the clonal propagation of sugarcane. Multiply the planting material rapidly without impairing the genetic purity. It has established its merit in several of the clonally propagated crops including sugarcane. Multiplication rate of sugarcane clones through this technique is extremely high. Field establishment capacity of the tissue-cultured seedlings is also fairly high. However, it is yet to be tested as a tool for large-scale seed multiplication and its economics have to be worked out.

Current status of the seed cane standards in India

The seed cane certification standards approved by the Technical Committee of Central Seed Certification Board in 2001 is given below:

Sugarcane (Saccharum spp; hybrid)

Age of the seed cane crop at harvest for seed purpose shall be 6 to 8 months and 8 to 10 months for the sowing in tropics and sub-tropics, respectively seed cane material undamaged and reasonably clean. Each node of seed cane shall bear on one sound bud. The number of nodes without sound bud shall not exceed 5% (by number) of the total number of buds per seed cane. The number of buds, which have swollen up or have projected beyond one centimeter from the rind surface shall not exceed 5% (by number) of the total number of buds.

1. Application of general Seed Cane Certification Standards

The General Seed Cane Certification Standards are basic and together with the following specific standards constitute the standards for certification of sugarcane seed cane. The certified classes shall be produced from seed canes and/or meri-clones whose sources and identity may be assured and approved by the Certification Agency.

2. Land requirements

i) A seed crop of sugarcane shall not be eligible for certification if planted on land on which sugarcane was grown in the previous season.
ii)Land/seed crop shall be kept free from sugarcane residues and drainage from other sugarcane fields.

3. Heat treatment

Foundation Stage (1) shall be raised from heat-treatment seed cane

4. Field inspection

A minimum of three inspections shall be made as under:

Stage-I The first inspection shall be made at 45-60 days after planting in order to verify isolation and detect volunteer plants, designated diseases and pests and other relevant factors.
Stage-II The second inspection shall be made at 120-130 days after planting to verify off-types, designated diseases and pests and other relevant factors.
Stage-III The third inspection shall be made 15 days prior to the harvesting of seed canes to verify the age of cane, off-types, designated diseases and pests and other relevant factors.

5. Field standards

A. General requirements

Isolation: The sugarcane seed production fields shall be isolated from other fields with a minimum distance of 5 m to avoid mechanical mixture of other varieties.

B. Specific requirements

S.No.	**Factors**	**Stage of field inspection**	**Maximum permissible limits (%)**	
			Foundation	**Certified**
I.	Off-types	1, II, III	None	None
II.	Plants affected with designated diseases			
	Red rot	I, II, III	None	None
	Smut	I	0.02*	0.10*
		II	0.01*	0.10*
		III	None	None
	Grassy shoot	II	0.05*	0.50*
		III	None	None

S.No.	Factors	Stage of field inspection	Maximum permissible limits (%)	
			Foundation	Certified
	Wilt	III	0.01*	0.01*
	Leaf scald	II	0.01*	0.05*
		III	None	None
III.	Plants affected by designated Insect-pests			
	Top borer	II & III	5.0	5.0
	Internode borer	III	10.0* None**	10.0 None**
	Stalk borer	III	20.0+ None**	20.0 None**
	Plassey borer, Gurdaspur borer, Scale insect, mealy bug	III	5.0 None**	5.0 None**

* Subject to immediate roguing of the whole clump
** In areas where the presence of the pest has not been recorded
# It gives around 10% affected buds
+ It gives around 0.5% affected buds.

Designated diseases shall be

1. Red rot (*Glomerella tucumanensis* (Speg.) Arx & Muller)
2. Smut (*Ustilago scitaminea* Sydow)
3. Wilt (*Cephalosporium sacchari* Butler)
4. Grassy shoot disease (Mycoplasma-like-organism)
5. Leaf scald (*Xanthomonas albilineans* (Ashby) Dowson

Designated insect-pests shall be

1. Top borer (*Scirpophaga excerptalis* Wlk.)
2. Internode borer (*Chilo sacchariphagus indicus* Kapur)
3. Stalk borer (*Chilo auricilius* Ddgn.)
4. Plassey borer (*Chilo tumidicostalis* Hmpsn.)
5. Gurdaspur borer (*Acigona steniellus* Hmpsn.)
6. Scale insect (*Melanaspis glomerata* Green)
7. Mealy bug (*Saccharíphagus sacchari* Cockerell)

Note

1. All off-types and diseased plants shall be rogued out along with roots and destroyed.
2. Maximum permissible limits for the stripping of dry foliage shall be 2.0%
3. The crop should not have more than 10% lodged canes.

4’ Seed canes should not have nodal roots. In water logged areas, relaxation may be given up to a maximum of 5%.

5. Moisture in seed cane should not be less than 65% on wet weight basis.
6. Germinability of buds should not be less than 85%
7. Physical purity of seed should be 98%.
8. Genetic purity of seed should be 100%.

Standards for Tissue Culture Raised Plants (TCRPs)

In view of increasing use of tissue culture raised plants (TCRP) for seed purposes, it was felt during ICAR-DAC Interface that certification standards should be extended to such plants. This is also imperative as it was frequently noticed that the commercial crop raised from tissue culture plants displays many off-types.

In this sequence, ICAR has constituted a committee, which has given the recommendations in 2006. Since a few methodology are yet to be standardized, the notification on certification standards of TCRP will take some time. The salient features of the recommendation are as follows: The plant material for producing TCRP must be of a notified variety or released by the SVRC or registered with State Agencies. Genetic purity should be certified by the originating centre or sponsored breeder. Freedom from diseases and pests should be certified by the accredited laboratory. Seed cane of a crop raised from TCRP is considered as Breeder Seed, which should be tagged as per provisions of Seed Act. Seed cane standards as prescribed by Govt. of India should be followed for production of Foundation and Certified Seed.

Future strategies in seed cane production and replacement

There is wide gap between the availability/distribution of seed cane and the actual required quantity. The ever increasing population needs vertical growth rate in sugarcane production to meet its requirement. In this purview, there should be a strategy for seed cane production and replacement since the quality seed is a crucial factor for vertically increasing sugarcane production. The suggestions given below may be adopted to improve seed cane replacement programme in India.

1. Popularization of quality seed of improved cane varieties

In India, still majority of the farmers are not inclined to purchase quality seed cane because either they are not aware about its impact or because of their socio economic status they are unable to spare money for purchasing the seed cane. Therefore, the seed cane replacement rate is very low and hence suitable technology transfer strategies needs to be worked out to popularize the good quality seed cane particularly of improved cane varieties. The provision of short/ medium term credit facilities for purchasing seed cane may further improve the situation.

2. Seed demand and forecasting

The information base on which forecasting of seed cane demand can be done is not well developed in India. Thus, seed cane demand needs thorough estimation based on the recommended seed cane replacement rate and other parameters. A demand matrix is required and to be updated annually.

3. Liaison between scientists and cane development agencies/ sugar mills /farmers

The reach of the good quality seed to the farmers is still far from satisfactory. For popularization of improved sugarcane varieties and strengthening of seed cane programme, there should be proper liaison among research organizations, cane development agencies, sugar mills and sugarcane farmers. This will help in proper estimation and production of different classes of seed for seed production chain.

4. Production of disease free seed cane

To produce quality seed cane, seed health has to be given top priority. Diseases not only affect the seed crop but can also spread in the new area through the seed. Survey and surveillance of disease incidence and quick reliable detection techniques in addition to control measures should be adopted.

5. Phasing out of obsolete and disease susceptible varieties

The system of regular phasing out of obsolete varieties already exists in many countries with developed seed sectors but it is not popular in the countries with emerging seed sector. This should be done in a systematic way by the respective institutions. The denotification proposal based on the level of varietal decline and reduction in seed cane demand should be submitted by the respective institutions where the variety was developed. The seed of the denotified variety should be phased out from the seed production chain. The replacement of old and obsolete varieties with the recently released improved varieties has been the major considerations to increase the sugarcane seed production. The varietal replacement component is very low in sugarcane. Hence, there is need to bring awareness in the farming community with respect to recently released varieties and their adaptive potential to realize high yield.

6. Varietal characterization and intellectual property rights

The seed cane replacement in India may now be modified to fit the existing IPR regime under which, provisions have been made to register new varieties with PPV&FR Authority. The registration of varieties will create avenues of benefit sharing through sale of seed cane, which will prompt new seed cane producers to invest in the field of seed production and marketing.

7. Human resource development

Human resource development is very week in seed cane production and replacement programme. The majority of personnel from cane development agencies/ sugar mills and even farmers engaged in seed production and replacement programme, require proper education/training, which will certainly help in production of better quality and higher quantity of the seed cane required for replacing old seed cane with new one.

Suggested Readings

Gumber, R.K., Sidhu, G.S. and Kuldeep Singh (2001). Quality seed: Better sugarcane yield. Indian Farming, 51 (8): 30-30.

Gupta, S.C.; Verma, K.P.; Singh, M.P. and Misra, S.C. (1978). Control of diseases by hot water treatment of sugarcane seed material. *Indian Sugar Crops J.* 5:28-29.

Hunsigi, G. (2001). Management of seed cane in Sugarcane in Agriculture and Industry. Prism Books Pvt. Ltd. Pg. 249.

Hagos H, M Luel and M. Yohannes (2014). Determining optimum harvest age of sugarcane varieities on the newly establishing sugar project in the tropical area of Tendano. Ethiopia Advances of Crop Sciences and Technologies. doi: 10.4172/2329-8863. 1000456.

Jalaja, N.C. (2001). A practical manual for the sugarcane micro-propagation. A publication from Sugarcane Breeding Institute, Coimbatore

Kumar, Sanjeev, Praveen Kumar Singh and Jyotsnendra Singh (2017). Ensuring high seed cane quality to harness varietal potential in sugarcane. Indian Farming, 67 (02): 19.22.

Misra, S.R. (2003). Recent Advances in seed production of sugarcane. Coop. Sug. 34 (10): p 805-808.

Misra, S.R and Singh, P.K (2003). Sugarcane Nucleus and Breeder Seed Production manual, IISR, Lucknow: 1-19.

Nagarajan, R. (2000). Seed nursery programme in sugarcane. 32nd meeting of sugarcane research and development workers of Tamil Nadu. P. 174-176.

Narasimhan R. Srivastava K.K. and Shukla R.K. (1981). A technology for rapid multiplication of seed cane. Indian Sugar 345:435-7

Nath M. N. (1992). Cost-effectiveness of transplantation nursery raised sugarcane bud chips plants on commercial sugarcane plantations. Abstract, ISSCT 21: p.93

Panje, R.R. (1965). How to multiply seed cane? *Indian Sugar* 15(5): 339-342.

Panje, R.R. (1974). High seed propagation ratios by the use of low seed rates in sugarcane. *Proc. Intern. Soc. Sugar Cane Technol*. 15: 743-745.

Panje R.R. and Gill P.S. (1963). The IISR polyethylene nursery system of sugarcane planting. Indian Sugar 12(12):737-742

Panje, R.R., Mathur, P.S. and Motiwale, M.P. (1969). Effect of cutting, puncturing and addition of water to internodes on the sprouting of buds and formation of shoots in sugarcane. *Indian J. Agric. Sci*. 39: 1142-1149.

Shahi, H.N. (2000). Sugarcane seed: Production and certification, pp.251-260. In: 50 Years of Sugarcane Research in India (2000), Shahi, H.N., Shrivastava, A.K. and Sinha O.K.(Editors). Indian Institute of Sugarcane Research, Lucknow, pp. 409.

Singh, K. (1977). Sugarcane diseases and three-tier seed programme. *Sugar News* 9:81-89.

Singh N. and Rao GSC (2009). Reference of new high sugar content and high yielding sugarcane varieties in three zones of Uttar Pradesh. Proceedings of 70th Conv. of STAI, Udaipur, India: pp 98-110

Singh, V. and Singh J. (2002) Healthy seed production. Indian Farming. 51(11): 37-43.

Chapter No. 18: Advances in sugarcane planting methods for resource use efficiency and enhancing cane yield

A.K. Singh and Ajeet Kumar
Sugarcane Research Institute
Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur-848125, Bihar

Sugarcane is one of the important cash crops in India. It is grown in two distinct agro-climatic regions; tropical and sub-tropical. Over 45 million farmers are involved in sugarcane production and about 7.5 % rural population is directly or indirectly dependent on the sugar industry. During 2020-21 the country produced 401.8 million tonnes of sugarcane from an area of 5.3 million hectares achieving productivity level of 76.0 tonnes/ha. However, there have been fluctuations in these parameters in last decade. The reasons are many but climate plays major role. Frequent droughts put heavy impact on sugarcane productivity in *space* and *time*. On the other hand, sugarcane crop requires considerable quantity of water being 1400-1500 mm in sub-tropical region and 2500-3000 mm in tropical region. Moreover, the irrigation efficiency at farmers' fields seldom exceeds 35-45%.

Sugarcane in its life cycle both in tropical and sub-tropical India faces extremely high temperature coupled with hot desiccating winds during April to June causes extreme soil moisture stress resembling with high degree of drought. The period also coincides with dwindling water resources from surface and ground water bodies. Drought is the single most important factor limiting sugarcane productivity. Drought (soil moisture stress) even of small magnitude can cause yield reduction, if it occurs at initial stage(s) of growth.

Sugarcane is one of the most productive plant known in terms of dry matter production as it potentially produces from 41 to 65 t of dry matter ha^{-1} year $^{-1}$ (Cheeroo-Nayamuth, *et al*, 2000).Physiologically, sugarcane being C_4plant is one of the most efficient converters of solar energy into sugar and during the peak growth period it has the potentiality to produce around half a tonne of dry matter ha^{-1} day^{-1} (Yadav, 1991). However, such performance of the crop depends upon establishment methods and types of genotype as it is directly influenced by amount of harvestable solar radiation and crop stand. In recent years pit method of planting has been reported to produces higher proportion of thick and heavy primary shoot, contributing more to final population and the yield. Differential response of sugarcane to planting technique is attributed to soil moisture storage and its depletion rate advocated that planting method should provide enough opportunity to conserve soil moisture to facilitate settling establishment. Planting technique- genotype interaction is an important consideration for realising the potential of a genotype as the ultimate number of millable stalk which a genotype is able to carry depends upon a set of environment that a planting method provides. Keeping this in view the present manuscript has been prepared.

Under such situation, inputefficient planting techniquesvis-à-vis water saving irrigation methods can mitigate the effect of soil moisture stress to a great extent. It is in this context that the present paper addresses these critical issues.

The critical agro-techniques for scientific management of sugarcane are as under:

- Sugarcane varietiesSeed material
- Planting period
- Planting geometry
- Planting method
- Nutrient management
- Water Management
- Weed management

- Harvesting schedule
- Ratoon management

Panting Methods:

1. – Flat method of planting
2. – Trench method of planting
3. – Partha method of planting
4. – Deep trench planting
5. – Rayungan method or Rajoeng method of planting
6. – Seblong or sprouted bud method of planting
7. – Distance planting method
8. – Align method of planting
9. – Tejblock method of planting
10. – Modified trench system of planting
11. – Contour system of planting
12. – Single bud direct planting
13. – Chip bud or bud chip technique of planting
14. – Pit planting
15. – Skip furrow planting
16. – Paired row planting
17. – IISR 8626 method of planting
18. – Ring planting
19. – Spaced transplanting technique (STP)
20. – Polybag seedling transplanting method
21. – Ridge and furrow method of planting (FIRB)
22. –Cane node planting (CNP)

Before planting, the dry leaves of the cane stalks are removed by hand in order to avoid any possible damage to buds. Thereafter cane is cut into three budded setts usually 30 to 45 centimetre long. About 35000 to 40000 setts are needed to plant one hectare which can be obtained from about 60-80 quintals of cane depending upon planting season and methods.Some important planting methods are discussed below.

Flat planting

Flat method of planting is mainly followed in subtropical belt of India. The land is prepared by one or two deep ploughing with a soil turning plough or chisels to uproot the old stubble and break the land into clods followed by two or three harrowing and planking to break the clods and bring the soil to a fine tilth. High cost of production and acute shortage of labour led to a rethinking on the conventional practice of deep tillage for sugarcane. Conservation tillage with two to three ploughing and compacting by planking is enough to realize a high yield of cane. Repeated ploughing and compaction break the capillary pores and create a kind of soil mulch and thus helps in conserving soil moisture.

After placing the setts in furrows, these are covered immediately by soil and the soil is again compacted by heavy wooden plank to conserve soil moisture. Thus the setts are covered with about 3-5 cm soil layer. In this system of planting, the germination of planted buds is very low in north India and takes long time, particularly in autumn. The crop receives only 6-8 irrigations. 150 kg N + 60 kg P_2O_5 + 60 kg K_2O per hectare is required to realize a good cane tonnage. This system is recommended for low or moderately fertile soils with scarce irrigation.

Ridge and furrow planting

Ridge and furrow is the most ideal easy system of planting under intensive irrigated sugarcane cultivation. This system is also followed in south India. The system facilitates easy irrigation, provides good soil aeration and adequate support to the plant when proper earthing up is done. In finely prepared field, ridges and furrows are formed using tractor drawn or bullock drawn ridger keeping a distance of 60-

135 cm from one furrow to another. The most common spacing is 90 cm. Closer spacing of 60-75 cm is desirable for short duration early and shy tillering varieties, low soil fertility, moisture stress or waterlogging and late (summer) planting conditions. Wider spacing is advisable under high fertility conditions with good irrigation facilities and for long duration and high tillering varieties. Spacing upto 150 cm, can be adopted to facilitate mechanized planting and harvesting operations.

Trench planting

Trench system is practised mostly in coastal Andhra Pradesh in heavy clay soils, mainly in wet lands where clod formation is common. In this system, U shape furrows or trenches of 25-30 cm deep and 40-60 cm wide are made using spade and heaping clods manually. The distance between the centers of two adjacent trenches being 100 cm in case of *eksali* and 120 cm in case of *adsali* crop. Nearly 10 cm soil at the bottom of the trench is loosened and the soil is allowed to weather for about 3 weeks. About 50 cartloads of farmyard manure per hectare is applied in trenches prior to planting and left as such for about a month. This system is useful to prevent lodging which is quite common in the east coast region. In areas of high rainfall and clay soils prone to waterlogging, slant planting at an angle of 45^{o} called *Partha* method is adopted. In this technique, three bud setts are planted 2-5 cm deep either on the top of the ridge or on the side of the ridge so that one bud is buried in the soil and two buds are exposed. The two exposed buds germinate. When monsoon recedes the setts are pressed horizontally so that one or two germinating shoots from each sett strike roots.

In subtropical India, trench planting is adopted to economize on water. After land has been thoroughly prepared, trenches are made in October-November by keeping 90-100 cm distance from the center of one trench to another. Each trench is approximately 20 cm deep, 40 cm wide and separated by a ridge of 50-60 cm wide from the next trench. The ridges are formed by taking soil from the trenches. Cane setts are placed with last bud overlapping at the bottom in the centre of the furrow and then covered with the soil.

In this method of planting, the crop gets a good basal anchorage which prevents lodging at early stage of crop growth. A saving of about 15 per cent irrigation water and a yield increase of 5-10 t/ha can be anticipated over flat planting. The greatest disadvantege is that it is highly labour intensive. However, The deep trench maker developed at IISR, Lucknow is very useful for this method of sugarcane planting.

IISR 8626 method of planting

The system involves basic concept of plant internal factor (i.e. auxin action) and edaphic factor (i.e. soil compaction). Auxins which emanate from growing points of sugarcane control the activity and growth of bud while soil compaction hinders root growth and its proliferation. These two facters along with another aspect – lengthening of growth period, have led to develop a new method of cane planting called IISR 8626 method of planting (Panje*et al.* 1968). In this technique, efforts have been made to increase the use efficiency of inputs and to enhance the overall productivity of cane so that it could fully exploit the soil and sunshine resources within a given period of time. Finally, the technique is intended to exploit to the fullest extent the sub-soil moisture and native soil fertility. On these account, the technique is considered profitable one.

Ring Pit Method of planting

Mother shoot technology or no tiller technology

- Pit diameter : 90 cm
- Depth : 45 cm
- Centre to centre : 120 cm
- No. of pits/ha : 6900

Ring-Pit method also suitable for drought prone areas, undulating topography, light textured soils, saline - sodic soils, multiple rationing, high yielding, tall and thick cane varieties

FIRB system of sugarcane planting with wheat

Wheat - sugarcane (plant) – ratoon - wheat is the prevalent sugarcane based cropping system in north-western zone of sub - tropical India It is estimated that about 14 % of the sugarcane areas in the country with more than 2/3rd in western U.P. are covered under this cropping system. Inspite of low yield of sugarcane in this system, the farmers are not ready to sacrifice the production of wheat as it meets the requirements of their family and livestock. By induction of FIRB optimum yield of both the crops may be obtained.

Table 1.:Effect of planting methods on cane yield and water productivity

Yield components (millable cane, cane length, diameter of cane, cane weight and cane yield)

Treatments	Millable canes (000 ha^{-1})	Cane length (cm)	Diameter of cane (cm)	Cane weight (g)	Cane yield (t ha^{-1})
T_1	91.50	193.00	2.50	860.33	77.53
T_2	96.60	198.00	2.61	873.33	82.50
T_3	100.33	200.00	2.63	879.66	86.20
C.D. (P=0.05)	3.270	2.68	0.04	13.258	2.828
S.E. ±	0.811	0.66	0.01	3.289	0.701

Table 2: Quantity of irrigation water applied and water productivity

Treatments	Irrigation water applied (ha-cm)	Total water input (ha-cm)	Water productivity (q ha-cm^{-1})
T_1	277.83	359.78	2.82
T_2	245.49	327.44	3.37
T_3	229.11	311.06	3.79
C.D. (P=0.05)	NS	NS	NS
S.E. ±	18.688	18.688	0.239

NS=Non-significant source: ***Guru Prem et.al 2017***

Three planting methods viz., T_1- conventional planting (60 cm row spacing), T_2-paired rowtrench plantation method (60:120 cm spacing) and T_3- paired row ridge and furrow plantation method (100:120 cm spacing).

Table 3: Effect of planting methods on productivity of sugarcane varieties

Treatment	Brix value(%)Single cane weight(kg)	Single cane weight(kg)	Number of millable canes (000 ha-1)	Cane yield (t ha-1)	Days to maturity (Days)	Per day productivity (kg ha-1)
M_1	19.79	1.27	102.5	141.5	337.2	419.1
M_2	19.54	1.14	118.9	149.5	336.6	443.0
M_3	19.79	1.27	97.7	136.1	338.2	402.7
M_4	19.50	1.37	83.3	128.7	340.2	378.5
SE(m)±	0.235	0.029	1.45	1.62	0.20	4.84
CD(0.05)	NS	0.10	5.0	5.6	0.7	16.7

Source: Gulati et.al 2015

Four treatments viz. M_1 - Mega pit (150cmx150cm, spacing, 30cm depth,15 settling per pit), M_2 - Small pit (120cmx 60cm spacing 30cm depth with three settlings per pit), M_3 - Trench method (spacing-30cm width x 30cm depth, 12 settlings with paired systems of planting), M_4 - Conventional (spacing-15cm width x 15cm depth, 12 settlings with end to end planting).

Table 4.:Effect of paired-row planting on cane yield (Autumn planting, (CoLk 8001)

Treatment	Cane yield (t ha^{-1}) 1989-91	1990-92	Mean
1. Conventional planting single rows spaced 90 cm apart, 40,000 three-eye bud setts	69.3	75.3	72.3
2. Single rows spaced 90 cm apart, 80,000 three-eye bud setts	71.4	80.8	76.1
3. Paired rows (double) spaced 30 cm apart with the paired rows 60 cm apart, 80,000 three-eye bud setts	99.0	108.8	103.9
1sd 0.05	8.3	6.7	5.8

Source: Yadavet.al. 1997

Table 5.:Effect of different t planting methods on cane yield (Autumn planting, (CoLk 8001)

	Planting methods	Cane yield (t ha^{-1})
1)	Flatbed planting (conventional)	54.9
2)	Ridges and furrows	67.8
3)	Trench planting	87.9

Source: Srivastava and Seth, 1990

Planting techniques to mitigate drought impact:

Followingplanting techniques of sugarcane have been developed and adopted to mitigate the impact of drought through conserving soil moisture, enhancing water use efficiency and effecting saving in irrigation water. These planting methods play crucial role in assured plant population by ensuring higher germination, optimizing shoot density and reducing tiller mortality. These inturn, govern the exploitation of plant morphological (structural) and plant physiological (functional) responses within soil-crop-atmosphere continuum and finally determine the productivity and quality of cane. Further, these improved planting techniques dictate other agro-techniques like, planting geometry and seed rate, fertilizer schedule, irrigation methods, inter-cultural and earthing -up operations.

Ring pit method :

In this method, seed setts are adjusted in circular pits of 90 cm diameter and 45 cm depth and pits are arranged in square geometry in the field. The centre to centre distance is 120 cm and number of pits work out to be 6900 / ha. Further, modifications in pit specification have been made including 75 cm diameter, 45 cm depth, 105 cm centre to centre distance accommodating 9000 pits/ha. This method encourages more development of mother shoots rather than tillers and therefore, it is termed as Mother Shoot Technology or No Tiller Technology.

Ring-pit method of planting is advocated for maximizing cane yield on undulating light and saline-sodic soils. The dose of soil amendments is also reduced with this system of planting. Nutrient use efficiency is enhanced due to localized placement and provide greater efficiency of solar energy utilization because of the better interception of sun light.

Population density of 162 thousand millable canes/ha and yield of 184 t/ ha has been harvested in ring-pit planting system (Yadav, 2007). Since only mother shoots are allowed to grow, the millable canes are taller, thicker, heavier and of same age and give higher sugar recovery.

This is most drought proofing planting technique of sugarcane as the root zone is in lower surface which remains moist, hence the plants require less water. It requires less time and less water per irrigation. At the same time, only about 36% of area is covered, hence rest of the area is always available for cultural operations. Besides, it holds promise for high yielding tall and thick cane varieties as the crop does not lodge. The technique is also ideal for multiple ratooning on one hand and conservation farming on the other. The B.C. ratio is 1.8.

Trench method :

Trench method of sugarcane planting is a modification of ring-pit method. In this system, U shaped trenches of 25-30 cm deep and 40-60 cm wide one made using spade and heaping clods manually. Now this operation is easily, performed by trench maker designed and developed by ICAR-IISR, Lucknow.Center to center distance between two adjacent trenches is kept 100-120 cm. Bottom 10 cm soil is loosened and mixed with FYM. Cane setts are placed 5-7 cm deep in double parallel rows and irrigated. Rides are leveled up gradually with subsequent hoeings.

Trench system is practiced mostly in coastal Andhra Pradesh in heavy clay soil, mainly in wet lands where clod formation is common. In subtropical India, trench planting is adopted to economise on water (MenhiLal and Singh, 2007) This method leads to better germination because of higher moisture content in trenches and thin soil layer over the setts. Trench method provides higher capacity to roots for nutrient uptake from deeper layers. The crop gets a good basal anchorage which prevents lodging of full grown crops. The trench system is suitable for drought conditions because of deeper penetration of root mass. Moreover, a saving of about 15% in irrigation water and a yield increase of 5-10 t/ha can be anticipated over flat planting. Apart from enhancing water use efficiency and making the plants to with stand drought conditions more effectively, the method also ensures better ratoons and results in B:C ratio of 2.15.

Furrow Irrigated Raised Bed System – FIRB System :
Problem:

Wheat - sugarcane plant – ratoon is the most important cropping system, which has attracted the attention of the scientists and development workers in recent years. It is estimated that 0.3 millon hectare of sugarcane area in India is under this system. The importance of the system lies in the fact that more than 60% of the sugarcane area in wastern U.P. and 10-14% in other states is covered by this system. A drastic reduction (30-50%) in sugarcane yield is very common if sugarcane is planted late (summer- April end to May end) after the harvest of wheat crop. High to very high temperature at planting and germination time, low humidity, over mature seed cane, little time for tillering, heavy in infestation of weeds and insect-pests are majors factors responsible for poor cane yield.

Concept:

In ordered to enhance the productivity of sugarcane in wheat-sugarcane rotation innovative wheat + sugarcane intercropping system under Furrow Irrigated Raised Bed – FIRB has been developed at ICAR-IISR, Lucknow (Singh *et al,* 2004). The technology is most suited for sandy loam and loam soil.

Approach I:Operations partially mechanized:

In this system wheat is sown on raised beds in the month of November/December and irrigated upto 2/3rd height of furrow which creates congenial moisture environment and dynamics of solute movement in the modified bed configuration. Three rows of wheat are accommodated at 17 cm row spacing on each raised bed (48-50 cm top width) and sugarcane is planted manually in 80 cm spaced rows (30-32 cm top width and 20-22 cm depth) by wet planting method in the month of February, the optimum time of its planting. Thus under FIRB system, sugarcane plating is advanced by 60 days and gets optimum time span for tillering and grand growth phases.

Approach II: Operation fully mechanized:

With the development of Raised Bed Maker cum Seeder-Planter at ICAR-IISR, Lucknow, the seeding of wheat on Raised Beds and planting of sugarcane in furrows are done simultaneously in single pass in the month of November/December. On raised beds, pulses and/or oilseed crops can also be sown instead of wheat.

An increase of 35-40% in cane yield could be obtained with FIRB system as compared to wheat-sugarcane sequential system besides 25-30% saving of irrigation water and effective weed control. It is reported that system provides additional net profit of Rs. 25000/ha with higher B:C ratio of 2.24 in wheat + sugarcane intercropping under FIRB as against 1.88 in wheat – sugarcane sequential system under flat planting.

Water use efficient technologies:

Efficient water management using different technologies to cope-up with drought and improve agricultural productivity holds prime importance. Water saving technologies such as drip/fertigation are mostly practiced in horticulture, vegetables and sugarcane crops at present for up scaling water and nutrient use efficiency. The following agro-techniques are recommended in sugarcane.

Skip furrow irrigation:

Skip furrow method of irrigation to sugarcane is one of the low cost technologies to improve the productivity of water. In this technique 45 cm wide and 15 cm deep furrows are made in alterative inter-row spaces and the crop is irrigated through these furrows. The soil surface of alternate- inter- row spaces in which furrows are not made, remains almost dry. The evaporation losses are reduced to the extent of 35-40% resulting in saving of irrigation water. This results in less evapo-transpiration and improvement in water use efficiency by 60-65% Next irrigation could be done in alternate furrows to realize normal yield and quality of sugarcane. There is 30% saving of water and the method is suited to drought prone areas under well irrigation (Shukla*et al,* 2018).

Trash mulching:

Sugarcane trash is a crop by product available after harvesting of the crop. It is estimated that the quantity of trash per hectare is almost equal to the seed cane planted (7-8 t/ha) depending upon the variety. This trash is spread in the alternate inter-row spaces in ratoon crop at the time of its initiation. As a result the evaporation loss of moisture is considerably reduced and the effectiveness of irrigation is increased. Since, the trash mulch keeps the soil moisture conserved at the higher level for a longer time as compared to uncovered soil surface, the water use efficiency and crop yield increase by 40 and 26% respectively. Increase in sugarcane yield due to trash mulch is attributed to favorable moisture conditions, increased microbial activities and addition of water soluble nutrients particularly K up to 30 kg/ha from trash which in turn governs the water balances in plant cells. In long run soil organic carbon content is also improved. This is why, it said that **cash the trash in sugarcane culture**.

Extensive Irrigation:

This system of irrigation is advocated where such sugarcane varieties are available which can withstand drought (soil moisture stress) at certain stages (tolerant) of growth. It permits to schedule irrigation over large areas only at moisture sensitive (critical) stages of crop to realize maximum total production under limited water availability situation. Ensuring irrigation at critical period of water need of the crop and deferring the same at somewhat less critical period, improves irrigation water use efficiency and cane productivity. These critical stages for sugarcane are emergence, first order of tillering, second order of tillering and third order of tillering. Depending upon the availability of water, the crop is irrigated at these stages. If two irrigations are available, then the irrigations are provided at the second and third order of tillering. If three irrigations are available, then the irrigation are provided at all three orders of tillering. If four irrigations are available, then the irrigations are provided at all the four critical stages.

Drip Irrigation/Fertigation

It is an advanced method of supplying required quantity of water to the root zone through network of tubing and drippers/emitters/nozzles placed along with water delivery. This conceptualizes precise application of water including fertilizers (fertigation) with great water economy. There is slow release of water in the root zone, almost at the rate at which plant can absorb the same. Under wide row planting, drip irrigation may be more advantageous since laterals will be placed at wide distances. The quantity of laterals required may also be less. If drip irrigation is followed, then heavy earthing-up may have to be avoided and alternative land configuration may be followed to facilitate placing the laterals.

Advantages of drip irrigation:

- Saving of irrigation water by 30-40%
- Yield increase by 30-50%
- Economy in fertilizer use
- Uniform water application
- Less weed growth

Sub-soiling:

Sub-soiling in done to loosen or break the hard pan formed by continuous ploughing at a particular depth and/or use of heavy machinery for farm operations. Since sub-soiling is energy intensive process development and use of sub-soiler has made the job easier. Sub-soiling at 2- 4 meters distance upto 25-30 cm depth, provides an opportunity to conserve rain and/or irrigation water in deeper layers for use by the crop in the event of drought. Further, cross sub-soiling increases the capacity of soil to retain considerable amount of water for crop use during unprecedented drought. In the process deep localized placement if fertilizers in root zone could also be done to enhance nutrient use efficiency. An equipment named as sub-soiler cum deep and differential rate fertilizer applicator, has been developed at Pantnagar. While in operation, it can place fertilizers at equal depths by three times or variable depth 15-20 cm by shallow leading tines and 30-45 cm by central main tine. The amount of fertilizers could be kept uniform or variable in the ratio of 80% by shallow tines and 20% by main tine as per the density of roots. The placement of fertilizer is done while sub-soiling the field.

REFERENCES

Alexander, D.1993. Natural Disasters, UCL Press, London.

Gautam, R.C. and Bana, R. S. 2014.Drought in India, its impact and mitigation strategies.Indian. J. Agron. 49 (2): 179-190.

Gulati, J.M.L, Sunmarg, Ch, Behra, Jitendra, Jena, S.N., and Lenka, Subhrasini2015.: Effect of planting methods on productivity of sugarcane varieties 49(3): 222-228

MenhiLal and Singh, I. 2007. Conventional methods of sugarcane planting and their improvemet.

Nagarajan, R. 2003. Drought: Assessment, monitoring, management and resource conservation Capital Publishing Company New Delhi, P.312.

Prem, Guru, Kumar, Ramesh, Singh, Vikram.D., Kumar, Amit, Choudhary, Rakesh and Ahmad, Afzal. April 2017. Effect of planting methods on cane yield, water productivity and economics of spring planted sugarcane (Saccharumofficinarum L.) in Ambala (Haryana) 10 (1). Pp. 186-190.

R.L. and Yadav, D.V. (Editors).Sugarcane planting techniques and crop management IISR, Lucknow U.P. India pp 1-6.

Roy, A.K. and Hirway, I. 2007. Impact of droughts and assessment of drought policy in major drought prone states in India; Project Report submitted to the Planning Commission, GOI, New Delhi.

Srivastava, S.C., and Seth, S.R. 1990: Sugarcane agronomy and cropping. Recent advances in sugarcane, ed. P.N. Rao. 207-246. KCP Ltd, Vuyyuru, Andhra Pradesh, India.

Shrivastava, A.K. 2002. Abiotic stresses and sugarcane production, Indian Farming 51(11): 18-21.

Shukla, S.K., Yadav, S.K., MenhiLal and Pathak, A.D. 2018. Alternate/skip furrow irrigation. In low cost technologies in sugarcane agriculture, IISR Lucknow p 44.

Singh, I., MenhiLal, S.K. Shukla and P.R. Singh, 2004.Enhancing water use efficiency in wheat + sugarcane overlapping cropping system through FIRB system.Golden Jubilee National Symposium on Conservation Agriculture and Environment. BHU, Varanasi, Extended Summaries pp 422-423.

Swami, S.K. 2001.Management of drought in India.UNDP Sub-regional Seminar on Drought Management Mitigation, Iran. 28-29 August 2001. www.ndmindia.nic.in /documents/drought – iran ppt.

Yadav, R.L. 2007.Ring-Pit technology in sugarcane production.Yadav, R.L. and Yadav, D.V. (Editors).Sugarcane planting techniques and crop management IISR, Lucknow U.P. India.pp 17-19.

Yadav, R.L., Singh, R.V., Singh, R., and Srivastava, V.K. 1997: Effect of planting geometry and fertilizer N rates on nitrate leaching, nitrogen use efficiency and sugarcane yield. Trop. Agric. 74 (2): 115-120. Trinidad.

Chapter No. 19: Furrow irrigated raised bed system for enhancing resource use efficiency in wheat + sugarcane system

T. K. Srivastava
Principal Scientist (Agronomy), Division of Crop Production
ICAR- Indian Institute of Sugarcane Research, Lucknow

Wheat and sugarcane are important crops of sub-tropical region of India, the first is widely used as staple food whereas the second a cash crop, being the only source of sweetener, is crucial for rural agro-industrial economy.The most accepted cropping system of sugarcane-ratoon-wheat has attracted the focus of many researchers. The reason behind this was the drastic yield reduction in late planted (April end to May) sugarcane yield which is taken up after the harvest of wheat. An innovative wheat- sugarcane intercropping system under Furrow Irrigated Raised Bed (FIRB) was developed in the institute. In this system, wheat is sown on raised beds and sugarcane in the furrows. Sugarcane is planted in the month of February in already existing wheat, sown in November, thus advancing the optimum time span for tillering and grand growth phase and thus finally 35-40 per cent yield improvement. This technology is mostly suitable for sandy loam and loamy soil.In western parts of Uttar Pradesh, large area of sugarcane is under late planting. In summer planting, farmers grow wheat in the winter and sugarcane is planted after wheat harvest in the months of April/May. This delayed planting reduces tillering span and restricts cane crop maturity to 9-10 months resulting into lower cane yield. The yield of late planted cane is low because of unsatisfactory plant stands and lowers individual cane weight. Experimental results have indicated that March and April planting of sugarcane crop reduces the cane yield by 17 and 26 %, respectively when compared with February planted crop. Sugarcane yield further declines when it is planted in May month.It is estimated that 0.3 million hectares of sugarcane area in India is under this system. The importance of the system lies in the fact that more than 60% of the sugarcane area in western UP and 10- 14% in other states is covered by this system. A drastic reduction (30-50%) in sugarcane yield is a common feature when the sugarcane is planted late (April end to May end) after the harvest of the wheat crop. High to very high temperature at planting and germination time, low humidity, over mature seed cane, little time for tillering, heavy infestation of weeds and insect-pests are the major factors responsible for poor cane yield. The recent approaches for the management of this system include simultaneous planting of sugarcane and wheat (taking wheat as reference crop) and wheat + sugarcane under Raised Beds.

In order to enhance the productivity of sugarcane in wheat-sugarcane system, an innovative, wheat-sugarcane intercropping under Furrow Irrigated Raised Bed (FIRB) system has been developed. This technology is most suited for sandy loam and loamy soils. In this system, sugarcane is planted in furrows in November and wheat is sown on raised beds in November /December in view of the fact that both the crops are heavy feeder for nutrients and compete for moisture and light. Nutrients are applied in the rhizosphere of the respective component crops. Accordingly, nutrients for wheat are placed on the raised beds and for sugarcane in the furrows after wheat harvest. Since the irrigation water is applied only in the furrows, it creates variable moisture environment and dynamics of solute movement in the modified bed configuration. The root proliferation of the component crops is also in different depths. Thus, it provides ample opportunity for exploiting spatial and temporal complementarities, enhances input use efficiency and increases the profitability and sustainability of the system.

Under wheat- and sugarcane- based cropping system in North India, wheat is taken either as intercrop in autumn sugarcane or as a sole crop followed by sugarcane planting in summer months (April–May). The shading of wheat plants as intercrop adversely affects the emerging shoots of autumn sugarcane in March–April. Moreover, wheat yield is also less as an intercrop than its sole crop as only two rows of wheat are there in 90 cm spaced autumn sugarcane. When sugarcane is planted after wheat harvesting, sugar and sugarcane yield is low due to less time available to late-planted cane. So, there is a need to develop production technologies for getting better cane and wheat yield under sugarcane–wheat cropping system. Furrow irrigated raised bed (FIRB) system may be a better option for higher productivity and net returns, as both the crops can be sown timely and gave better yields. To evaluate FIRB system, field experiments were conducted at Punjab Agricultural University, Regional Research Station, Faridkot, during 2011–2013, 2012–2014 and 2013–2015 in a randomized block design with nine treatments {T1: autumn sugarcane, T2: T1 + wheat (1:2), T3: T1 + wheat (1:3), T4: wheat sown in November—late sugarcane, T5: wheat sown in December—late sugarcane, T6: FIRB wheat November (75 cm with three rows of wheat) + sugarcane in furrows in February, T7: FIRB wheat November (75 cm with three rows of wheat) + sugarcane in furrows in March, T8: FIRB wheat December (75 cm with three rows of wheat) + sugarcane in furrows in February, T9: FIRB wheat December (75 cm with three rows of wheat) + sugarcane in furrows in March}. Wheat was taken as an intercrop and also as sole crop sown in November and December month, while sugarcane was also planted as sole autumn crop and as spring crop in furrows of standing wheat on beds (45 cm) as wet planting method. The results showed that the average yield of wheat sown under FIRB system was 44.2 q/ha that was significantly higher than the average yield (41.7 q/ha) of bed sown wheat. Under FIRB system, both timely and late sown wheat with spring sugarcane (T7 and T8) produced higher number of millable canes, i.e., 107.2 and 105.8 thousands/ha, respectively, than remaining treatments, while cane yield (82 t/ha) of timely sown wheat with sugarcane planted in furrow during the third week of February (T6) produced 2–40% more production than other treatments. This combination (T6) also recorded high wheat yield (49.6 q/ha). Maximum cane equivalent yield was also obtained from T6 and T7 treatments. Thus, for getting high production from both crops, the FIRB system with three rows of wheat and furrow planted sugarcane during spring season can be advisable to the farmers for additional benefits with high monitory values.

Planting of sugarcane in standing wheat sown by Furrow Irrigated Raised Bed (FIRB) Method: In wheat and sugarcane based cropping system when sugarcane is planted after wheat harvest, it requires 50% higher seed and there is more attack of early shoot borer. Farmers face the problem of seed availability for planting sugarcane in April–May (as mills close cane crushing upto this period). Moreover, the late planted sugarcane does not mature at the crushing time, resulting in loss of cane yield for farmers as well as loss of sugar recovery to sugar mills. To minimize these losses from late planted sugarcane, Punjab Agricultural University has recommended growing sugarcane in the standing wheat sown by "Furrow Irrigated Raised Bed" (FIRB) method by putting the sugarcane setts in furrows (Plate 5). In FIRB system two rows of wheat are sown on 37.5 cm wide bed with 30 cm furrow for irrigation. These furrows can be used for sugarcane planting without affecting the productivity of both the crops. When sugarcane is planted in February-March in the furrows of bed sown wheat there is no competition between wheat and sugarcane because sugarcane germination takes place after 30-40 days and wheat is towards maturity during this time. Moreover, wheat is on beds and sugarcane is in furrows so there is less competition due to spatial variation. In this system farmers can sow wheat with bed planter. Bed planting of wheat helps in better use of fertilizers, because of chances of retaining the basal dose of applied fertilizer in the bed, where plant roots are concentrated more and second dose of N fertilizer is also drilled within beds. Whole N can be applied at sowing before preparing the beds. In January reshape the beds if necessary to deepen the furrows.

Plant the sugarcane in February–March by wet planting method. Irrigate the furrows in the evening and place the three budded setts in the furrows next morning and press them with foot. Use the furrows for irrigation up to earthing up. After earthing up, wheat beds will become furrows. This method will enable the farmers to use good quality sugarcane seed available in February-March. Water and labour required to maintain the sugarcane seed in field up to May for sowing it after wheat harvesting can be saved. This method will increase the area under bed sown wheat thus helping water saving in wheat also. Area under sugarcane will also be increased by this method.

Furrow Irrigated Raised Bed Method (FIRB) planting of sugarcane in standing wheat

In Haryana state, sugarcane is planted in autumn, spring and late spring seasons. The autumn planted sugarcane gives 15-20% higher cane yield than spring and 30-40 % over late planted cane. Autumn planting has not gained popularity among farmers due to late harvesting of kharif crops, myth of losing Rabi crop and lack of transfer of technology. The growth rate of sugarcane at initial stages (90-100 days) is rather slow with low leaf canopy providing sufficient uncovered area for some crops to be grown. This uncovered area can be used by the intercrops for efficient utilization of nutrients, moisture, space and solar energy thereby increasing water, nutrient and other input use efficiency, reducing the production cost and making system sustainable. Wheat is an important crop for food security of the nation and farmers are also not ready to leave wheat crop on the cost of autumn planting of sugarcane. Hence, the intercropping of wheat with autumn planted sugarcane is a suitable option for enhancing the area under autumn planted sugarcane and also income of the farmers in the sub-tropical region. There is a limit to horizontal expansion of vegetable based intercropping systems. But there is no restriction as far as wheat is concerned. Moreover, the technology has the flexibility. For one or the other reason if planting of sugarcane is not possible in the month of October, it can be safely done in the month of February-March as the furrows are clear for sett placement.

Further Reading:

Singh K, Chaudhary OP, Singh H, 2012a. Effects of sub soiling on sugarcane productivity and soil properties, J Sugarcane Res, 2: 32-36.

Singh K, Gill MS, Singh A, Singh D, Uppal SK, Singh J, 2012. Sugarcane planting in standing wheat using furrow irrigated raised bed (FIRB) method, Sugar Tech 14: 351-56.

Singh Ambika, Lal N, 1963. Effect of bulk density of soil on growth of sugarcane, Annual Report, 1962-63, IISR, Lucknow, pp 38-39.

Singh J, Singh AK, Sharma MP, Singh PR, Srivastava AC, 2011. Mechanization of Sugarcane cultivation in India, Sugar Tech, 13(4): 310-314.

Chapter No. 20: Integrated nutrient management and optimizing fertilizer schedule in sugarcane

S.R. Singh
Principal Scientist
Division of crop Production, ICAR-Indian Institute of Sugarcane Research, Lucknow

Summary

In order to reduce the overuse of chemical fertilizers and achieve a balance between fertilizer inputs and crop nutrient requirements, integrated nutrient management (INM), an agronomic practice, aims to coordinate the application of inorganic fertilizers, organic manures, bio-fertilizers, green manuring, and crop residues. INM works to preserve soil fertility, improve soil health, and consistently provide plants with the nutrients they need, in addition to maximizing yield output, profitability, and therefore reducing environmental pollution. The essential elements of INM in sugarcane include trash mulching, pulse-based intercropping, and the use of byproducts of the sugar mill such as press-mud and bagasse, which boosted sugarcane output and preserved soil health. Combination application of various organic manures + inorganic fertilizers resulted to increase 14–27 t ha^{-1} greater cane yields compared to inorganic fertilizers alone. Press-mud, FYM, and chicken manure outperformed other organic sources in terms of cane output, whereas press-mud outperformed poultry manure in terms of sugar yield. Weed growth, moisture loss, nutrient losses owing to water erosion, and the leaching of soluble nutrients from the soil are reduced by green manuring, cover cropping, and residue management. Green manuring crops especially legumes provide N to soils through biological N fixation, and increase the soil N supply to subsequent crops. The required doses fall between 70 and 400 kg N, 0 and 80 kg P_2O_5, and 0 and 141 kg K_2O ha^{-1}. Depending on the sugarcane's lifespan and the fertility of the soil, up to 400 kg N, 170 kg P, and 180–190 kg K ha^{-1} of fertilizer need be applied. The fastest absorption of nitrogen occurs within 90 days after planting. Therefore, for a crop that would last 12 to 14 months, nitrogen should be applied between 60 and 90 DAP. Nitrogen is applied in two or three splits over the course of 90 days, depending on the type of soil; sandy soils receive three splits, whereas loams and sandy loams receive nitrogen in two splits.

The vision of a world without hunger and zero poverty, which is being exacerbated by rising living standards notably in rural areas, where the majority of poor people live, and their complete reliance on agriculture for a living to meet their food demands, are the main challenges facing agriculture planners and farming decision makers in the coming years. The key to ending current suffering is the development of a strategic plan that promotes prosperous farming and enables farmers to achieve agricultural growth, reduce poverty, and maintain high returns. Thus, the key challenge in the coming years is to answer the following question. Can agriculture meet the world's food needs, which have been attained ~8.0 billion populations across the world by the year 2022? (FAO, 2012). If an increase scarcity of land and water, most agriculture plans rely on the use of chemical fertilizers and the development of new high-yielding crop varieties. However, both components are costly, and liable to increase pressure and responsibility for financial investments, resulting in an increase in total costs. Meanwhile, fertilizer prices rise year-after-year due to the increased amount of fertilizer required in each seasons compared to the first season to maintain current yield production at an economical level. Despite the increase in the quantity of fertilizer application, a part of applied fertilizers and soil native nutrients were already consumed by the current and previous crops, especially in the case of intensive agriculture, where two to three crops are annually cultivated. Furthermore, the use of chemical fertilizers is not a practical option for many poor farmers notably in sugarcane crop grown in various regions around the world, because many poor farmers do not have enough money to pay the claim of fertilizer price, in addition to its scarcity and unavailability in times of need.

Integrated nutrient management (INM) is an agronomic practice that aims to harmonious use of inorganic fertilizers, organic manures, bio-fertilizers, green manuring, and crop residues incorporation to create a combination that can be applied for reducing the massive use of chemical fertilizers and achieving a balance between fertilizer inputs and crop nutrient requirement options. It can maintain soil fertility, restore soil health, and continuously supply plants with their nutrient requirements to achieve an optimum level of yield production, maximize the profitability, and subsequently reduce the environmental pollution (Selim 2018). Finally, integrated nutrient management is defined as a low-to-no-cost-effective technology for restoring soil health that can be produced and used in the same location. Integrated nutrient management is the technique of using a minimum effective dose of sufficient and balanced quantities of organic and inorganic fertilizers in combination with specific microorganisms to make nutrients more available and most effective for maintaining high yields without exposing soil native nutrients or polluting the environment. INM can serve as a driving force, able to support plans for converting marginal lands into productive ones, thus achieving the strategy agenda of increasing cultivated land. Although many researchers and specialists may be surprised by the results of INM practices, farmers still require significant efforts and additional assistance from a variety of disciplines, including scientific researchers, extension specialists, government sectors, and non-governmental organizations (NGOs), to make them well known and capable of recognizing entire aspects of such practices.

Many subheadings can be introduced under the heading of INM practices, such as the use of farmyard manures, natural and mineral fertilizers, soil amendments, crop residues, farm waste recycling, agroforestry, green manures, and compost (Selim and Al-Owied, 2017; Selim 2018). Some researchers, on the other hand, have concluded that the effects of organic manures are not always positive, and that some organic materials may indeed be inhibitory to plant growth, possibly due to the presence of high levels of phytotoxins and a high C: N ratio, particularly in immature organic materials (Craft and Nelson, 1996). Thus, the recycling of organic wastes, by the farmers themselves, may be a valuable and acceptable option for many of agriculture planners and numerous farmers to overcome the traditional methods of organic waste disposal, with or without the slight risk to the plants, groundwater or ecological pollution, and human health to achieve the best use of existing natural resources (Abdel-Aziz and Al-Barakah 2005). The key component of the INM goal is to reach the most effective and homogeneous combination that could lead to good management and be an effective target of the fertilizers, sufficient and balanced use of their quantity and quality, and be straightforwardly up taken by plants for higher yield without jeopardizing soil native nutrients or polluting the environment. It is ultimately viable to achieve such a target through the wise application of integrated nutrient management (INM) approach, which is known as a balanced mixture of organic, inorganic, and bioorganic microorganisms in combinations in different practices (Janssen,1993). It can also improve all aspects of molecule absorption of macronutrients (NPK) and micronutrient inputs. Furthermore, it can match crop nutrient requirements and alleviate nutrient deficiency constraints while having no negative effects on the environment or products. Mismanagement, on the other hand, always results in soil degradation, nutrient deficiency, and rapid soil run off.

The main goal of integrated nutrient management is to maintain economic yield for a long time with little effect on native soil fertility and environmental pollution, making some changes in farmer's awareness toward the eco-friendly technique (organic farming system) for producing healthy food free of contaminants and ensuring satisfactory economic returns. Soil corrosion, mining, degradation, and loss of fertility are the primary causes of an irreversible decrease in plant production and massive damage to sustainable agriculture. As a result, overcoming the problem of low soil productivity is critical to sustaining soil health and restoring soil productivity. Serious efforts have been made, including the promotion of more productive use of integrated nutrient management, an ancillary component of the organic farming system. Furthermore, considerable attention must be paid to determining soil nutrient balance, including nutrients absorbed by the current crop, as well as to the requirements of the succeeding crop. Thus, continuous assessment of current soil fertility changes is required to determine nutrient loss through crop absorption, erosion, and leaching and to mirror soil balance, because rapid depletion of soil fertility and reduction in soil organic matter is expected (Yu et al., 2014). Furthermore, some constraints are impeding the progress of integrated nutrient management. To begin with, some poor farmers have difficulty obtaining organic manure due to difficulties in obtaining FYM and bio-fertilizers, as well as a lack of knowledge, poor advisory services, and skills in recycling organic wastes to produce high-quality compost. Furthermore, biotic or abiotic stresses are ranked in the second succession, poor tillage is ranked in the third succession, and lack of equipment is ranked in the fourth succession. Furthermore, the absence of extension services and non-governmental organizations (NGOs) to assist farmers and direct their attention to the importance of using integrated nutrient management and its benefits in conserving soil properties, soil nutrient balance, environmental impacts, and their role in increasing profitability is a constraint. Finally, all of these were difficult to detect and could be added to the previously mentioned issues.

Preparing the soil for maximum capacity is an important goal and a complex process that requires the cooperation of many factors, many of which rely on more than one factor to achieve the best results, including soil nutrient content, which must not only be in an appropriate and accurate quantity but also in an easy and available form for plant absorption at the right time of plant requirement. A good nutrient management package is a way to achieve ideal growth and yield levels for most crops across different agro-ecological zones, with or without minimal environmental risk (eco-friendly strategy) (Prasad, 2002, Yu, et al., 2014).

Components of INM:

Major elements of INM can be grouped into five broad groups are as follows:

1. Organic manures
2. Green manuring/cover crop/crop residues
3. Bio-fertilizers
4. Cropping system/intercropping
5. Inorganic fertilizers

1. Organic Manures

Organic manure is organic material derived from animal, human, and plant waste that contains plant nutrients in complex organic forms. Manures, which include farm wastes, cattle shed waste, night soil, vermicompost, slaughterhouse waste, fish meals, poultry, sheep wastage, cakes (edible and non-edible), and byproducts of agro-industries such as press-mud, bagasse, and molasses, are the most important organic sources (Table 1). In turn, organic matter allows plant food to enter the crops. These manures also improve soil drainage and allow a soil to hold more water. They provide organic acids that aid in the dissolution of soil nutrients and make them available to plants. Farmers have very well known since ancient times that applying organic manure can restore soil health, resulting poor and marginal farmers used to apply farmyard manure on a regular and direct basis after crop harvest. Because, the practice of using organic manures after harvesting has been linked to improved soil health and physical, chemical, and biological properties, particularly in marginal soils, which already have low organic matter and native nutrient content, low productivity, and limits and unavailability of essential nutrients [3-7]. Moreover, the organic farming system provides organic food, which many customers prefer despite higher prices. In this context, organic manures have a greater residual effect on subsequent crops than inorganic nutrients, which are quickly lost due to water leaching and runoff into underground water. Under the bold title of using integrated nutrient management, recently escalated calls emerged inviting farmers and agriculture specialists to change their awareness toward substituting a portion of inorganic fertilizers with cheaper, more sustainable, higher nutrient use of efficient, and eco-friendly nutrients derived from natural resources (Compost) (INM).

The combination application of various organic manures + inorganic fertilizers resulted in the increased 14–27 t ha^{-1} greater cane yields compared to inorganic fertilizers alone (Babu et al. 2007). Press-mud, FYM, and chicken manure outperformed other organic sources in terms of cane output, whereas press-mud outperformed poultry manure in terms of sugar yield. Application of the recommended fertilizer dose (250-125-125 kg N-P-K ha^{-1}) coupled with either FYM or press mud (supplying 25%, or 62.5 kg N), with the use of bio-fertilizers in the sugarcane plant and ratoon, plus the incorporation of waste. Experiments conducted in Kolhapir, Maharashtra revealed that using press-mud cake at 10 t ha^{-1} for the plant crop and trash mulch at 5 t ha^{-1} for the ratoon crop in conjunction with recommended NPK, increased cane yield by 13-16 t ha^{-1} (Saini et al. 2006). Combined application of sulphitation press-mud (@ 10 t ha^{-1}) + farmyard manure (@ 10 t ha^{-1}) produced the most millable canes and cane length (Srivastava et al. 2008). In Nigeria, plots incorporated with cow dung at 10 t ha^{-1} and supplemented with inorganic fertilizer at 120N-60P_2O_5-90K_2O kg ha^{-1} found superior in respect of sugarcane growth and yield (Gana 2008). The performance of the application of 224 kg N ha^{-1} alone was exceeded by the application of 112 kg N ha^{-1} along with press mud at a rate of 4 t ha^{-1} and *Azotobacter* at a rate of 5 kg ha^{-1}. Under subtropical circumstances, the application of 150 kg N ha^{-1} along with FYM (20 t ha^{-1}) and sulphitation press-mud cake (20 t ha-1) greatly improved the production of plant cane and had a noticeable aftereffect on the yield of two additional ratoons (Singh et al., 2001). Gangwar and Sharma (1997) from Uttar Pradesh, India, reported that the highest sugarcane yield was obtained with the INM practice, which included the recommended fertilizer dose (160 kg N, 60 kg P_2O_5, and 60 kg K_2O ha^{-1}), FYM (10 t ha^{-1}) and cowpea biomass incorporation (6 t ha^{-1}).

Table 1. Nutrient contents (%) of some commonly used organic materials in South and SE Asia (Nepal, 2018).

S. No.	Organic materials	Nutrient content (%)			
		N	P_2O_5	K_2O	S
1.	Cow dung (Fresh 60% MC)	0.50	0.34	0.60	-
2.	Cow dung (Decomposed 30% MC)	2.06	2.29	1.92	1.3
3.	Farm yard manure (70% MC)	1.00	1.90	2.04	0.56
4.	Poultry manure (55% MC)	2.50	1.28	0.90	1.10
5.	Duck manure	2.15	2.59	1.38	-
6.	Goat manure	2.00	3.41	2.94	-
7.	Swine manure	2.76	6.05	1.764	-
8.	Compost (rural 40% MC)	0.75	1.37	1.20	-
9.	Compost (urban 40% MC)	1.50	1.37	1.80	-
10.	Mustard oilcake (15% MC)	5.00	4.12	1.44	-
11.	Linseed oilcake (15% MC)	5.50	3.21	1.44	-
12.	Sesame oilcake (15% MC)	6.20	4.58	1.44	-
13.	Groundnut oilcake	7.00	3.44	1.56	-
14.	Bone meal (raw, 8% MC)	3.50	20.61	-	-
15.	Bone meal (steamed, 7% MC)	1.50	22.9	-	-
16.	Dried blood (10% MC)	11.00	1.10	0.70	-
17	Fishmeal (10% MC)	7.00	3.50	1.00	-

Source: Timsina 2018; * MC = Moisture content; - indicates data not available.

2. Green manuring/cover crop/crop residues

Green manuring is the practice of growing a short-duration, succulent, and leafy legume/non-legume crop in the same field and ploughing the plants before they form seeds. Green manures are crops grown specifically for adding biomass into the soil which improved physical, chemical and biological properties as well as substituting mineral fertilizers. Slow nutrient release from green manure decomposition may provide plants with more time to absorb nutrients, potentially increasing nutrient uptake efficacy and crop production. Green manuring crops reduce weed growth by preventing the leaching of soluble nutrients from the soil. Green manuring crops especially legumes are widely known to provide N to soils through biological N fixation, and increase the soil N supply to subsequent crops. Green manuring technology is economically viable, environmentally sustainable, and socially acceptable in sustainable agricultural systems (Fageria, 2007). Green manuring crops are divided in to two group viz., leguminous crop (sun hemp, sesbania sp., mung bean, cowpea, berseem), non-leguminous plant (pearl millet, maize, sunflower) and green leaf manures (*Neem*, *Pungamia*, *Gliricidia*, etc) (**Table 2**). Ramesh et al. (2002) recommended 62.5 kg P_2O_5 ha^{-1} as RP along with phosphobacteria at pre-planting and daincha incorporation at 45 DAP in combination with the recommended doses of N and K for higher cane, sugar yields, highest net return and benefit cost ratio. Integrated nutrient management in sugarcane increases N, P, and K available in the soil without significantly altering the soil fertility status rating. Wider row spacing of 120 cm, cross planting, intercropping black gram followed by sunnhemp, and application of recommended fertilizer doses along with *Acetobacter* (10 kg ha^{-1}) and foliar spraying of micronutrient mixture (1% at 45 and 75 DAP) yielded the highest single cane yield of 150 t ha^{-1} (Manimaran et al. 2009).

According to estimates, there are 15.6 million t of sugarcane crop residues available in India, with an average nutritional content of 0.45, 0.08, and 1.20% NPK that had nutritious potential of 0.27 million t (Bharadwaj and Gaur 1985). According to Yadav (1995), sugarcane trash adds a significant quantity of recyclable leftovers to the field during the cane growth cycle in the form of dry leaves known as trash (7–10%), root biomass, and stubble (6–8%), which are essential not only for preserving soil organic carbon but also substituting some amount of essential nutrients to the sugarcane. Gross carbon input from the sugarcane trash was added in the soil that ranged from 11.7–12.4 t ha^{-1} $year^{-1}$. Thus, trash is an important source of plant nutrients which contains 0.42% N, 0.15% P, and 0.57% K and 26, 2045, 236, and 17 ppm Zn, Fe, Mn, and Cu, respectively (Yadav et al. 1987). Therefore, integration of sugarcane trash with mineral fertilizers may help to subsidize some amount of mineral fertilizers. However, many farmers elect to burn waste before and even after harvest due to practical reasons, management challenges, and the fact that it decomposes more slowly than other crop wastes. Large amounts of C, N, and S included in the plant leftovers are lost during the burning of sugarcane waste by volatilization. The addition of *Trichoderma* inoculated trash at a rate of 10 t ha^{-1}, along with 150 kg N ha^{-1} and *Azotobacter* at a rate of 4 kg ha^{-1}, was found to be beneficial for maintaining soil health, increasing sugarcane productivity, and obtaining higher net returns (Thakur et al. 2010). Through effective composting, trash might be repurposed as mulch or transformed into organic manure. Additionally, it provides opportunities for growing worms and making vermicompost. The discarded waste can be used as organic manure, and the garbage can serve as a substrate for oyster mushroom cultivation. The composting process is sped up by the addition of fresh cow dung (50 kg t^{-1} of pressmud) as a starter and urea (5 kg t^{-1} of pressmud) to lower the C: N ratio. Decomposition and composting take 15-20 weeks to complete. Vermicompost can also be made using a 1:2 mixture of garbage and pressmud that has partially decomposed. By mulching sugarcane waste, you can greatly improve soil quality while lowering electrical conductivity and surface bulk density.

Table 2. Nutrient contents (%) of some commonly used green manure crops and crop residues in South and SE Asia

S.No.	Green Manure Crops/ Crop Residues	Scientific Name	Moisture (%)	Nutrient Content (%)			
				N	P_2O_5	K_2O	S
1.	Dhaincha	*Sesbania sp.*	80	2.51	0.92	0.20	-
2.	Mung bean	*Vigna radiata*	70	0.80	0.46	1.15	0.30
3.	Black gram	*Vigna mungo*	70	0.80	0.46	1.15	0.30
4.	Cowpea	*Vigna unguiculata*	70	0.70	0.34	1.15	-
5.	Pea	*Pisum sativum*	-	1.97	-	-	-
6.	Sun hemp	*Crotolaria juncea*	70	0.70	0.27	1.15	-
7.	Rice straw	*Oryza sativa*	30	0.58	0.23	3.16	-
8.	Wheat straw	*Triticum aestivum*	20	0.50	0.69	2.06	-
9.	Maize stover	*Zea mays*	15.5	0.59	0.71	3.00	-
10.	Sugarcane	*Saccharum officinarum*	20	1.00	1.15	3.21	-
11.	Rice hull	*Oryza sativa*	15	0.31	0.16	0.85	-
12.	Coconut husk	*Cocos nucefera*	-	1.75	0.27	2.06	-
13.	Banana stem	*Musa sp.*	-	1.00	1.05	19.4	-
14.	Leucaena	*Leucaena leucocephala*	-	4.29	0.44	3.14	-
15.	Azolla	*Azolla sp.*	-	3.68	0.46	0.34	-
16.	Acacia (leaves)	*Acacia Arabica*	-	2.61	0.39	2.75	-

3. Bio-fertilizer

A bio-fertilizer is a product that contains living microorganisms that colonize the rhizosphere or plant internal tissues and induce plant growth when applied to soil, seeds, or plant surfaces. Bio-fertilizers are typically bacteria or fungi that are capable of nitrogen fixation, phosphate solubilization, sulphur oxidation, plant hormone production, or organic compound decomposition. Plant-growth-promoting rhizobacteria (PGPR) are the most common bio-fertilizers and biocontrol agents currently in use in many crops including sugarcane. PGPR colonizes the rhizospheres of many plant species, where they induce beneficial effects for the host, such as increased plant growth and reduced susceptibility to diseases caused by plant pathogens such as nematodes, fungi, bacteria, and viruses. Increased seed germination rate, root growth, yield, leaf area, chlorophyll content, nutrient uptake, protein content, hydraulic activity, tolerance to abiotic stress, shoot and root weights, and delayed senescence are some of the benefits of PGPR (Adesemoye and Kloepper,2009). Bio-fertilizers that are commonly used in sugarcane include: *Acetobacter diazotrophic*, *Azotobacter, Azospirillum* as nitrogen-fixing biofertilizers, while as *Pseudomonas striata, Bacillus polymixa, Aspergillus awamori*, and *Penicillium digitatum* are phosphorus-solubilizing biofertilizers in sugarcane. Application rate of urea is reduced by 10-15% due to integration of FYM, bio-fertilizers and Sakthi special as reported by (Narayanamoorthy 2005). *Gluconeacetobacter diazotrophicus* inoculation was also found helpful in improving the nitrogen use efficiency of various fertilizers in sugarcane crop (Suman et al., 2009). It is highly desirable practice as NUE of sugarcane is only 35–40% of applied chemical N fertilizer (150 kg ha^{-1} for sugarcane plant and 200 kg ha^{-1} for ratton crop) in subtropical India (Yadav, 2008). Saini et al. (2006) reported that there is positive impact of various bio-fertilizers on the yields parameters viz. height, weight and girth of millable cane. It is mainly due to increased levels of fertility by the application of bio-fertilizers. It has been observed that both the morphological and yield parameters of sugarcane are improved to a good extent when bio-fertilizers are applied in combination with chemical fertilizers (Hari and Srinivasan, 2005). Sugarcane can specifically interact with *Gluconacetobacter diazotrophicus*, a nitrogen-fixing bacterium. Unlike rhizobium-legume symbiosis, where bacteria are restricted to nodules, these diazotrophs are endophytic, colonizing intercellular spaces and vascular tissues of most plant organs without causing damage to the host. They promote plant growth possibly by fixing nitrogen and also by the production of plant hormones. Jamuna and Panneerselvam (2014) reported that co-inoculation of *Gluconacetobacter diazotrophicus* @ 10 kg ha^{-1} with AM fungi [(@ 25 kg ha^{-1}) + Azophos (@ 10 kg ha^{-1}) + 75% RDF produces maximum number of millable cane. Similar results were given by Shankaraiah and Nagaraju (2002) who also elucidated that the soil inoculation with *Azotobacter chrococcum* and *Azospirillum brasiliense* (@ 2.5 kg ha^{-1} each) gave higher jaggery yield in both main and ratton crop. Saini et al. (2006) also reported that inoculation of nitrogen fixing microbes like *Azospirillum, Azotobacter and Acetobacter* improves the economics of sugarcane crop to an extent of 20- 25% besides improving the residual nitrogen content of soil (Table 3). Similarly, phosphorus solubilising microorganisms viz., *Bacillus megstherium, B. poIymyxa, Pseudomonas striata, Aspergillus awamori* etc. bring improvement in P use efficiency of various phosphate fertilizers. The use of bio-fertilizers in ratoon crops is critical for maintaining soil health and increasing productivity.

Table 3: Contribution of microorganisms in biological N-fixation

S. No	*Crop/Plant*	*Associated organisms*	*Typical levels of nitrogen fixation (kg N/ha/yr)*
1.	***Symbiotic***		
	Legumes (nodulated)		
	Ipil iplil tree (*Leucena leucocephala)*	Bacteria (*Rhizobium*)	100-500
	Locust tree *(Robina spp.)*		75-200
	Alfalfa *(Medicago sativa)*		150-250
	Clover *(Trifolium pratense L.)*		100-150
	Lupine *(Lupinus)*		50-100

	Vetch *(Vicia vilbosa)*		50-150
	Bean *(Phaseolus vulgaris)*		30-50
	Lentil *(Lens)*		90-100
	Pea *(Pisum sativum)*		52-77
	Gram *(Cicer aeritinum)*		85-110
	Redgram (Cajanus cajan)		168-200
	Cowpea *(Vigna unguiculata)*	Bacteria (*Bradyrhizobium*)	50-100
	Peanut *(Arachis)*		40-80
	Soybean *(Glycine max L.)*		50-180
	Pigon pea *(Cajanus)*		150-280
	Kudzu *(Pueraria)*		100-140
	Greengram *(Vigna radiata)*		50-55
2.	***Non-symbiotic***		
	Sugarcane		
	Bacteria heterotrophs	*Azotobacter*, *Azospirillum* *Clostridium*, *Beijerinckia*	5-20
	Autotrophs	Cyanobacteria	20-200
	Endophytic and Colonizing	*Gluconacetobacter diazotrophicus-*	

4. Cropping system/intercropping

There have been several changes in cropping pattern in India and currently farmers opt towards crop diversification. Crop diversification in India is typically viewed as a shift from traditionally grown less remunerative crops to more remunerative crops. This acts as a powerful tool in minimizing the risks in farming as well as reducing nutrient mining from the soil (Chand and Chauhan, 2002). Among different cropping systems, pulse-based sugarcane cropping systems are environmentally sustainable as it requires lower amount of fertilizers, pesticides and irrigation due to their mutualism which enhances the overall productivity by increasing the yield of subsequent crops (Reddy, 2009). The N-fixed by *Rhizobium* is released within the soil, liable to contributes in improving soil fertility. The fixed N can at least partly reduce the N fertilizer requirement in the field during crop rotation. The carryover effect of N for succeeding crops maybe 60 to 120 kg/ha for berseem, 75 kg/ha for cluster bean, 35 to 60 kg/ha for fodder cowpea, 68 kg/ha for chickpea, 55kg/ha for black gram, 54 to 58 kg/ha for groundnut and 36 to 42 kg/ha for pigeon pea (Ghosh et al., 2007). Thus including legumes and fodder legumes as preceding or intercrops is an efficient cropping system towards sustainability. Now-a-days, inclusion of pulses, cereals, millets and oilseeds along with sugarcane in cropping system is practiced to ensure food security (Reddy and Suresh, 2009). Due to the legume's ability to release amino acids into the rhizosphere, leguminous intercrops can improve soil fertility. Given that sugarcane stays in the field for more than nine months following the harvest of the legumes, the N-fixed by the intercropped legumes may be made available to it during the current growing season. The addition of crop leftovers, which increase soil fertility after decomposition, is another way to increase soil fertility. There is a chance to reduce the amount of nitrogen used through fertilizer because intercropping adds a significant amount of nutrients. Wide row spacing in sugarcane will be a crucial agronomic factor in the future, particularly in emerging nations like India. In the furrow-irrigated raised-bed system (FIRBS), intercropping pulses including rajmash, chickpea, and lentil with sugarcane seeded in the fall works well to increase crop yields. Intercrops are sown in elevated beds beside the sugarcane, which is grown in furrows here. The technology offers great potential for improving agricultural output and input utilization effectiveness. At IISR Lucknow, intercropping French beans and autumn sugarcane has been lucrative (Singh et al., 2020). In terms of shot count in the grand growth stage, intercropping two rows of French beans (PDR-14) had a strikingly good impact on sugarcane growth. The system produced 1664 kg/ha of French beans, which gave the impression that it was highly lucrative. Chickpeas can be managed effectively with sugarcane planted in the autumn, which produced a 25% N economy (Lal and Singh 2004) Through intercropping pulse crops with sugarcane, resource use efficiencies (nitrogen use efficiency, weed control efficiency, water use efficiency, etc.) and land equivalent ratio could be enhanced. The best sugarcane equivalent yield was obtained by autumn sugarcane intercropped with two rows of lentils (DPL 15), receiving 150 kg N/ha in addition to *Azospirillum*, but it was comparable to the inadequate dose of 112.5 kg N/ha (Lal and Singh 2004). As intercrops with sugarcane, vegetables like potatoes, carrots, peas, and squash are excellent choices for cash crops since they grow easily, offer good yields, and fetch a better price in markets than cereals (Singh et al., 2013). Vegetable production and export from India have a strong future because of the rising annual demand for veggies. Additionally, these vegetable crops are suited for small and holdings' compensation, and their incorporation into conventional cropping systems might enhance the system's nutritional value because they are abundant in vitamins, minerals, and other health-promoting elements.

5. Inorganic fertilizers

Industrially manufactured substances (Urea, DAP, ammonium sulphate, muriate of potash, calcium ammonium nitrate, diammonium phosphate etc.) which contains essential plant nutrients in particular amounts and supplies nutrients when applied to the plants or soil. Fertilizers are typically classified into two major categories, according to the source. The first is an organic (natural) source, and the second is an inorganic source (mineral, synthetic, or synthetic or manmade). Inorganic fertilizers are the key component of INM supplies required amount of all the essential nutrients to plant through specific mineral fertilizers. Since the early 1990s, agricultural production for major food crops has been increasing or has even tended to decrease, whereas global food production needs to increase to more than 4 billion metric tonnes by 2050 to meet rapidly increasing population needs. Further increases in agricultural production, however, have been linked to negative effects on global warming, water scarcity, land degradation, erosion, and soil nutrient balance, as well as soil organic carbon depletion and subsequent soil runoff (Brisson et al., 2013). Agricultural practices account for the majority of these emissions. The massive increase in recent years is primarily due to the widespread use of synthetic fertilizers and pesticides, particularly in intensive agriculture (Peng et al., 2002). Thus, the use of chemical fertilizers, particularly nitrogen, phosphorus, and potassium (NPK), is a critical factor and the primary cause of environmental pollution and land erosion in some developing countries due to their long-term use. Furthermore, global consumption of synthetic fertilizers has increased by 49%, 19%, and 33%, respectively, for nitrogen, phosphorus, and potassium (Zhang et al., 2012). Some recent studies found that intensive use of synthetic fertilizers and pesticides did not result in a significant increase in yield. This could be due to a combination of factors, such as high nutrient losses through leaching, runoff, volatilization, releases, and immobilization, or low nutrient-use efficiency. Thus, the opposite trend are required and essential in developing an agriculture strategy plan to find a way that allows for higher yield production over long periods of time, encourages conservation of natural resources, minimizes ecological impacts, and promotes global climate change mitigation and adaptation, while also matching with other agricultural programmes aiming to increase production and ensure the environment. As a result, it is critical to seek out innovative practices that can guarantee higher yields while posing minimal risks to our environment. Thus, the INM technique can play wider role and continue to be the most effective way to achieve food security, improve environmental quality, and meet global food demand without negative consequences, particularly in countries with rapidly growing populations.

Optimizing Fertilizer Schedule in Sugarcane

Nutrient requirement of sugarcane

Sugarcane, a long-lasting crop with C4 metabolism yielded very heavy biomass as well as required a large amount of moisture, nutrients and sunlight for achieving its productivity. It has been estimated that 0.56–1.20 kg of N, 0.38–0.82 kg of P_2O_5, 1.00–2.50 kg of K_2O, 0.25–0.60 kg of Ca, 0.20–0.35 kg of Mg, 0.02–0.20 kg Na and 2.0–2.7 kg of SO_4 besides micronutrients removes for harvesting per tonne cane yield (Zende 1990). On average 208, 53, 280, 30, 3.4, 1.2, 0.6 and 0.2 kg N, P, K, S, Fe, Mn and Cu were removed from the soil to yield about 100 t cane ha^{-1} (Singh and Yadav 1996). However, nutrient requirement varies from soil to soil and varietal differences in nutrient use efficiency as determined by the amount of nutrients removed per tonne of cane harvested. King et al. (1953) attributed that the N content was reduced from 4.8 g kg^{-1} to 2.2 g kg^{-1} after 22 years of sugar cane cultivation in a virgin soil in Australia.

Fertilizer Recommendations

Since sugarcane is one of the biggest consumers of fertilizers and reacts well to fertilizers application, studies on sugarcane's nutritional needs and increasing fertilizer usage effectiveness have drawn interest from the start. Since fertilizer accounts for almost 50% of the increase in output, it is the most crucial part of an integrated nutrient supply system for sugarcane farming. The major sugarcane growing states in India have different fertilizer recommendations for sugarcane based on the soil type, length of the crop, yield level, and irrigation/rainfed conditions. The required doses fall between 70 and 400 kg N, 0 and 80 kg P_2O_5, and 0 and 141 kg K_2O ha^{-1} (Singh and Yadav 1996). In comparison to subtropical states, the recommended fertilizer doses are typically larger in tropical states. According to Saini et al. (2006), the application of fertilizers up to 400 kg N, 170 kg P, and 180–190 kg K ha^{-1} is advised for sugarcane depending on its lifespan and the soil's fertility level. Because it is a component of all amino acids, proteins, enzymes, and nucleic acids, nitrogen is crucial for the nutrition and physiology of sugarcane. This crop is better able to absorb nitrogen and potassium [3]. Because of the increased meristematic activity of the shoots due to the absorbed nitrogen, there is more tillering and leaf area index (LAI).

Saini et al. (2006) also reported that application of nutrients up to 400 kg N, 170 kg P and 180–190 kg K ha^{-1} is recommended for sugarcane depending upon its duration and fertility status of the soil. Nitrogen is important for the nutrition and physiology of sugarcane because, among other functions, it is a constituent of all amino acids, proteins, enzymes, and nucleic acids. Nitrogen and potassium are absorbed in greater amounts by this crop. The absorbed nitrogen increases the meristematic activity of shoots, resulting in greater tillering and leaf area index (LAI). Additionally, N lengthens the life of leaves. In addition to cultivar, crop age, and the availability of N and other elements in the soil solution, soil and climate conditions also affect sugarcane's ability to accumulate nitrogen. Around 1.2 kg t^{-1} of sugarcane shoots' natural matter is extracted for nitrogen. The production of roots and rhizomes is thought to account for about 30% of the total biomass of the entire sugarcane plant. An estimated 1.5 kg of nitrogen (N) is accumulated by the plant for every t of natural matter that a cane shoot accumulates. Therefore, for a system with as productivity >120 tons ha^{-1} of natural matter, the amount of N absorbed by the crop exceeds 180 kg ha^{-1}. In these systems, the use of nitrogen fertilization at doses ranging from 60 to 100 kg ha^{-1}.

Time of Fertilizer Application

The time of fertilizer application assumes great significance in maximizing the benefits from sugarcane cultivation. The highest quantity of nitrogen is absorbed within 90 DAP, according to van Dilewijn (1952). Therefore, nitrogen should be administered between 60-90 DAP for a crop that will last 12 to 14 months. Depending on the type of soil, nitrogen is delivered in two or three splits within 90 days, with sandy soils receiving three splits while loams and sandy loams receive nitrogen in two splits (Hunsigi 1993). Singh and Yadav (1996) found that applying nitrogen in two or three splits between 45 and 90 DAP improved sugarcane's ability to use nitrogen in tropical and subtropical environments. They advised applying nitrogen in three equal splits during planting, shortly after germination, and before the start of the monsoon season to maximize cane yield. A late supplemental N application is advantageous for a two-year crop or for regions with two wet seasons. With lower sucrose and higher glucose content in the seed cane, extending nitrogen administration up to 135 days had a positive impact on seed quality (Lakshmi et al. 2006). Delayed N application may result in late tiller production and prolongation of the maturity phase with greater accumulation of reducing sugars. The juice quality could suffer as a result. Both an excessive rate and a delayed application of N may result in quality loss. Studies done at the Tamil Nadu Agricultural University have shown that applying nitrogen too late has a negative impact on cane output as well as juice quality (Srinivasan 1995). Fertilizer Management in Ratoon crops follow the plant crop or the preceding ratoons on the same soil. The ratoon cane ability to absorb nutrients may also be hampered by the deficient soil physical conditions and relatively underdeveloped root systems. For ratoons to produce good yields, sufficient amounts of manures and fertilizers must be provided. Numerous studies have demonstrated the requirement for early fertilizer application to ratoon sugarcane. Nitrogenous fertilizers can be spread out over two or three split applications for ratoon crops. To guarantee there is enough nitrogen in the soil to overcome transient immobilization of nitrogen caused by microbial activity on the disintegrating stubbles, ⅓ to ½ the dose of nitrogen should be supplied immediately at the time of ratoon initiation. When starting the ratoons, the full amount of phosphorus should be administered along with the first dose of N (Verma 2002). More nitrogen is needed to produce one tonne of ratoon cane than in a plant crop. According to reports, plant cane has the highest recorded nutrient use efficiency, and it gets worse with each additional ratoon. Ratoon crop decreased ability to efficiently nutrients use is attributed due to imbalance in shoot-root ratio at juvenile stage, delayed shoot-root growth, and relatively ineffective stubble roots. From all the states that cultivate sugarcane, responses to increased levels of nitrogen application in the ratoon crop have been documented. Ratoon crops have been discovered to typically require 25–50% more nitrogen than plant cane. Tamil Nadu had the highest cane and sugar yields when 25% extra nitrogen was applied 5-7 days after ratoon initiation (Mahendran et al. 1995). In the case of ratoon sugarcane, yield response to nitrogen application at the required dose was observed to be 254 kg of cane per kg of nitrogen applied at Anakapalle, 215 kg at Kanpur, 160 kg at Shahjahanpur, 160 kg at Muzaffarnagar, 136 kg at Mandya, 120 kg at Lucknow, and 119 kg at Jalandhar (Verma 2002).

With an overall improvement in the quality of the resource base, integrated nutrient management holds considerable potential for addressing the expanding nutritional needs of intensive sugarcane production and maintaining productivity at greater levels. It contributes to enhancing and maintaining soil fertility and offers a strong foundation for agricultural production systems to adapt to changing needs. The physical, chemical and biological environment of soil must be maintained by the balanced use of organic, inorganic, and bio-fertilizers, which also provide the soil's microbial biomass with energy. By properly recycling agricultural leftovers and manufacturing wastes coupled with bio-fertilizers, it is possible to restore the nutrients that crops have used up while maintaining sugar output. As organic manures frequently have a significant aftereffect, suggestions must be made on a cropping system basis.

References

Abdel-Aziz , R. A. and Al-Barakah, F. N. (2005). Composting technology and impact of compost on soil biochemical Properties. Arab Gulf Journal of Scientific Research, vol. 23, 80–91.

Bharadwaj, K.K.R., and A.C. Gaur. (1985). Recycling of organic wastes. New Delhi: ICAR.

Chand, R., and Chauhan, S. (2002). Socio Economic Factors in Agricultural Diversification in India. Agricultural Situation in India. 58(11): 523-530.

Craft, C. M. and Nelson, E. B. (1996). "Microbial properties of composts that suppress damping-off and root rot of creeping bentgrass caused by *Pythium graminicola*," *Applied and Environmental Microbiology* 62:1550–1557.

FAO, "FAOSTAT (2012). FAO database—statistics division food and agriculture organization of the United Nations, Romehttp://faostat.fao.org/.

Gana, A.K. (2008). Effects of organic and inorganic fertilizers on sugarcane production. African Journal of General Agriculture 4 (1): 55–59.

Gangwar, K.S., and Sharma. S.K. (1997). Integrated nutrient management in summer-planted sugarcane on cultivator's fields. Indian Journal of Agronomy 42: 181–183.

Ghosh, P.K., Bandyopadhyay, K.K., Wanjari, R.H., Manna, M.C.,Misra, A.K., Mohanty, M., Subba Rao, A. (2007). Legume effect for enhancing productivity and nutrient use-efficiencyin major cropping systems-an Indian perspective: a review. Journal of Sustainable Agriculture. 30(1): 59-86.

Hari, K., and Srinivasan, T. R. (2005). Response of sugarcane varieties to application of nitrogen fixing bacteria under different nitrogen levels. Sugar Tech, 7(2&3): 28-31.

Hunsigi, G. (1993). Production of sugarcane—theory and practice. Berlin: Springer-Verlag.
Jamuna, E. and Panneerselvam, R. (2014). Studies on the soil nutrient dynamics and PGPR populationin sugarcane cultivated soil supplemented with bio-inoculants and its effect on yield parameters. Proc. ofthe Natl. Sem. on Recent Advances and Challenges in Sugarcane Research, 23-24.
King, N.J., Mungomery, R.W. and Hughes. C.G. (1953). Manual of cane growing. Australian Agricultural and Livestock series. Sydney, Australia: Angus and Robertson.
Lakshmi, B.M., Chitkala Devi, T. and Raju. D.V.N. (2006). Nitrogen management in sugarcane seed crop. Sugar Tech 8 (1): 91–94.
Menhi, L. and Singh. A.K. (2004). *Technology package for sugarcane-based intercropping systems*. Lucknow: Published by Indian Institute of Sugarcane Research.
Mahajan A, Choudhary, A.K., and Bhagat, R.M. (2002) Integrated plant nutrient management (IPNM) system for sustainability in cereal based cropping system. *Indian Farmers' Digest* **35**(**7**): 29–32.
Mahendran, S., Karamathullah, J., Porpavai, S. and Ayyamperumal. A. (1995). Effect of planting systems and ratoon management on the yield and quality of ratoon cane. Bharatiya Sugar 22 (1): 123–127.
Manimaran, S., Kalyanasundaram, D., Ramesh, S. and Sivakumar, K. (2009). Maximizing sugarcane yield through efficient planting methods and nutrient management practices. Sugar Tech 11 (4): 395–397.
Narayanamoorthy, A. (2005). Economics of Drip Irrigation in Sugarcane Cultivation: Case Study of a Farmer from Tamil Nadu. Indian Journal of Agricultural Economics, 60(2): 235-248.
Prasad, P. V. V., Satyanarayana, V., Murthy, V. R. K., and Boote, K. J. 2002. Maximizing yields in rice-groundnut cropping sequence through integrated nutrient management," *Field Crops Research* 75: 9–21, 2002.
Ramesh, T., Chinnusamy, C. and Jayanthi. C. (2002). Integrated nitrogen and phosphorus management on productivity and profitability of early planted sugarcane (cv. Co 86032). Indian Sugar 52 (2): 99–104.
Reddy, B.N. and Suresh, G. (2009). Crop Diversification with OilseedCrops for Maximizing Productivity, Profitability and Resource Conservation. Indian Journal of Agronomy. 54(2): 206-214.
Saini S. K., Singh, D., Bhatnagar, A. (2006). Integrated plant nutrient management in sugarcane based cropping system. In: Souvenir, 26th All India Workshop of AICRP on Sugarcane, 60–63. Pantnagar, Uttaranchal: GBPUAT.
Saini, S.K., Singh, D., and Bhatnagar, A. (2006). Integrated plant nutrient management in sugarcane based cropping system. In Souvenir, 26th all India workshop of AICRP on sugarcane, 60–63. Pantnagar, Uttaranchal: GBPUAT.
Selim, M. (2018). Potential role of cropping system and integrated nutrient management on nutrients uptake and utilization by maize grown in calcareous soil," *Egyptian Journal of Agronomy* 40: 297–312.
Selim, M. M., and Al-Owied, A.J. (2017). Genotypic responses of pearl millet to integrated nutrient management, *Bioscience Research* 14: 156–169.
Shankaraiah, C. and Nagaraju, M. S. (2002). Economical and eco-friendly practices for sustainable sugarcane. Cooperative Sugar, 33(8): 647-653.
Shankaraiah, C., Hunsigi, G. and Nagaraju. M.S. (2000). Effect of levels and sources of phosphorus and phosphate solubilizing microorganisms on growth, yield and quality of sugarcane. Sugar Tech 2 (1–2): 23–28.
Singh, A.K., Pathak, A.D. Srivastava, T.K., Singh, R.K., Singh, A.K., Singh, A.K., Ekta Singh, Singh, R.K., Sharma, A.K. and. Rai Singh. M.M.S.P. (2020). Sugarcane based integrated farming system models for enhancing farmers' income and livelihoods. *Indian Farming* 70 (05): 02–06.
Singh, G.B., and Yadav, D.V. (1996). Plant nutrient supply needs, efficiency and policy issues for sugarcane for the years 2000–2005. In Proceedings of symposium on plant nutrient supply needs, efficiency and policy issues: 2000–2025, ed. J.S. Kanwar and J.C. Katyal, 169–181. New Delhi, India: National Academy of Agricultural Sciences.

Singh, R.P., Padmaja, P., Solankey, S.S., Antra, Chatterjee. (2013). Cropping Systems in Vegetables. Book: Olericulture-Fundamental of Vegetable Production. 1: 347-373.

Srinivasan, T.R. (1995). Crop production technologies I. In Sugarcane production manual, ed. K.C. Alexander and S. Arulraj, 26–42. Coimbatore: Sugarcane Breeding Institute.

Srivastava, T.K., Singh, K.P., Lal, M., Suman, A. and Kumar, P. (2008). Productivity and profitability of sugarcane (*Saccharum spp*. complex hybrid) in relation to organic nutrition under different cropping systems. Indian Journal of Agronomy 53 (4): 310–313.

Suman, A., Singh, K. P., Singh, P. and Yadav, R. L. (2009). Carbon input, loss and storage in sub-tropical Indian Inceptisol under multi ratooning sugarcane. Soil and Tillage Research, 104: 221-226.

Thakur, S.K., Jha, C.K., Kumari, G. and Singh, V.P. (2010). Effect of trichoderma inoculated trash, nitrogen level and biofertilizer on performance of sugarcane (Saccharum officinarum) in calcareous soils of Bihar. Indian Journal of Agronomy 55 (4): 308–311.

Timsina, J. Can organic materials supply enough nutrients to achieve food security? J. Agric. Forest. Univ. 2018, 2, 9–21.

van Dillewijn, C. (1952). Botany of sugarcane. Waltham, USA: Chronica Botanica Co.

Verma, R.S. (2002). Sugarcane ratoon management. Lucknow, India: International Book Distributing Co.

Yadav, D.V. (1995). Recycling of sugar. Factory pressmud in agriculture. In Recycling of crop, animal, human and industrial wastes in agriculture, ed. H.L.S. Tandan. New Delhi: Fertilizer Development and Consultation Organization.

Yadav, D.V., Singh, T. and Srivatsava, A.K. (1987). Recycling of nutrients in trash with N for higher cane yields. Biological Wastes 20: 133–141.

Yadav, R. L. (2008). My journey in changing facets of agronomic research during three decades of green revolution in India. Indian Journal of Agronomy, 53(4): 245-254.

Yadav, R.L. (2008). My journey in changing facets of agronomic research during three decades of green revolution in India. Indian Journal of Agronomy 53 (4): 245–254.

Yu, Y., Xue, L., and Yang, L. (2014). Winter legumes in rice crop rotations reduces nitrogen loss, and improves rice yield and soil nitrogen supply. Agronomy for Sustainable Development 34, 633–640.

Zende, G.K. (1990). Soil fertility management for higher sugar and sugarcane production. In Recent advances in sugarcane, ed. P.N. Rao, 99–200. Vuyyuru, Andhra Pradesh: KCP Ltd.

Chapter No. 21: Role of micronutrients in improving sugarcane yield and sugar recovery

Jagannath Pathak[1],Richa Raghuvanshi[2],Shivam Singh[3], Amar Singh Gaur[4]& Deepak Prajapati[4]
Banda University of Agriculture and Technology, Banda (U.P.) 210001
Department of Soil Science and Agricultural Chemistry
Corresponding Author Email: jagannathpathak@yahoo.in

Sugarcane (*Saccharumofficinarum* L.) is a sustainable agricultural resource that produces sugar, ethanol, manure and fiber. It is one of the world's most important commercial sugar crops. It is a key cash crop, which contributes greatly to the economic prosperity of farmers around the world. Crop output per hectare must be raised to meet the needs of an ever-growing population, with the possibility of developing cultivable land in remote locations. Even though the present cultivars have a high production potential, yet more could be achieved with the use of balanced fertilizers. Soil micronutrients deficiencies are one of the yield-limiting variables. Organic matter depletion and micronutrient shortages were caused by intensive farming, mono-cropping without appropriate crop rotation and the adoption of high-yielding hybrid varieties. Various soil problems such as salinity and an abundance of carbonates and bicarbonates worsen micronutrient deficits. Aside from these aspects, a lack of understanding among farmers about crop micronutrient requirements is another major cause of low yields. For best sugarcane growth and development, an optimum supply of micronutrients is required. These elements, though in smaller amounts, are just as vital for plant development as phosphorus, potassium and nitrogen. Furthermore, a deficiency of micronutrients in both the soil and the plants reduces agricultural productivity. Micronutrient deficiency negatively affects crop yield and quality, can cause a widespread infestation of a variety of diseases and pests, and can cause low nutrient use efficiency. Micronutrient requirements for sugarcane vary depending on soil texture and local climatic zones. Micronutrient deficiency in sugarcane is evident under light-textured, calcareous, and heavily farmed soils.

---

1. Professor &Head, Department of Soil Science and Agricultural Chemistry, BUAT, Banda
2. P.G. Student, Department of Soil Science and Agricultural Chemistry, BUAT, Banda
3. Ph. D. Student, Department of Soil Science and Agricultural Chemistry, SVBPUAT, Meerut
4. Ph.D. Student, Department of Soil Science and Agricultural Chemistry, BUAT, Banda

Plant Nutrients

The normal green plant is autotrophic that means it can synthesis all its organic substances, provided it is supplied with all the inorganic elements and growth under normal condition. The nutrition of green plant is therefore, solely inorganic. It is in fact commonly called mineral nutrient. Elements absorbed from the soil by the roots are generally known as plant nutrient or mineral nutrients.

Criteria of essentially of an element

Arnon&Stout (1939) proposed three criteria for the essentiality of an element.

a) In the absence of an element, it is not possible for plant to complete its vegetative or reproductive cycle (Lifecycle).
b) The role played by an element is specific and it cannot be replaced by any other element (deficiency symptom/disease can be cured by the supply of the particular element).
c) The element is directly involved in nutrient of the plant.

Essential element for plants

Plants contain small amount of 90 or more elements, only 17 of which are known to be essential to plants. These elements are C, H, O, N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, Mo, B, Cl& Ni.

Major/macro nutrients

Those absorbed in large amount from soil and fertilizers are known as macro nutrients which are; C, H, O, N, P, K, Ca, Mg & S

Basic Nutrients;C, H & O

Primary nutrients; N, P& K
Secondary Nutrients;Ca, Mg & S

Minor / micro nutrients / trace elements

Those absorbed in lesser quantities from soil and fertilizers are known as micro nutrients which are; Fe, Mn, Zn, Cu, Mo, B, Cl& Ni.

Classification of plant nutrient on the basis of mobility in plant

Mobile Nutrients	**Partially mobile**	**Immobile Nutrients**
Chlorine	Zinc	Calcium
	Copper	Boron
	Manganese	
	Molybdenum	

Ideal concentrations of Micronutrients in plants

Elements	**Concentration (mg kg^{-1})**	**Elements**	**Concentration (mg kg^{-1})**
Zinc	20	Chlorine	100
Copper	6	Iron	100
Molybdenum	0.1	Manganese	50
Nickel	0.1	Boron	20

GENERAL FUNCTIONS OF MICRONUTRIENTS

Iron (Fe)

1) helps in chlorophyll formation
2) Acts as oxygen – carrier in oxidation – reduction reaction
3) Helps in protein synthesis and servedin metabolic reactions
4) Iron is a constituent of enzyme systems and so it helps for carrying out different enzymatic reactions in plant like, cytochrome oxidase, Catalase. Peroxidase, Acotinase and Nitrogenase.

Manganese (Mn)

1) Acts as a catalyst in oxidation – reduction reaction
2) Acts as an activator of many enzymes
3) Helps in chlorophyll synthesis
4) Mn influences auxin levels in plants and high concentration of MN favour the breakdown of IndoleAcetic Acid (IAA).

Copper (Cu)

1) Help in oxidation- reduction reaction
2) It is constituent of certain protein.
3) Cu helps in the utilization of iron during chlorophyll synthesis. Lack of Cu causes iron to accumulate in the nodes of plants.
4) It also acts as electron carrier in enzymes which bring about oxidation-reduction reactions in plants.

Molybdenum (Mo)

1) helps in the fixation of atmospheric nitrogen in the roots of legume by nodule bacteria
2) Helps in protein synthesis.
3) It is an essential component of the major enzyme nitrate reductase in plants
4) MO is also structural component of nitrogenase enzyme.

Chlorine (Cl)

1) Essential for the photosynthesis process
2) Keeps osmatic pressure normal in cell sap
3) Encourages growth in cabbage carrot lettuce& wheat

Boron (B)

1. Helps in the uptake of calcium
2. Encourage efficient utilization of calcium in plant
3. Helps in protein synthesis.
4. It acts as a regulator of K/Ca ratio in the plant
5. Boron is necessary for proper pollination and fruit or seed setting
6. It is necessary for the translocation of sugars starches, phosphorus etc.
7. It helps in the absorption of nitrogen
8. Boron regulates carbohydrate metabolism.

Zinc (Zn)

1. ZN is associated with water uptake and water relations in the plant
2. It is a constituent of a number of enzymes e.g. Carbonic Anhydrase (CA), alcohol dehydrogenase and various peptidases.
3. Helps in the formation of growth hormones (auxins)
4. Enhances heat and frost resistance of plant
5. Affects the uptake of phosphorus by plants
6. Acts as a catalyst in chlorophyll formation
7. Zn is helpful in reproduction of certain plants.
8. Zn also stabilizes ribosomal fractions.

Nickel (Ni)

1. Ni is required for the enzyme urease to break down urea to liberate the nitrogen into a usable form for plants.
2. Ni is required for iron absorption.
3. Seeds need nickel in order to germinate and grow.
4. Available to plant as Ni^{2+}.

DEFICIENCY SYMPTOMS OF MICRONUTRIENTS

Copper (Cu)

1. In tobacco and potato, the young leaves remain permanently wilted
2. The tip of leave may turn white

Irion (Fe)

1. The new leaves show chlorosis in between veins the veins remain green

Boron (B)

1. The leaves thicken and margins roll upward
2. The leaf tip and margin of older leaves die prematurely
3. Terminal bud dies
4. The younger leaves are dwarfed
5. Diseases due to boron deficiency are top rot of tobacco heart of sugar beet, lack of head formation in cauliflower

Manganese (Mn)

1. Small brown patches develop on leaves (potato)
2. Incotton, the upper leaves become yellow wish –grey while veins remain green

Molybdenum (Mo)

1. Curling of leaves
2. Petiole of leaves remain intact but shedding of margin and other parts of leaves

Chlorine (Cl)

Yellowing of leaves (whole plant)

Zinc (Zn)

1. Growth stunted
2. Reddish – brown spots appear on lower leaves
3. Later on the whole leaf become rusty brown colour

4. The midrib of the younger leaves, especially at the base, become chlorotic

Nickel (Ni)

1. Dwarfing of foliage is a primary indicator of Ni deficiency.
2. Young nickel deficient leaflets also exhibit considerably more reddish pigmentation than nickel sufficient seedlings.
3. As leaflets aged, nickel deficient leaflets become darker green, thicker, and remained much smaller in leaf area than nickel sufficient leaflets.
4. Ni deficient, plants may fail to produce.

CONTROL OF MICRONUTRIENTS DEFICIENCY

A. Management for Zn

- ❖ The efficiency of sparingly soluble Zn sources such as ZnO, $ZnCO_3$, Zn frits and highly soluble $ZnSO_4$ $7H_2O$ source was at par in fine textured high Zn fixing soils. However, in coarse textured soils, soluble zinc sources proved better.
- ❖ Micronutrient blended macronutrients sources such as zincatedurea,zincated super and boronated super were found inferior to zinc sulphate or chelates in highly Zn or B deficient soil.
- ❖ For root dipping and seed coating before transplanting, Zinc oxide and Zinc phosphate were better sources than zinc sulphate.

B. Management for Fe

- ❖ Foliar sprays of 1-2% un-neutralized ferrous sulphate solution three to four times efficiently correct the iron chlorosis. Soil application of Fe is inferior and less profitable than foliar sprays.
- ❖ Iron chelates are more efficient than inorganic sources in combating Fe deficiency but farmers do not prefer to use chelates due to high cost except in cash crops.
- ❖ Iron deficiency in rice seedling can be effectively controlled by raising them under puddled nursery beds supplemented with requisite dose of FYM or compost. Ponding of water in nursery beds during dry spell is essential to mitigate Fe chlorosis.
- ❖ Green manuring, use of FYM and compost helped in mobilization of native soil iron during its decomposition. Combination of green manure (GM) or organic manures with foliar spray of un-neutralized 1% $FeSO_4$. $7H_2O$ solution is more effective in increasing crop yield than either GM or spray of sulphate solution alone.

C. Management for Mn

- ❖ Three to four foliar spray of 0.5-1.0% $MnSO_4$ solution is more efficient and economical than basal application for enhancing wheat yield in sandy soils.
- ❖ Durum wheat genotypes are more susceptible to Mn deficiency than aestivum wheat.

D. Management for B

- ❖ Borax, granubor& boric acid proved equally efficient in combating B deficiency in crops.
- ❖ Basal application of B proved superior than foliar sprays. Sprays controlled B deficiency in standing crops but less effectively.

E. Management for Mo

- ❖ Ammonium molybdate and sodium molybdate are common sources of Mo to rectify Mo deficiency in soils and crops.
- ❖ Vegetables, pulses and oilseeds are more responsive to Mo application than cereals in Mo deficient soils.
- ❖ Application of 0.4-0.5 kg Mo ha^{-1} is sufficient to meet the Mo requirement of the crops in Mo deficient red acid soils. Mixing of ammonium or sodium molybdate with phosphatic fertilizers proved very effective to increase Mo use efficiency.

F. Management for Cu

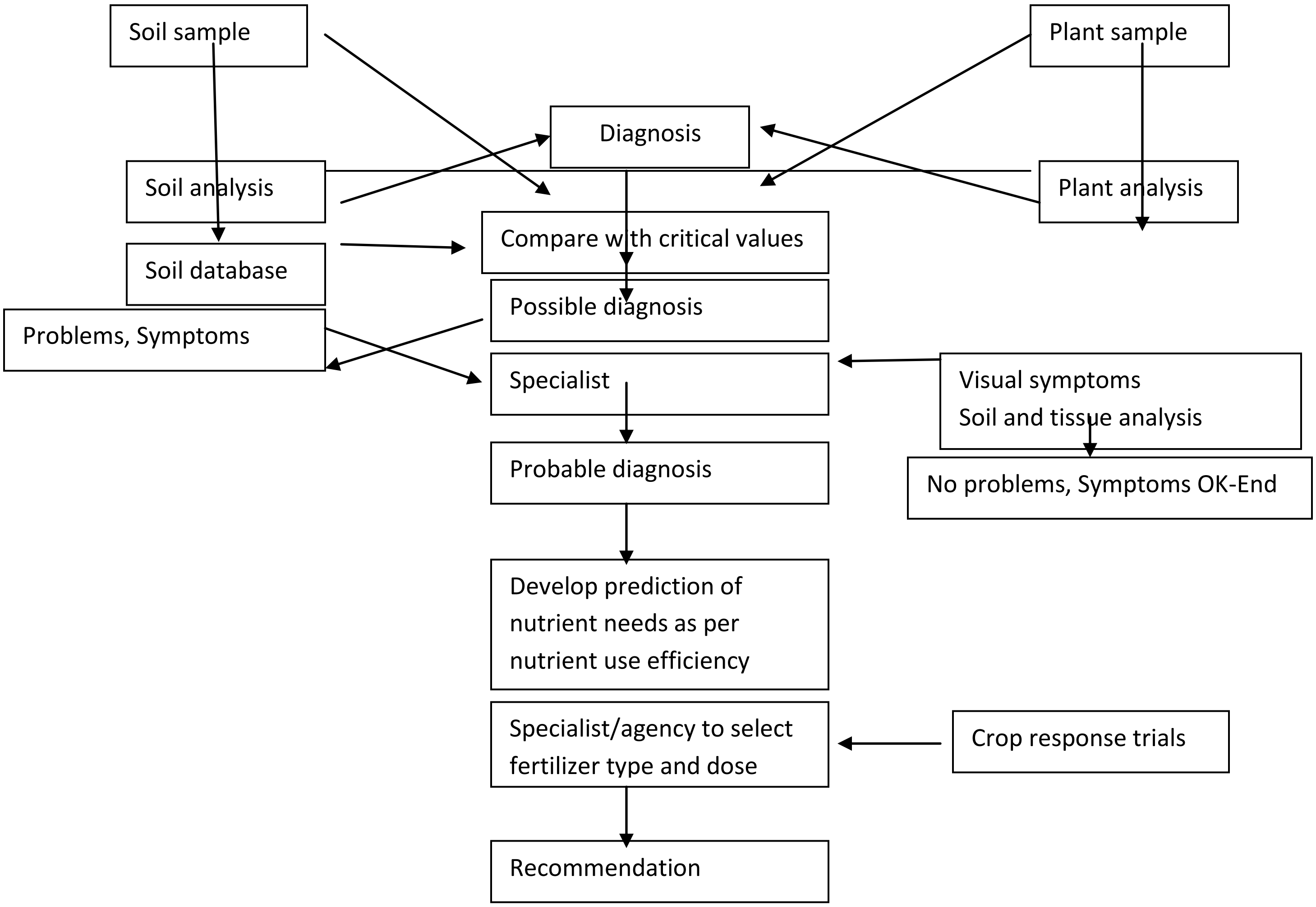
- ❖ Copper sulphate is commonly used for the correction of deficiency of copper. It may be applied in soil or used as foliar spray. Copper sulphate dissolve in water with calcium hydroxide for spraying otherwise $CuSo_4$ injures the foliage.

Nutrient contents of some micronutrient fertilizers

S. No.	Materials	Element/Forms	Contents (%)
1.	Zinc sulphate (heptahydrate)	Zn	21.0
2.	Manganese sulphate	Mn	30.5
3.	Ammonium molybdate	Mo	52.0
4.	Borax	B	10.5
5.	Boric acid	B	17.0
6.	Copper sulphate	Cu	24.0
7.	Ferrous sulphate	total Fe	19.5
		Fe^{++}	19.0
		Fe^{+++}	0.5
8.	Chelated Zn (as EDTA)	Zn	12.0
9.	Chelated Fe (as EDTA)	Fe	12.0
10.	Sodium molybdate	Mo	39.0
11.	Zinc Sulphte (mono-hydrate)	Zn	33.0
12.	Granubor II Borax pentahydrate	B	15.0

Name of diseases caused by micronutrient deficiencies

NAME OF DISEASE	NUTRIENT
Take – all disease of wheat	Cl
Brown or black heart of sugar beets	B
Internal cork of apple	B
Lumplyfruit disease of Citrus & Papaya	B
Gummy disease of Albedo	B
Hollow hearts of Peanuts	B
Pith in hollow stem: Cabbage&cauliflower	B
Browning (brown rot or red rot)- hollow stem of cauliflower	B
Gummosis or die back in citrus	B
Grey speck of oats	Mn
Marsh spot of peas	Mn
Speckled yellow of sugar beets	Mn
Mottled leaves of citrus	Mn
Die- back of corn/ citrus	Cu
Rosetting disease of many plants	Zn
White bud of corn & sorghum	Zn
Little leaf of cotton	Zn
Die- back of citrus	Zn
Whiptail of cauliflower	Mo
Die- back or blisters on young branches/leaves Is also known as exanthema of citrus	Cu
Peach leaf of citrus	Cu
Khaira disease of rice	Zn



Flow diagram for developing recommendations for micronutrients

Research findings related to the effect of micronutrient on sugarcane yield and other properties.

Effect of boron on yield and quality of sugarcane

A field experiment was conducted at sugarcane research institute, Shahjahanpur (U.P) to test the seven doses of boron @ 0.5 to 3.5 ppm alongwith control. Results indicated that application of boron@ 1.5 ppm was found effective in gradual increase in yield. The cane yield was 9.35% higher in comparison to control, but data did not reach to level of significance. Under this treatment, the sucrose percent of juice was significantly increased from 15.44 to 15.95 at 12th month crop age which was 3.30% higher over the control. The critical level of boron in plant was computed in 6.5 ppm which showed that below this level, the cane yield and sucrosepercent injuicewill be affected adversely.

Effect of Caneplex on growth, yield and quality of sugarcane

Efficacy of Caneplex, a micronutrient combination of calcium, magnesium, molybdenum, manganese, zinc, copper, iron and sulphur, was tested during spring planting season in three consecutive years-2005-06, 2006–07 and 2007–08, on growth, yield and quality of sugarcane at the research farm of UP. Council of Sugarcane Research, Shahjahanpur (UP.)using the variety CoS97264. Application of Caneplex enhanced the germination, shoot population, NMC and consequently the yield of sugarcane. The results showed that the germination was significantly increased by the application of Caneplex @ 25 or 30kg/ha as basal whereas top dressing of the same doses did not affect the germination significantly. Application of Caneplex @ 25 or 30kg/ha as basal followed by the same amount as top dressing showed significant increase in germination by about 4–5% over untreated control. Application of Caneplex @ 25 or 30 kg/ha as basal followed by the same amount of Caneplex as top dressing increased the shoot population and number of mill able canes significantly as compared to control. The cane yield was marginally increased due to the application of Caneplex as basal or top dressing alone, the basal application being slightly better. A significant increase in cane yield was recorded after application of Caneplex @ 25 or 30 kg/ha as basal followed by the same amount of Caneplex as top dressing. Sucrose percent in juice at 10th month crop age was not affected significantly by the application of Caneplex at any dose under various treatments. Conclusively, the application of Caneplex @ 25 or 30 kg/ha as basal followed by the same amount of Caneplex as top dressing increased the cane yield significantly.

Sugarcane productivity as a function of Zinc dose and application method

Zinc exhibits intense participation in the enzymatic systems that regulate the initial stages of tillering and plant growth, and it is vital for root system development. Thus, in the initial phase of plant development, Zn tends to accumulate in the roots, absorbed as Zn^{++}, but translocation to the shoots is small. In addition, the root absorption of Zn may be impaired due to the adsorptive action exerted by soil particles. It may explain the lack of response to Zn fertilization in the furrow concerning the number of tillers at 145 DAT since the sugarcane plants were in their youthful stage. Regarding the tillering phase, initially, there is an increase in the number of tillers until approximately 180 DAP, and some varieties can produce more than 25 tillers per clump. However, this number tends to decrease until it stabilizes. Thus, there is an intermediate phase, marked by severe tiller death, until reaching the final phase when the number of tillers is stabilized. However, foliar fertilization at doses of 260 and 330 g ha^{-1} contributed to the maintenance of the number of tillers beyond 180 DAP since these doses resulted in an increased number of tillers at 206 DAP, confirming the efficiency of foliar fertilization compared to furrow fertilization and the proper positioning of foliar application, preparing the plant for its grand growth phase of development. At 206 DAP, the crop was at the beginning of its intense growth phase of development, and Zn contributed to maintaining tillering, as well as the stalk growth, in terms of length, reflecting the intense division, differentiation, cell elongation, and an exponential increase in the shoot dry matter mass.

References:

De Almeida Silva, M., Germino, G.H., De Holanda, L.A., Oliveira, L.C., Santos, H.L. and Sartori, M.M.P. (2022).Sugarcane Productivity as a Function of Zinc Dose and Application Method. *Agriculture*, *12*(11):1-12.

Sahai, V.N. (2015). Fundamentals of Soil.Kalyani Publishers, New Delhi., pp1-243.

Shukla, A.K., Behera,S.K., SubbaRao, A. and Singh, A.K. (2012).Stat- wise micro and secondary nutrients recommendations for different crops and cropping systems.Research Bulletin No.1/2012. All India Coordinated Research Project of Micro and Secondary Nutrients and Pollutant Elements in Soils and Plants. Indian Institute of Soil science, Bhopal.,pp 1-40.

Singh, A., Gupta, R.K. and Sharma, B.L. (2015).Effect of Boron on the yield and quality of sugarcane. *Agrica***,** *4*(1):20-24.

Singh, S.P., Johari, D. and Sharma, B.L. (2015).Effect of Caneplex on Growth, Yield and Quality of Sugarcane. *Agrica*,*4*(1):38-40.

Chapter No. 22: Integrated weed management in sugarcane

V P Singh
Principal Scientist (Agronomy)
ICAR-Indian Institute of Sugarcane Research, Lucknow

Despite the significant achievements in food grain production since independence, Indian agriculture continues to face serious challenges from ever increasing population. Our population has crossed 1 billion and is expected to be 1.5 billions by 2025 and more than 2 billions by the end of this century. India would need about 300 million tonnes of food grains by 2020 i.e., an increase of about 5 million tonnes per year in the next 20 years. Weeds are a component of our crop production systems. They continually interfere with profitable crop production by competing with crop plants for nutrients, soil moisture and solar radiation. In addition, weeds can harbour insects and disease pests and noxious weeds and weed seeds can greatly undermine crop quality. The cultivation of dwarf high yielding crop varieties responsive to fertilizers and irrigation and the new intensive cropping systems have aggravated the problem of weeds. In general, impact of weeds on crop yields varies from high input to low input crop production systems.

"A weed is a plant growing where it is not desired" is a definition given by Jethro Tull (1731) when he was writing a book on 'Horse Hoeing Husbandry'. Weeds are unwanted undesirable plants which interfere with the utilization of land and water resources and thus adversely affect human welfare. They can also be referred as plants growing out of place. Conclusively it can be defined as "*Weeds are plants growing in places where they are not desired. They interfere with our activities be it a crop field, play ground, or a pond. In commercial angle, they involve expenditure on control and reduce profit. However some plants termed as "weed" are beneficial to mankind. They find use in ayurvedic medicine, animal feed, compost making etc, and are rich source of genes with resistance to biotic and abiotic stresses*".

In crop lands and forest, weeds compare with the beneficial and desired vegetation reducing the yield and quality of produce. Undesirable vegetation also flourishes in aquatic system, forestry and noncropped areas like industrial sites, road sites, railways and air fields, land escapes, water tanks, water base etc. Thus plants may be weeds in a particular situation. It has been estimated that of all the total annual loss of agricultural produce from various pest in India, weeds account for nearly 25-30% of the total damage caused by total pests.

1. Major Weeds

The magnitude of weed problem varies with the agro-ecological conditions and the level of management. Pulse and oilseed crops grown in rainy season are more heavily infested with weeds than the crops grown in winter and spring season. *Trianthemaportulacastrum* is the most serious problem during monsoon and spring/summer season. The major weeds associated with sugarcane are listed in Table-1.

Table - 1: Major weeds of Sugarcane

Monocot weeds			
1	*Dactylocteniumaegyptium*(L.) Willd.	Crowfoot grass	Poaceae
2	*Digitariasanguinalis* (L.) Scop.	Larg crab grass	Poaceae
3	*Cynodondactylon* (L.) Pers.	Bermuda grass	Poaceae
3	*Echinochloacolona* (L.) Link	Jungle rice	Poaceae
4	*Eleusineindica*(L.) Gaertn.	Goose grass	Poaceae
5	*Eragrostistenella*(L.)	Japanese lovegrass	Poaceae
6	*Brachiariarepens* L.	Running grass	Poaceae
7	*Commelinabenghalensis*L.	Dayflower	Commelinaceae

8	*Sorghum halepense*	Johnson grass	Baru
Dicot weeds			
1	*Achyranthusindica*	Prickly chaff flower	Amaranthaceae
2	*Euphorbiahirta* L.	Garden spurge	Euphorbiaceae
3	*Amaranthusviridis*L.	Pig weed	Amaranthaceae
4	*Trianthemaportulacastrum* L.	Carpet weed	Aizoaceae
5	*Anagallisarvensis*L.	Scarlet pimpernel	Primulaceae
6	*Medicagodenticulata* L.	Bur clover	Leguminosae
7	*Oxalis corniculata* L.	Wood sorrel	Oxalidaceae
8	*Xanthium strumarium* L.	Burweed, Common cocklebur	Asteraceae
9	*Corchorusacutangulus* L.	Pod rush	Tiliaceae
10	*Gynandropsispentaphylla* DC.	Caravella, Wild spider flower	Amaranthaceae
11	*Leucas aspera* (Wild) Link	-	Lamiaceae
12	*Tridaxprocumbens* L.	Coarbuttons	Asteraceae
13	*Bidenspilosa* L.	Beggar-ticks.	Asteraceae
14	*Convolvulus arvensis*	Field bind weed	Convolvulaceae
15	*Commelinabenghalensis*	Tropical spider wort	Commelanaceae
16	*Ageratum conyzoides*	Bill goat weed	Compositae
17	*Celosia argentea*	White cock;s comb	Amaranthaceae
18	*Ipomoea haderacea*	Morning glory	Convolvulaceae
19	*Boerhaaviadiffusa*	Hig weed	Nyctanginaceae
20	*Eclipta alba*	False daisy	Compositae
21	*Vicia sativa*	Common vetch	Leguminosae
Sedges			
1	*Cyperusrotundus*L.	Purple Nut grass	Cyperaceae
2	*Cyperusesculentus*L.	Yellow Nut grass	Cyperaceae
Parasiticweed			
2	*Strigasp*	Witch weed	Scrophulaceae

2. Critical Period of Crop-Weed Competition

One of the major principles of crop-weed competition is that the plants establishing in the soil earlier try to smother another species of plant coming at later stages. Pulse and oil seed crops are very slow in seedling growth stage. In addition, they are row spaced and do not have much canopy in terms of branching and leaf size during initial growth to stand up to weed competition.Emergence of weeds in sugarcane crop begins before germination of crop, leading to severe competition. In rainy season, weeds emerge in succession almost throughout the crop season because of favourable environmental conditions and frequent rains. The degree of yield loss depends on the nature of weeds and the stage and duration of weed crop competition. Therefore, the weed free requirement of 60-120 days after planting is of utmost importance to make weed management practices more effective and economical.

3. Principles of weed control:

Weed control is the process of limiting weed infestations so that crops could be grown profitably and other activities of man conducted efficiently. The aim of weed control is to manage the vegetation on land and in water bodies in such a way as will encourage the growth of plants beneficial to our interests and will suppress the remaining unwanted plants. However indiscriminate application of control measures against plants is not the objective of weed control In variance with weed control, weed eradication is complete removal of all live plant parts and seeds from an area. It is an expensive adventure since it costs more than that of the land. Besides complete elimination of all the common weeds is not warranted since many of them are useful. Hence eradication of some noxious weeds such as *Cuscuta*, *Lantana*, *Striga*etc.

is needed. Eradication should start when the weeds are small and limited in growth but not when the weed is well grown and has invaded larger areas.

Hence the concept of weed management instead of control is important. While weed control aims at putting down the weeds already present, weed management is a system approach whereby whole land use planning is done in advance to minimize the very invasion of weeds in aggressive form and give crop plants a strong competitive advantage over the latter. The systems approach is called *integrated weed management* (IWM). Concerted efforts towards its widespread adoption and understanding of the principles behind the practices were triggered by 1) build-up of previously minor species (perennials) into dominant levels because of repeated use of the same methods to control existing dominant species (annuals); 2) increasing concern over pesticide effects on human health and the environment; and more recently 3) development of herbicide resistant weeds. IWM is defined as the management system of weed populations aiming to keep infestation levels below those causing economic injury by combining any two or more of preventive, cultural, chemical, or biological methods. The definition implies that IWM is largely a decision making process involving 1) when to apply control measures with use of critical thresholds and 2) what combinations will provide best control at greatest profits. The long-term objectives of IWM are 1) to avoid or reduce anyadverse environmental impact of control methodsand 2) prevent build-up of any one weed species.The general pre-requisites of a successful weedmanagement programme are as follows.

- One must gain knowledge of the biology ofweeds under attack before choosing a systemfor their control.
- The nature of weed problems must be surveyedin the target area.
- Weed control measures must be planned for thewhole farm and not just against weeds in afield.
- Weed control system must follow upprogramme of weed prevention measures.

4.0 Integrated weed management technique (IWM):

All crop management practices starting from field preparation to harvesting have implications on weed competition. Weed removal at farm level in India is largely restricted to mechanical and cultural methods. Although the farmers are aware of weed problems, they err in their assessment of potential damage the weed may cause mainly because of their fatalistic attitude towards weeds. The weed control they adopt is often inadequate and untimely. Weed control is attempted late when weeds have already inflicted considerable damage on crops. Inadequate labour supply and high wages, force farmers to give weed control the last priority. Inclement soil and weather conditions automatically rule out timely weeding.

Integrated weed management (IWM) has been defined as the application of numerous alternative weed control measures, which include cultural, genetic, mechanical, biological and chemical means of weed control. None of the individual control measures on their own can be expected to provide acceptable levels of weed control. However if the various components of IWM are implemented in a systematic integrated manner, significant advances in weed control technology can be achieved.

By using several techniques to control weeds the chances of a weed species to adapt under a particular control technique are reduced. For example, if a herbicide is used over a long period of time, a weed species can build up a resistance to the chemical. A long-term integrated weed management plan, that considers all available management control techniques or tools to control weeds, can be developed for a particular area. Any integrated weed management plan or strategy should focus on the most economical and effective control of the weeds and include ecological considerations. The long term approach to integrated weed management should reduce the extent of weeds and reduce the weed seed bank in the soil. It should emphasize on achieving this goal without degrading the land, its native ecology or agricultural crops.

Under Integrated weed management (IWM), weeds are controlled through a long-term management approach, using several weed management techniques such as preventive, mechanical, cultural, chemical and biological methods. A successful IWM programme must include prevention of weeds from invading, knowing the identity and details of the weed species, mapping its distribution and damage, formulating control strategy based on knowledge of potential damage, cost of control method and environmental impact of the weed, using a combination of control strategies to reduce the weed population to an acceptable level, and finally evaluation of its effectiveness.

The goal of weed management programme should be to keep the competition offered by weeds under check and not the complete removal or eradication from the ecosystem. To achieve this comprehensive action plan utilizing preventive methods, scientific knowledge, management skills, monitoring procedures, and efficient use of control practices should be devised making conditions unfavourable to the weeds and their survival.

A theoretical model suggested by Noda, 1977 depicts the process of IWM.

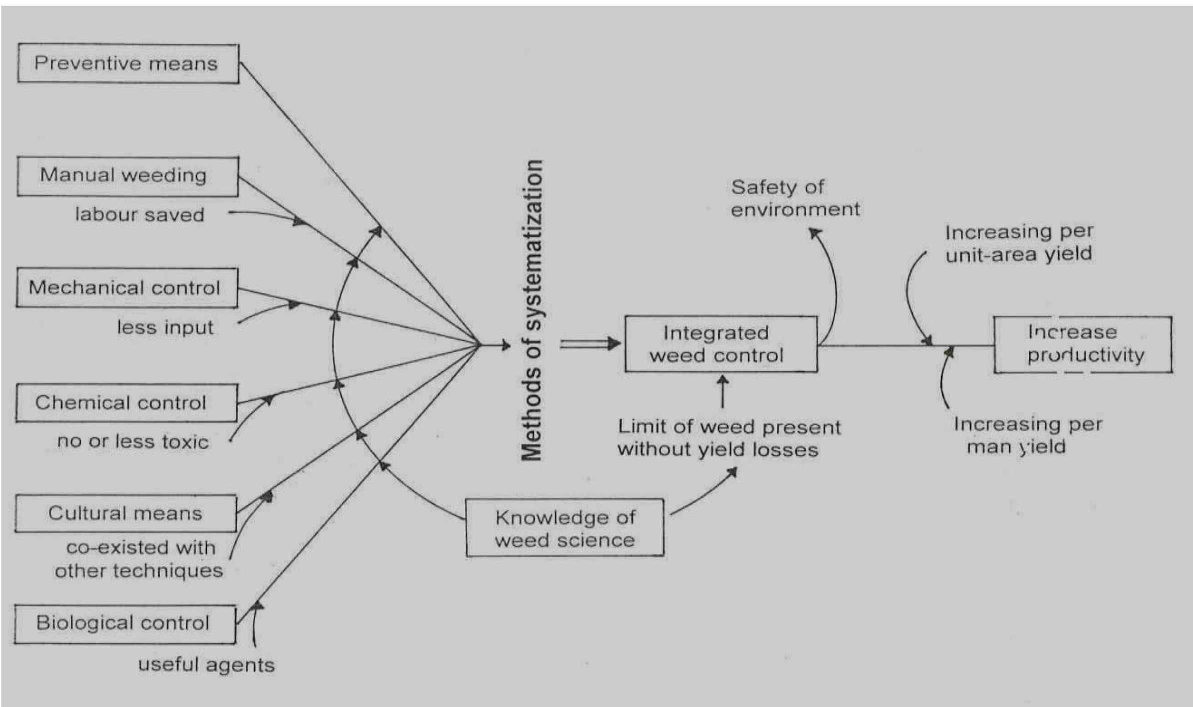


Figure : A concept ional model of integrated weed control, Noda, 1977.

4.1. Components of IWM:

4.1.1 Preventive measures: "Prevention is better than cure", and is usually easier and less costly than control or eradication. Among all the weed control strategies, prevention is an important component which needs greater attention. The following measures can be suggested to prevent the introduction of weeds into non-inhabited field.

- Using clean crop seed (weed seed-free) for sowing/ planting.
- Applying organic manures only after thorough decomposition to prevent weedseed emergence in the field. Un-decomposedfarm yard manures are a major source ofweed seeds
- Cleaning of tillage implements beforemoving to non-weed infested area.
- Avoiding transportation or use of soil fromweed infested area.

- Inspecting nursery stock or transplant forseed and vegetative propagules of weeds.
- Removing weeds that are near irrigationditches, fence rows and other non-crop land.
- Preventing reproduction of weeds.
- Using weed seed screens to filter irrigationwater.
- Restricting livestock movement in to non-weedinfested area.

4.1.2 Cultural measures: Cultural weed controlcomprises the principles of using plant competitionor cropping practices to suppress weeds, eitherthrough use of smother or competitive crops andcrop rotation. Cultural methods may include cropsowing time and spatial arrangement, cropgenotype, cover crops, intercropping, and cropfertilization.

4.1.3 Crop sowing time and spatial arrangement:Making modification in crop sowing date, andsowing pattern can either reduce weed emergenceand/or increase competitive ability of the crop. Increasing seed rate may increasecompetitive ability of crop against weeds, but mayalso cause reduction in crop yield and quality ofproduce. However, anoptimum spacing may provide the benefit of bothcompetitive ability of crop and better yield,showing the importance of closer spacing asa weed management strategy. They have also reported about the lower uptake ofnutrients by weeds, and higher weed controlefficiency in closer spacing.

4.1.4 Crop genotype choice: Crop genotypes may have higher or lowercompetitive ability against weeds. Genotypeshaving faster seedling emergence, and quickcanopy establishment can reduce the need for direct weed control measures; however, the expression of competitive advantage of a genotype may vary depending upon the prevalent environmental. Some traits i.e. plant height are known to provide competitive advantage against weeds, however, may not be exploited due to some other associated disadvantage i.e., lodging. Allelopathy in some cultivars may be exploited as a part of cultural weed control.

4.1.5 Fertilization: Soil nutrition influences the crop weed competition hence specific methods to use fertility management as part of IWM are needed. Management strategies that maximize nutrient uptake by crops may reduce the harmful effects of weeds to some extent and minimize nutrient availability to weeds. Fertilizers applied in close proximity to the crop row, can improve weed management as the probability of the crop to capture nutrients (especially N) increases. Band placement of fertilizer lowered weed density, biomass, and N uptake and resulted in increased wheat yield. Other methods to alter the relative nutrient availability to crops and weeds can also be manipulated by change in timing of fertilizer applications, altering nutrient sources, and by using materials such as nitrification inhibitors. Nutrient availability can also be altered by applying organic amendments, especially for nitrogen and phosphorous. Soil nutrient concentrations strongly influence the germination and early growth of many weed species.

4.1.6 Crop rotation: Crop rotation is considered as an important component of weed management. Growing similar crops in rotation over the years favours weed species that are similar to the crop. Whereas, crop rotation disrupts the growing cycle of weeds and prevents selection of the flora towards increased abundance of problem species. Environmental conditions specifically created by crop rotations affect weed survival, propagule production, and germination in the soil, and thereby subsequent weed population dynamics.

4.1.7 Intercropping: Intercropping compared to crop monocultures can influence the competitive suppression of weeds. Intercrops of differing growth forms, phenologies, and physiologies can create different patterns of resource availability, especially light, to weeds. As resource availability influences weed occurrence the most, increased resource utilization underintercropping can provide better opportunities for IWM. Intercrop sown in a row-by-row layout, besides increasing the the ecological diversity in a field is increased by intercropping which decreases relative soil cover of weeds, and may result inincreased total crop yield.

Table 2: Recommended herbicide for sugarcane-based intercropping

Sugarcane+Potato	**Pendimethalin 1250 g/ha PE, Metribuzin 1250 g/ha PE &PO Ametryn 1500 g/ha PE & PO**
Sugarcane+Rajmas/Lentil/Chickpea	Pendimethalin 1250 g/ha PE, Oxyfluorfen 250 g/ha PE
Sugacane+Mustard/Toria	Pendimethalin 1250 g/ha PE,
Sugarcane+Wheat	Pendimethalin 1250 g/ha PE, Metsulfuron 6 g/ha PO Metribuzin 1000 g/ha PO
Sugarcane +Veg. crops	Pendimethalin 1250 g/ha PE,

4.1.8 Cover crops: Cover crops may be grown for weed control, thereby replacing an unmanageable weed population with a manageable cover crop. There are at least two major types of cover crops that can be used for weed control. Off-season cover crops may be taken to produce sufficient plant residue or allelochemicals to create an unfavorable environment for weed seed germination and establishment. While a smother crop, displaces weeds from the harvested crop through resource competition. Basic understanding of the mechanisms by which cover crops change weed population dynamics is required for improving the effectiveness. The effect of cover crop on weeds depends upon cover crop species and composition of weed community. It has been reported that smallseeded weed species are more sensitive to physical as well as to allelochemicals effects of cover crops compared to large-seeded weed species.

4.2 Mechanical measures: Mechanical measures may include physical removal of growing weeds from the field by hand weeding, hoeing, mowing, burning, tilling, etc. Annual and biennial weeds and non-creeping perennials can be removed by pulling them out. This is best done when the soil is moist and before seed is produced. However, it may not be suitable for large acreages.

Mulching is done to exclude light from the tops of the weeds until the reserve food supply in the roots is exhausted and the weeds wither away. Mulches may include crop straw, hay or manure, sawdust and transparent or black plastic.

Soil solarization technique is employed to kill weed seeds through solar heating. To make the solarization effective, the soil surface must be evenly prepared and must contain enough moisture to favour heat transfer throughout the profile to damage reproductive structure of weeds. Its effect may last up to one resulting in reduced weed seed germination.

Soil tillage influences the weed flora through changes in seed distribution in the soil, effects on seed predators, and effects on weed control practices. It is important to change the tillage practices in component crops year after year so that weed density is reduced greatly.For example, conventional tillage (CT) – zerotillage (ZT) rotation was found better than CT-CTor ZT-ZT rotation in terms of weed management ina rice-wheat system.

4.3 Chemical strategies: Several factors which mustbe looked into, while formulating chemical optionsof weed control are the effectiveness of thechemical methods like application methods andstage of application and selection of suitableherbicide on the basis of nature of weeds. Whilefaulty herbicide application methods may causeinjury to the crop, environmental factors, herbicideresidues in the farm produce, residual effects ofpersistent herbicide in soil, compatibility problemwith other pesticides, occupational hazard to theapplicator should be studied in detail. Developmentof herbicide resistant weeds in recent years and itspossible consequences on weed managementsuggests that over reliance on chemical methodsalone may not be the best strategy.

Table 3 : Promising herbicides for weed control in sugarcane crops.

Crops	Herbicide	Dose (Kg/ha)	Time of application	Weeds controlled
Sugarcane	Atrazine	2.0	Pre-em	Grassy and sedges
	Metribuzin	1.0-1.25	Pre-em or PO	Broadleaved, Grassy & Sedges
	2,4-D	1.5-2.0	PO at 90 DAP	Broadleaved, & Sedges and parasitic weed *Striga*
	Ametryn	1.5	PO at 45-60 DAP	Broadleaved, Grassy
	Halosulfuron-methyl	0.09	PO at 45 DAP	Only for sedges

PPI - Pre plant incorporation, Pre-em – Pre-emergence, Post-em - Post emergence

Precautions in Herbicide Application

1. Use lower rates in light soils and higher rates in heavy soils.
2. Apply herbicides using a sprayer fitted with flat fan or flood jet nozzles in 500-600 liters/ha of water.
3. Apply spray solutions immediately after preparation. If delay is inevitable, stir the solution or shake the sprayer thoroughly before application to prevent settling down of herbicide in the bottom.
4. Match the swath correctly. Overlapping of spray may lead to crop phytotoxicity and gaps may lead to poor control of weeds.
5. Separate sprayer need to be used for herbicide and for insecticide spray. If not, then sprayer has to be thoroughly washed soap water after the herbicide spray before it is used for insecticide spray.
6. Avoid spraying on windy days as spray drift may damage the susceptible crops growing near by.
7. Do not spray against the wind.
8. Avoid smoking or eating during spray application.
9. Wash sprayer thoroughly after each spray.
10. Handle chemicals carefully. Always keep them away from children and food articles.
11. Dispose the empty containers by burying in the soil or by burning.
12. Use protective clothing (gum boots, gloves, etc.,), goggles and mask wherever possible.

4.4 Biological strategies: Biological control may bedefined as 'the actions of parasites, predators andpathogens in maintaining another organism'sdensity at a lower average than would occur in theirabsence'.It uses natural agents such asinsects, nematodes, pathogens, herbivorous fishand even grazing animals for the control of weeds.The objective in bio-control is to reduce a weed'sdensity to non-economic levels, not its eradication.Bio-control is mostly followed for non-cultivatedlands with troublesome biennial or perennialweeds. It is usually not practiced in cultivatedlands as the weed food source for the biotic agent isremoved periodically. An early success inbiological control of weeds in Australia was the usein the 1920s of the Cactoblastis Moth(***Cactoblastiscactorum***) to control Prickly Pear(***Opuntiastricta***), which at the time wassmothering large tracts of north-east Australia, andspreading rapidly each year. Another example isthe discovery of a specific fungus disease whichcontrols round-leaved mallow in wheat fields.

Thus, integrated weed management (IWM) is acomponent of integrated crop management. Theresearch approach to the development of an IWMsystem must take all aspects of the cropping systeminto consideration.

Referneces:

Das, T K. (Ed.). 2011. Weed Science: Basic and Applications. Jain Publisher.

Gupta, O P. (Ed.). 2011. Weed management: Principles and Practices 3rd edition. Agrobios publisher.

Yaduraju, N T., Sharma, A R. and Das, T K. (Eds.). 2016. Weed Science and Management, 402 p, Indian society of Weed Science, Jabalpur and Indian Society of Agronomy, New Delhi.

Chapter No. 23: Role of Nano fertilizer in sugarcane

K.K. Singh
Principal Scientist
ICAR-Indian Institute of Sugarcane Research, Lucknow

Nano fertilizers are fertilizers, fertilizer bulk materials or extracts of botanical, microbial or animal origin manufactured through chemical, physical,or biological method either through Top-Down or Bottom-Down manufacturing process. The term nano material is based on the prefix nano which originates from Greek word meaning dwarf. More precisely, the word nano means 10^{-9} or one billionth of a meter. The word nanomaterial is generally used for materials with a size ranging between 1 and 100 nm. India's largest fertilizer co-operative IFFCO has begun the mass production of nano urea invented by 33-year-old Indian scientist Ramesh Raliya.

Nano-Fertilizer and Their Roles

Nano-fertilizers play very important role the improvement of production in the variety of crops. The nutrient use efficiency of conventional fertilizers is very low and is hardly exceed 30–35 % for N , 18–20 % for P , and 35–40 % for K. Besides nano-fertilizers are also release nutrients slowly and steadily which is available to the crops for extended period of time viz. for more than 30 days which may assist in improving the nutrient use efficiency without any associated ill-effects. Because of its slow release the nano-fertilizers/ nano coating based fertilizer release nutrients slowly over a long period of time therefore , the nutrients losses is substantially low and enhanced environmental safety.

Three classes of nano-fertilizers:

1) Nanoscale fertilizer (nanoparticles which contain nutrients),
2) Nanoscale additives (traditional fertilizers with nanoscale additives), and
3) Nanoscale coating (traditional fertilizers coated or loaded with nanoparticles)

Production of Nano-Fertilizer

Beacuse of the unique properties of the nano particle , the nutrient use efficiency improved by use of nano fertilizer . The nano-fertilizers are synthesized by fortifying nutrients singly or in combinations onto the adsorbents with nano-dimension. Both physical (top-down) and chemical (bottom-up) approaches are used to produce nanomaterials, and the targeted nutrients are loaded as it is for cationic nutrients (NH4 + , K+ , Ca2+, Mg2+) and after surface modification for anionic nutrients (NO3 − , PO4 2−, SO4 2−). (Chinnamuthu and Boopathi , 2009). Encapsulation of fertilizers within a nanoparticle is one of these new facilities which are done in three ways a) the nutrient can be encapsulated inside nano-porous materials, b) coated with a thin polymer film, or c) delivered as particles or emulsions of nano-scales dimensions (Rai et al . 2012, Kanjur Wangdi , 2019).

Importance of Nano fertilizer in Sugarcane

Sugarcane is a most important cash crop of India. Over five million farmers are involved in the cultivation of sugarcane in tropical and subtropical India, the two distinct agro-climatic regions of the crop in the country (Geetha *et al*., 2015). At present, it is grown on 4.8 million hectares (M ha) in India in 2017-18, with cane production of 355 million tonnes (MT) and 29.5 MT of sugar (Annonymous, 2018). In northern India, the nutrient requirement of sugarcane is about 150-180 kg/ha N, 60 kg/ha P_2O_5 and 60 kg/ha K_2O whereas in southern India it is 250-350 kg/ha N, 100 kg P_2O_5 /ha, and 80-120 kg K_2O /ha. Nitrogen plays a very important role in sugarcane growth, yield and quality. It required for vegetative growth (tillering, foliage formation, stalk formation and growth) and root growth. However excess nitrogen application leads to adverse effect on crops *i*.e., delay maturity, increase reducing sugar content, increase soluble N in juice affecting clarification, reduce juice quality, increase susceptibility to lodging, pest and disease incidence. Indiscriminate use of N fertilisers also caused detrimental impacts on the diversity and functioning of the non-agricultural ecosystems due to eutrophication of freshwater and marine water (Beman *et al*., 2005). In addition, there can be gaseous emission of N reacting with the stratospheric ozone and the emission of toxic ammonia into the atmosphere. The nitrogen use efficiency by crops is very low (30-35 %) due to the loss of N to the tune of 50-70 % by leaching, volatilisation and microbial mineralization.

In order to increase nitrogen use efficiency N based nanofertilizers are sustainable option for sugarcane crop. It may regulate the release of nutrients and deliver the correct quantity of nutrients required by the crops in suitable proportion and promote productivity while ensuring environmental safety (DeRosa *et al*., 2010). Nanotechnology can be employed as a tool to modify nanoparticles in fertilizer formulations to increase their uptake in plant cells in such a way that nutrient loss is minimized, and to increase the crop use efficiency of fertilizer micronutrients. Nanoparticles (NPs) or nanoscale particles are molecular aggregates with dimensions of 1-100 nm (Roco, 2003). Their diverse physicochemical properties are due to their very small size (Nel *et al*., 2006), and their higher reactivity and biochemical activity depend on their high surface energy and the high surface-to-volume ratio . Nanofertilizers are nutrient carriers of nano-dimensions ranging from 30-40nm (one billionth of a meter) and capable of holding bountiful of nutrient ions due to their high surface area and release it slowly and steadily that commensurate with crop demand. Nanofertilizer release nutrient from fertiliser granules in controlled manner so as to improve nutrient use efficiency while preventing the nutrient ions either get fixed or lost to the environment (Subramanian *et al*., 2008). Subramanian and Rahale (2009) reported that nano-clay based fertiliser formulations are capable of releasing the nutrients for a longer period of time (> 1000 hrs) than conventional fertilisers (< 500 hrs). Hence there is need to use such type of fertilisers in long duration crops such as sugarcane for enhancing nitrogen use efficiency as well as crop productivity.

Role of nano fertilizer on crop growth, yield and quality

Nano Urea is cost-effective and required in low quantities. The most critical benefit of using Nano Urea for agriculture is its minimal impact on the environment. This will result in reducing the release of greenhouse gasses and improve the quality of air and water. The increased dependency on chemical pesticides and fertilizers has generated serious issues related to sustainability, environmental impact, and health hazards. As a result, the innovative approach of using environmentally friendly nanofertilizer or nano pesticide as alternatives to commercial chemical fertiliser and pesticides. Encapsulation of nutrients inside a nanoporous material release nutrient slowly and avoid interaction and losses via soil, water, air, or microorganisms (Rai *et al*., 2012). Zhu *et al*. (2011) found that nanourea treatment increased the grain yield and N agronomic efficiency with less N loss in paddy field. Kottegoda *et al*. (2011) observed that the behavior of the nanofertilizer (urea-modified hydroxyapatite) was like a burst at the beginning, and then the release was slow for 60 days; meanwhile, with the commercial fertilizer, sustained release occurred during the first 3 days. Subbaiya *et al*. (2012) evaluated the same formulation of nanourea–hydroxyapatite, and it was tested at different concentrations (10%, 20%, and 40%) in green gram [*Vigna radiata* (L.) R. Wilczek] through both seed treatment and direct application to the soil. The seed germination rate was 100% with the urea–hydroxyapatite formulation, while the common urea treatment resulted in a 30% lower germination rate, and the plant height was shorter with the regular urea treatment. Application of urea hydroxyapatite to the soil enhanced the utilization of the nitrogen source, reflected in better plant yield. Nanourea treatment increased the agronomic efficiency by 44.5% and grain yield by 10% in rice crop (Huang *et al.,* 2015). Post effect of nano fertilizer application in soil showed better pH, moisture, CEC and available nitrogen under nano fertilizer treatment than the conventional fertilizer.Kottegoda *et al*. (2017) synthesized urea–hydroxyapatite nanohybrids to achieve slow release of nitrogen and concluded that the use of nano urea can increase rice yields and reduce the use of conventional fertilizers. Normally, it takes 75 kg of dry urea to be sprayed by hand in one acre. In the nano urea, only 2-4 ml needs to be mixed with 1 litre of water and it takes 125 litres of water for spraying in one acre. Bhattacharya (2004) reported that the balanced application of NPK along with S, Zn, B and Mo will be an effective solution for higher grain yield of pulses in red and lateritic soils. Adequate NPK fertilization increased green and blackgram yields by 13% and 38% over the control. Qiang et al., (2008) reported that wheat grain yield and protein contents were slightly improved and soluble sugar content decreased by slow/controlled release fertilizer coated and felted by nano-materials compared with NPK chemical fertilizer. It was effective to use slow/controlled release fertilizer coated by nano-materials to improve wheat yield and quality.

Salient Features of Nano Urea

Eco-friendly
Suitable for all crops and soils
Protect the quality of the land, air, and water
At least a 50 percent reduction in urea

Benefits of use of Nano Urea

1. It successfully meets crop nitrogen requirements, boosts leaf photosynthesis, root biomass, effective tillers, or branches, and increases root biomass.
2. Increases farm income by increasing crop output and lowering input costs.
3. Because of its better efficiency, it can cut down the amount of traditional urea required by half or more.

Precautions to be taken during use

Nano-Urea has been assessed for biosafety and toxicity in accordance with the Department of Biotechnology (DBT) criteria, the Government of India, and OECD international guidelines. Nano urea is non-toxic and harmless for the user; nevertheless, while spraying on crops, it is advisable to use a face mask and gloves. Keep out of the reach of children and pets and store in a dry area away from extreme temperatures.

References

Anonymous. Department of agriculture cooperation and farmer's welfare, 2018

Beman JM, Arrigo K and Matson PM. Agricultural runoff fuels large phytoplankton blooms in vulnerable areas of the ocean. *Nature*, 434:211-214, 2005.

Bhattacharya SS, Debkanta GN, Mandal, Chattopadhyay, and Majumdar K (2004) Effect of Balanced Fertilization on Pulse Crop Production in Red and Lateritic Soils.Better Crops 88(4): 52-57.

Chinnamuthu CR, Boopathi PM. (2009) Madras Agricultural Journal 96,17-31.

DeRosa MC, Monreal C, Schnitzer M Walsh R and Sultan Y. Nanotechnology in fertilisers. *Nature nanotechnology*.(5) 2010.

Geetha P, Sivaraman K, Tayade AS and Dhanapal R. Sugarcane based intercropping system and its effect on cane yield. *Journal of Sugarcane Research.* 5 (2) : 1 - 10, 2015.

Huang S, Wang L, Liu L, Hou Y and Li L. Nanotechnology in agriculture, livestock, and aquaculture in China. A review. *Agron Sustain Dev* 35:369–400, 2015.

Kanjur Wangdi (2019) : Production of nanofertilizer -A mini review . International Journal of Engineering Applied Sciences and Technology, Vol. 4, Issue 3, ISSN No. 2455-2143, Pages 1-4.

Kottegoda N, Munaweera I, Madusanka N and Karunaratne V. A green slow-release fertilizer composition based on urea-modified hydroxyapatite nanoparticles encapsulated wood. *Curr Sci India,* 101:73–78, 2011.

Kottegoda N, Sandaruwan C and PriyadarshanaG.Urea–hydroxyapatite nanohybrids for slow release of nitrogen. *ACS Nano* 11:1214–1221,2017.https://doi.org/10.1021/acsnano.6b07781.

Qiang X, Fu-dao Z, Yu-jun W, Jian-feng Z, and Shu-qing Z (2008) Effects of slow/controlled release fertilizers felted and coated by nano-materials on crop yield and quality. 5-10.

Rai V, Acharya S and Dey N. Implications of nanobiosensors in agriculture. *J Biomater Nanobiotechnol* 3:315–324, 2012.

Rai V, Acharya S, Dey N (2012) Journal of Biomaterials and Nanobiotechnology 3,315-324,

Subbaiya R, Priyanka M and Selvam MM. Formulation of green nano-fertilizer to enhance the plant growth through slow and sustained release of nitrogen. *J Pharm Res* 5:5178–5183, 2012.

Subramanian KS and Rahale S. Synthesis of nanofertiliser formulations for balanced nutrition. Proceedings of the Indian Society of Soil Science- Platinum jubilee celebration. December 22-25, IARI, campus New Delhi. Pp:85, 2009.

Subramanian KS, Paulraj C and Natarajan S. Nanotechnological approaches in nutrient management. In: Nanotechnology applications in agriculture.ISBN:978-81-904337-3-0 Pp:37-42, 2008.

Zhu G, Wang S, Wang Y, Wang C, Risgaard-Peterse N, Jetten MS and Yin C. Anaerobic ammonia oxidation in a fertilized paddy soil. ISME J 5:1905, 2011.

Roco, M.C., 2003. Broader societal issue of nanotechnology. *Journal of Nanoparticle Research*. 5, 181-189.

Nel, A., Xia, T., Madler, L., Li, N., 2006. Toxic potential of materials at the nanolevel. *Science* 311, 622-627.

Chapter No. 24: Micro irrigation techniques for improving water use efficiency and economizing water use

K.K. Singh
Principal Scientist
ICAR-Indian Institute of Sugarcane Research, Lucknow

Micro-irrigation system is a modern method of irrigation in, which water is delivered slowly generally in the form of discrete droplets, continuous drops, streams, etc. Micro-irrigation system is known for its low cost and water-efficiency. Micro-irrigation systems is a low pressure system which consist spray, mist, sprinkler, and drip. The precise, slow and frequent discharge of water to the plants from the emitters from located at specific points is carried out along the water delivery lines called as laterals. Through this techniques controlled & frequent water application could be done around the root zone of the crop to ensure its better utilization.

Why micro-irrigation

Agriculture the largest consumer of groundwater in India and since the past few decades we have witnessed an alarming depletion of groundwater resources in the country. About almost half of the agricultural area cultivating food grains in India depends on irrigation, as high as 65 percent of these irrigated land holdings depend on groundwater to meet their water needs. While bore wells and tube wells continue to suck groundwater for agricultural use at alarming rates, putting the current consumption at as high as 84 percent of the total water available in the country, this withdrawn water continues to be used inefficiently. The conventional flood method of irrigation (FMI) still used by farmers in the country is highly inefficient, where water is allowed to flow in the field and seep into the soil.This results in wastage of water, since excess water flows off the surface without being utilised. This has led to India using 2 to 3 times more water than what major agricultural countries like China, Brazil and the US use to produce one unit of food crop (Source:https://www.indiawaterportal.org/articles/micro-irrigation-and-groundwater-use dated 11/10/2022).

Due to heavy pressure of water demand for irrigation and other non-agricultutal purposes , the over exploitation of ground water caused the depletion of ground water table and we are also witnessing problems in irrigation water supply in many areas. Depletion of groundwater levels over the years in some states of India given in Table 1 clearly established this fact . The most widely used methods of irrigation i.e. surface irrigation has very low water use efficiency and is only 40-50%. Further in the surface methods , since the water is applied after gaps of 7-25 days interval , plants feel water stress in this method depending on the soil, crop and climate which ultimately affect the growth and yield of crops. It is therefore , it becomes necessity to increase the water use efficiency by adopting the modern methods of irrigation with the use of micro irrigation technologies. Micro irrigation ensures 80-90% water use efficiency because water is applied efficiently according to the crop need and surface runoff and deep percolation is totally avoided. It is very difficult task to irrigate crops frequently by using surface irrigation methods but under micro irrigation crops get water daily and moisture is maintained at field capacity in the root zone of crop which results in higher crop yield. So by adopting Micro irrigation we can helps to save water and increases the water use efficiency by use of drippers, sprinklers and foggers. Micro irrigation can increase yields and decrease water, fertilizers and labour requirements. It can also help to bring the degraded, uncultivable land under cultivation

Present status of Micro Irrigation in India

Israel can be a source of inspiration for all of us in using micro-irrigation systems specially drip irrigation and making the country from a desert nation into a water surplus nation. It can save up to 3/4th of water that is used for irrigation. The average penetration of micro irrigation in India is 19% (as on February 3, 2021)**,** which is much lesser than many countries. It has been seen that up to 60% of irrigation water used for sugarcane, banana, okra, papaya, bitter-gourd and few other crops could be saved only due to adoption of drip irrigation system for their cultivation. Currently only Sikkim, Andhra Pradesh, Karnataka and Maharashtra have more than half of their net cultivable area under micro irrigation whereas 27 states in India have less than 30% micro irrigation system out of which 23 have less than 15%.Uttar Pradesh is the largest producer of Sugarcane, which is water intensive crop but has only 1.5% area under micro irrigation and Punjab has only 1.2 %.In September 2020, Honourable Agriculture minister Mr. Narendra Singh Tomar said that the government has set the target of covering 100 lakh ha land in the next five years under micro irrigation.

Types Of Micro Irrigation

There are majorly 5 types of Micro Irrigation Systems

Sprinkler Irrigation- It works in a pressurized form similar to natural rainfall. Devices used in this irrigation include high pressure sprinklers sprays or guns.

Drip Irrigation – In this the water is directly supplied to plant roots through emitters

Spray Irrigation – It utilizes the jet spray to deliver water and it is widely used.

Subsurface Irrigation – In this method the water is applied to the plants from below the soil surface. The tubes and pipes are hidden below the soil for water delivery.

Bubbler Irrigation- It is installed in areas where water requirement is high. Water is applied through small streams and fountains.

- **Governments initiatives for micro irrigation**
- Government of India initiated micro irrigation in 1992 and recognized this as a thurst area in 2006. Later National Mission On Micro Irrigation (NMMI) and National Mission for sustainable Agriculture (NMSA) were launched with a clear mission to promote Micro irrigation systems.
- Out of total 140.13 million hectares of sown area, the net irrigated area is 68.38 milion hectares while 71.74 million hectares are unirrigated. The government launched PMKSY (Pradhan Mantri Kisan Sinchai Yojana) to solve this problem. This scheme was launched in July, 2015, and is aimed at water conservation and increasing water use efficiency. It has a tagline “har khet ko pani” meaning assured irrigation to every farm. Under this scheme small farmers will be paid 55% subsidy to install micro irrigation systems (Source : https://krishijagran.com/agripedia/micro-irrigation-in-india-present-scenario-types-government-initiatives-challenges/ dated 7/11/2022)

Suitability of Micro-irrigation

- Wide spaced high value crops like coconut, citrus, cotton, sugarcane
- Highly sensitive crops like tobacco, banana.
- Nurseries, glass house grown plants which needs careful nurturing.
- Crops in which vegetative parts are harvested like tea, tobacco, etc.
- Acute water scarce areas.
- Areas where labour and energy scarcity is a major problem.
- Efficient irrigation in highly undulated lands without levelling.
- Very efficient for the areas where irrigation water quality is low (saline water).

Use of Micro- irrigation for water and nutrient delivery in sugarcane crop :

Water requirement of cane under traditional method of cultivation varies from 2000-2500 mm depending upon soil and climate (Arulkar *et al.*, 2004 and Rajegowda *et al.,* 2004). This conventional method of cane production not only leads to water wastage but also reduces fertilizer use efficiency. It is important to judiciously use the already existing water resources by adopting appropriate irrigation technology that not only increases sugarcane production per unit area but also per unit of water and nutrients used (Kadam, 2009). Thus a scientific and efficient management of water is needed to conserve the available water resources and to enhance water use efficiency and cane yield which is possible through drip fertigation besides getting higher quality cane juice.

Sugarcane being a huge biomass producing crop, requires application of NPK in adequate amounts for higher cane and sugar yields on a sustainable basis .The recommended doses for plant cane is 150:60:60 kg NPK . About 30-50 % of N and all the P, K nutrients are applied at the time of sowing. Not only nutrients but water requirement is also high in sugarcane crop. Water requirement is the total amount of water needed for raising a crop successfully. In the case of sugarcane, it includes the amount of water for meeting the needs of evapotranspiration and metabolic activities (known as consumptive use), losses during application of water and water needed for land preparation as pre-planting irrigation (S*hrivastava* Et al 2011). Water requirement of sugarcane crop varied in different regions depending upon whether conditins and texture of the soil . In sub tropical India (UP, BIhar, Punjab) it ranged from 140- 180 ha -cm. In tropical India (Andhra Pradesh, Karnatka, Tamil Nadu) it vaired from 160 - 240 ha-cm . In Maharashtra the WR of sugarcane crop is 250-300 ha-cm while in M.P it is 270 Ha-cm . Sugar producing regions in India have more than 80 percentage groundwater irrigation through deep-well pumping. Whereas, NASA's gravity recovery and climate experiment satellites have revealed faster depletion of groundwater stocks in India. These areas are cultivating 93 percentage of sugarcane. In India, sugarcane is an irrigated crop; and from 1980 to 2006 irrigation coverage has increased from 80 per cent to 93 per cent of the total sugarcane-cultivated area.

At the time of germination sugarcane crop do not depend much on soil applied fertilizer . Further initial growth in sugarcane crop is very slow therefore, for a long period of time sugarcane field looks like a bare land. The losses of N is enhanced due to lack of vegetation. The applied nutrients are taken up by the crop else it may change into unavailable form or may lost from the system. Urea normally hydrolizes and converted to ammonium and carbon dioxide within 2 to 4 days. Similarly major part of the applied P and K also become unavailable over the period of time due to fixation and other losses. Non-judicious use of nutrient in relation to amount , timing and balance has been identified as a possible reason for yield stagnation / decline and is a concern for the long term sustainability of intensively cultivated production systems . The nutrient use efficiency is very low and it ranges from 10-40 % ; 10-30% ; 20 to 60 % for N,P,K respectively. Sustainable nutrient management must be both efficient and effective to deliver anticipated economic, social and environmental benefits. To meet the sugarcane at affordable price and for sound environment, the cost of production remain relatively low by curtailing the cost on fertilizer with improved nutrient use efficiency. Improving the nutrient use efficiency can save significant amount of money invested for sugarcane production and ultimately reduced the cost of cultivation The relative NPK requirement is not uniform throughout the life cycle of the sugarcane plant. Therefore, applying matching amount of nutrients in active root zone as per plant needs will have greater synchrony between crop demand and nutrient supply and will ultimately enhance uptake , optimize growth with increase in NUE and minimize the available nutrients for different types of losses. The present practice of, N, P, K application (where entire P, K and $1/3^{rd}$ N are applied at the time of planting) do not match with crop requirement at this stage. Therefore, nutrients are vulnerable for different types of losses. With the surface irrigation it was not possible to place the required quantity of fertilizer at an appropriate time in the root zone. But through drip fertigation the fertilizer can be delivered at proper place and at proper time. Timing fertigation to coincide with period of demand from the crop is being used for maximizing fertilizer efficiency in many high value crops with complex phenology and nutrient requirements, but there have been no formal field studies to assess the merits of this concept in sugarcane for North Alluvial Plains of India. Therefore, the present research project has been formed.

Drip fertigation in Sugarcane

At the time of germination sugarcane crop do not depends on soil applied fertilizers. The present practice of application of1/3 rd doses of N and entire P and K does not match with the crop demand at this stage .Further a onetime 25 % increase in N fertilizer dose to ratoon crop may not meet the fertilizer requirements of several ratoon crop. The Non judicious use of nutrient in relation to amount , timing and balance has been identified as a possible reason for yield stagnation / decline and is a concern for the long term sustainability of intensively cultivated production systems . The nutrient use efficiency is very low and it ranges from 10-40 % ; 10-30% ; 20 to 60 % for N,P,K respectively. Improving the nutrient use efficiency can save significant amount of money invested for sugarcane production and ultimately reduced the cost of cultivation. Through drip fertigation the fertilizer can be delivered at proper place and at proper time. Sugarcane crop also required huge quantity of water to produce one tones of sugar. Keeping in view of present day crisis of irrigation water, the importance of use of drip/micro irrigation system in sugarcane production is the burning issue. The government also emphasizing the water saving majors such as sprinkler, drip use in agriculture. The drip not only save the irrigation water in sugarcane production but also enhance the sugarcane yield.In our country the Maharashtra and Karnataka government are emphasizing for installation of drip irrigation facility on farmers field. In north Indian states the area under drip irrigation is also increasing .The drip fertigation is economically viable even without subsidy. The concept of timing fertigation to coincide with period of sugarcane crop demand has not been assessed in North Alluvial Plains of India. Therefore, the present research project has been formed.

In India mllion of Rs could be saved by just enhancing the fertilizer use efficiency by 1or 2 % . The nutrient requirement is not uniform throughout the life cycle of the sugarcane plant. The relative N and P requirement is least during germination and establishment stage . It is commonly accepted that the efficiency of N use can be improved when it is applied by fertigation to most crops . Fertigation enables adequate supplies of water and nutrients with precise timing and uniform distribution to meet the crop nutrient demand. A drip irrigation system can easily be used for fertigation, through which the applied fertilizer is placed to the active root zone and crop nutrient requirements could be met out accurately (Boyhan and Kelly, 2001,).

Greater synchrony between crop demand and nutrient supply is necessary to improve nutrient use efficiency.Nutrient use efficiency is improved when it is applied by fertigation in most crops including sugarcane (Ng Kee Kwong KF & Deville ,1994; Haynes RJ, 1985). Gains in fertilizer use efficiency would be particularly useful for nitrogen (N) in sugarcane systems, as significant losses of N from volatilization and denitrification (Ferney et al., 1991; Weier et al. 1996) can occur with conventional means of application. Besides higher water use efficiency drip increases productivity , reduce weeds, soil erosion , energy use etc.(Narayana moorthy , 1996 & 2001) . Narayanamoorthy, 2005 analyzed the economic viability of drip investment in sugarcane cultivation and clearly suggests that drip investment in sugarcane cultivation is economically viabile even without subsidy. The benefit :cost ratio varies from 1.98 to 2.02under without subsidy condition and the same varies from 2.07 to 2.10 with subsidy (30 percent). Weed species remain competitive with crop species due in part to high rate of both growth and resources uptake (Wortman et al, 2011; Seibert and Pearce , 1993). Result of both green house and field experiments(Alkamper et al , 1979; Davis and Liebman 2001; Dyck et al. 1995)indicate that for certain crop weed combinations, delaying soil nutrient availability can shift the competitive balance to favor crop growth.

Challenges for Adopting Micro Irrigation

1. Inadequate water availability at farm level.
2. Non availability of uninterrupted electric power.
3. Inadequate focus on nationwide micro irrigation technology.
4. It has high cost of installation and maintenance, plus complicated procedures to redeem subsidies provided by the government for installation of Micro Irrigation (Source : https://krishijagran.com/agripedia/micro-irrigation-in-india-present-scenario-types-government-initiatives-challenges/Dated 11/11/2022)

References :

Ashok K. Shrivastava*, Arun K. Srivastava and Sushil Solomon (2011) Sustaining sugarcane productivity under depleting water resources . Current Science , Vol. 101, N0. 6, 25 : 748-754 .

Aggarwal, P. K., Joshi, P. K., Ingram, J. S. I. and Gupta, R. K., Adapting food systems of the Indo-Gangetic plains to global environment change: key information needs to improve policy formulation. *Environ. Sci. Policy*, 2004, **7**(6), 487–498.

Alkamper, J., E. Pessips, and Long. D.V. 1979. Einfluss der Du¨ngung auf die Entwickelung und Nahrstoffnahme verschiedener Unkra¨uter in Mais.European Weed Research Society Symposium, Mainz, Germany. Paris:European Weed Research Society.

Arulkar, K. P., Hiwase, S. S. and Deogirikar, A. A., 2004, Water requirement estimation from climatological data by probability analysis for sugarcane crop in Nagpur district. *New Agric*.,**15**: 75-78.

Boyhan G, WT Kelly. 2001. Onion production guide bulletin. 1198. College of agricultural and environmental sciences. University of Georgia. p.56.

Davis, A. S. and M. Liebman. 2001. Nitrogen source influences wild mustard growth and competitive effect on sweet corn. Weed Sci. 49:558–566.

Dyck, E., M. Liebman, and M. S. Erich. 1995. Crop-weed interference as influenced by a leguminous or synthetic fertilizer nitrogen source: I. Double cropping experiments with crimson clover, sweet corn, and lambsquarters.Agric. Ecosyst. Environ. 56:93–108.

Ferney JR, OT Denmead, PG Saffigna, AW Wood, LS Chapman, and AP Hurney. 1991. Ammonia loss from sugarcane fields as affected by placement, irrigation and canopy development. Proc Aust Soc sugar Cane Technol. 22 - 230.

Haynes RJ. 1985. Principles of fertilizer use in trickle- irrigated crops. Fert. Res. 6: 235-255.

Kadam, S. A., 2009, Effect of fertigation on emission uniformity of drip irrigation system. *International J. Agric. Engg*., **2**: 72-74.

Narayanamoorthy, A. 2005. Economics of Drip Irrigation in Sugarcane Cultivation:Case Study of a Farmer from Tamil Nadu. *Ind. Jn. of Agri. Econ. Vol. 60, No. 2,235-248.*

Narayanamoorthy, A. 1996. Evaluation of Drip Irrigation System in Maharashtra. Mimeograph Series No. 42, Agro-Economic Research Centre, Gokhale Institute of Politics and Economics, Pune, Maharashtra.

Narayanamoorthy, A. 2001. *Impact of Drip Irrigation on Sugarcane Cultivation in Maharashtra*, Agro-Economic Research Centre, Gokhale Institute of Politics and Economics, Pune, September.

Ng Kee Kwong KF, J Deville. Application of 15N- labeled urea to sugarcane through a drip – irrigation system in Mauritius. Fert Res. 1994;39: 223-228.

Rajegowda, M. B., Muralidhara, K. S. And Ravindrababu, B. T., 2004, Application of water balance studies in irrigated sugarcane. *J. Agrometeorology*. **6**: 138-141.

Seibert, A. C. and R. B. Pearce. 1993. Growth analysis of weed and crop species with reference to seed weight. Weed Sci. 41:52–56.

Weier KL, CW McEwan, I Vallis, VR Catchpole, JR Myers. 1996. Potential for biological denitrification of fertilizer N in sugarcane soils. Aust J Agric Res. 47- 67.

Wortman, Sam E; Schutte, Brian J; and . Lindquist, John L . 2011.Integrating Management of Soil Nitrogen and Weeds. Weed Science 59:162–170.

Table Changes in the water table (m) during June

1984–1994 in Punjab

District	Ground water depletion (m)
Amritsar	2.3
Ludhiana	1.9
Kapurthala	1.8
Ferozapur	4.5
Faridkot	4.5
Sangrur	5.1

Aggarwal *et al.*

Chapter No. 25: Ratoon management in sugarcane for higher productivity and income

V.P. Jaiswal
Senior Scientist
ICAR - Indian Institute of Sugarcane Research, Lucknow

Low productivity of ratoon greatly influences the national average of cane yields as ratoon occupies a sizeable share (>55-60%) in sugarcane acreage.. The ratoons are more prone to insect-pests build up and diseases which contribute negatively in improving the yield. In the tropics and subtropics most sugarcane is ratooned at least once. In Hawaii, where mechanical harvesting is employed, sugarcane is usually ratooned only once because of soil problems and mechanical damage to the stools. In Mauritius, where as many as seven ratoon crops are taken, 85% of the cane milled each year is produced by ratoon cane. Therefore, for improving sugarcane production on sustainable manner, it is important to adopt appropriate soil health and crop management techniques to improve the ratoon cane yield. Ratoon or stubble crop has got some limitations and it is important to understand them for their better management.

A-RATOON CANE PRODUCTION CONSTRAINTS

Environmental constraints

These are mainly temperature and soil moisture induced constraints. In subtropics, the harvesting of sugarcane starts during peak of the winter season in low to very low temperature. Stubble bud gets exposure to such odd ambience and usually yields gaps. Late harvesting too dries out the bottom buds of stubble and reduces plant population.

Soil-based production constraint

The compactness of the soil mainly under multi-ratooning system and build-up of weed flora and pests contribute to the loss of productive capacity of sugarcane-growing soils under long-term monoculture. The shallow root system of the ratoons reduces nutrient quenching ability and eventually makes the ratoon more sensitive to moisture stress and more demanding for available nutrients /addition of fertilizers.

Biotic constraints

Ratoon cane is subjected to biotic stresses like red rot, wilt, smut, grassy shoot, ratoon stunting and leaf scald diseases. The insect-pests like root borer, top borer, stalk borer, pyrilla and scale insect are the major pests causing damages to the crop in northern India.

Crop-based production constraint

Short life span- The maturity in the ratoon crop sets in prior to that of plant crop. It has been observed that under subtropical climatic conditions, the normal growth and vigour in both plant and ratoons remains conspicuous till elongation phase (mansoon). Thereafter, the plant crop takes a lead and develops more vigorously than ratoon.

***Root system*-** Sugarcane roots are short and die out quickly with little scope for substantial lateral growth, thus occupying smaller soil volume with limited foraging capacity and more prone to lodging.

***Arrowing and pith formation*-** Arrowing is characterized by cessation of growth and in case of ratoons, it sets in early than plant crop. Ratoons are also reported to have more pith than plant crop and thus cause less cane weight.

Varietal constraints

Sugarcane varieties having good ratooning potential under low/high temperature conditions are not available in plenty.

Cultural/operational constraints

Small holdings- Small holding sizes and socio-economic conditions of sugarcane farmers affect the adoption of improved mechanical devices and timely completion of cultural operations.

Planting and harvesting method- Sprouting of stubble buds occurs only at its favorable temperature. An early winter harvested plant crop may result in to more gaps; similarly harvesting of over matured canes during high temperature and desiccating winds in subtropical region render the bottom buds dry quickly and cause gaps. Piecemeal harvesting of plant cane creates problems in carrying out the cultural operations timely and the crop fails to obtain symmetry till its maturity.

The planting methods of sugarcane exhibit considerable impact in subsequent ratoon yields. Ratoons of Ring pit and trench method planted canes harvested close to the ground level by sharp edged chopper give higher ratoon yield over flat method of planting. Harvesting of cane leaving 4-6 inches above the ground portion give rise to poor ratoon crop.

Socio-economic constraints

Sugarcane is grown under highly diverse situations, poor socio-economic conditions and ignorance about the actual requirement of the ratoon cane for its nutrition and plant protection and other critical inputs for specific conditions result in low ratoon cane productivity.

B-TECHNOLOGICAL INTERVENTIONS

In order to raise the productivity of ratoon cane, to commensurate with the future sweetener requirement, it is essential to dispense the developed agro-techniques suitable for ratoon cane under different conditions.

Organic nutrition modules

For enriching rhizospheric microbial pool, maintaining soil health, enhancing cane productivity and making plant-ratoon system economically viable package of practices are recommended for plant/ratoon cane production. These are-

1. Irrigate the field 12-15 days after planting in spring and 18-20 days in autumn.
2. Blind hoeing at optimum field moisture to ensure adequate germination.
3. The irrigation and hoeing operations may be repeated at 15-20 days interval.
4. Earthing-up by mid of July for autumn and by mid of August in spring planted crop
5. Thereafter fixing and propping may be done to avoid lodging.
6. Autumn planted crop is harvested in February and spring planting in March.
7. Trash is aligned in the wind rows to facilitated operation for ratoon initiation.
8. Field is irrigated and inter-culture operation done at optimum field moisture.
9. Bio-manures viz., well composted SPM 10 t/ha + FYM 10 t/ha or SPM 10 t/ha + *Gluconacetobacter* proves ideal organic farming module

Adoption of suitable varieties

Cane varieties possessing high regeneration capacity and free from sett borne diseases are preferred. The optimum temperature for stubble bud sprouting ranges between 25-30^{0}C, therefore, harvesting of plant crop is to be scheduled accordingly. The characteristic features of varieties with better ratooning potential include- uniform and good bud sprouting and tillering in ratoon cane, non lodging tendency, less tiller mortality, adequate number of millable cane formation, resistant to insect pest and diseases, higher plant *vis-a-vis* ratoon yield and good cane juice quality.

Planting techniques and method of harvesting

Under low level of soil fertility, closer row spacing is better while in case of well fertile soils, wider row spacing is more remunerative . Tiller mortality is reported to be more in cases of 60 cm and 75 cm than 90 cm. Ring pit method of planting fetched the highest ratoon yields under multiple rationing system at Lucknow . The methods of planting of plant crop give rise to different levels of ratoon cane yield.

Climatic conditions during ratoon initiation

Proper development of ratoon crop is essentially dependent on sprouting of underground buds. Bud sprouting and germination is the function of optimum temperature, moisture and general vigour of the bud itself.

Stubble shaving

If the crop has been harvested close to the ground after flattening of ridges, then there is no need for stubble saving. But under farmers' practice where cane is harvested at 5-10 cm above ground level, stubble saving is essential because bud sprouted at apical portion dries up in due course of time for want of support, nutrients and water from the soil. This give rise to gappy stands in the field.

Off-barring

This involves cutting older roots from both sides of the cane row followed by fertilizer application near root zone when the soil attains proper tilth after irrigation. Due precautions are taken against approaching the cultivator beneath the stubble which may eventually disturbing it.

Plant population management

If the gaps are more than 15 per cent of the total clump population (27000-29000/ha) the productivity of the ratoon is adversely affected (Chauhan, 1992). Gaps could be reduced by putting sprouted stubbles of the same variety or through polybag raised sugarcane settlings. Material for gap filling (sprouted setts) should be 30-35 days old .

In order to sustain ratoon cane yield under multi-ratooning system, combination of various agro-techniques viz; trash mulching, gap filling, phorate application (15 kg/ha), stubble shaving and 20% extra seed to plant crop enhanced ratoon yield to the tune of 34,38,43, and 77% over control in Ist, IInd , IIIrd and IV ratoons, respectively. As an individual component technology, trash mulching and gap filling contributed 21-28 and 10-29% increase in yield, respectively indicating that these are the key management issues for multi-ratooning in sugarcane.

Ratoons have shallow root system and cannot tap nutrients from deeper soil layers unlike the plant crop, hence application of an extra 25 per cent nitrogen over the plant cane and specific micro-nutrients as per deficiencies exhibited by the crop are essential components for raising the productivity of the ratoon.

Use of Ratoon Management Device-an integrated approach

For raising a good ratoon crop above mentioned cultural operations *viz.* stubble saving, off-baring, fertilizer application and deep tilling in inter-row spaces are inevitable. To perform all these operations in time is an arduous task and labour intensive. The situation is more alarming for availability of manual workforce owing to Government aided different employment guarantee programs in the countryside. In order to provide a viable option to lend a technical support to the peasantry, the Indian Institute of Sugarcane research, lucknow has developed a machine called Ratoon Management Device (RMD), which can be operated by 35 HP tractor. The machine performs all the operation viz. stubble shaving, deep tilling, off-barring, placing of fertilizer/bio-agents and earthing-up simultaneously in a single pass. Its field capacity is 0.40 ha/h. The machine costs about Rs. 75000.

Intercropping with ratoon sugarcane

In order to harness the benefits of crop diversification, intercropping with ratoon sugarcane can be successfully adopted. In an intercropping of winter initiated ratoon with potato and wheat at Lucknow, Potato proved to be superior.

Nutrient Management

Various technologies have developed to provide nutrient requirements during sugarcane cultivation. These are-

- High C: N ratio at initial stage and less efficient root system of ratoon cane responds well with 25% more nitrogen than plant crop. Split application improves N use efficiency. Balanced nutrition is essential for both cane productivity and juice quality. Secondary and micronutrient are becoming critical in monoculture systems and must be supplemented wherever noticed.
- An integrated approach of nutrient management using organic manures, crop residues, green manures and bio-fertilizers with inorganic fertilizers is more effective in maintaining soil fertility and sustaining crop productivity.

- Intercropped green manure crop in plant cane and its residues in first ratoon increase the N use efficiency in terms of cane yield by 5.2% in the former and 13.4% in the latter case.
- Application of *Gluconacetobacter diazotrophicus* based bio-fertilizer saves 25-50 kg of chemical N/ha. *Berseem* (green manure) is reported to have increased the availability and uptake of water-soluble phosphorus (P) in the soil.

Water management

Ratoon cane transpire less water than plant crop but the amount of water required to produce per unit of dry matter is more in case of ratoons. The shallow root system and relatively more compact soil medium prefers light but frequent irrigation scheduling in ratoon crop. In subtropics the crop responds well when irrigated at 12-15 days interval depending upon the nature and type of the soil and crop stage. In tropical region the water requirement is about three times more than that of its subtropical counterpart.

***Water saving irrigation methods* –** These are

- **Selection of suitable varieties**
- Trash mulching
- Trench planting
- Applying irrigation at most critical stages of crop water need
- Sub-tropical belt (UP) : Skip furrow irrigation saves 36 % water
- Tropical belt (Maharashtra) : Drip irrigation economizes 45% water
- Water Use Efficiency-WUE : Skip furrow, FIRB and drip methods increase WUE

Weed management

In ratoons the "rapid-close-in" is much earlier than plant crop as the tillers emerge quickly just after harvesting as the apical dominance is removed. So, desirable weed free environment in ratoon fields is the first 10-12 weeks after its initiation.

Among cultural methods use of trash mulch has been found quite effective. Mulching in inter rows with cane trash holds promise as it is easily available in the field for ratoon crop. Triazines particularly atrazines and metribuzin (2 kg a.i./ha) applied at ratoon initiation stage as pre-emergence treatment (in relation to weeds) have been found quite effective in controlling weeds in ratoon fields. A post-emergence application of 2,4-D (0.5kg a.i./ha) could yield desired results.

Residue management

The crop residues (trash) left in the field after sugarcane harvesting accounts for about 10-15% of the weight of the cane harvested and left over root biomass in the soil constitute 5% of the cane harvest. Upon decomposition, this trash may supplement 30 kg N, 9 kg P and 24 kg K/ha. Conventionally the trash is burnt in situ to prevent the harboring of insects and pathogens as well as weeds and to clear the field at one go. The experiments have shown that for sustainable productivity under multiple ratooning systems, trash mulching is more useful than to burn it out. For accelerating decomposition of trash, application of *Trichoderma* is suggested. Trash mulching is done on alternate rows of ratoon cane to facilitate the irrigation and other cultural operations without interruption

Harvesting

Scheduling by variety

Sugarcane varieties are designated into early, mid-late and late, not exactly on the basis of crop-duration but on the prospective period of harvest during the harvest season. Thus, an early variety is required to be harvested first in the crushing season which also indirectly implies that it has attained maturity in terms of commercial sugar recovery. Similarly, Ratoons mature earlier than plant crop so their harvesting schedule is be prepared keeping in view the nature of variety and time of ratoon initiation.

Scheduling by date of ratoon initiation

When only one variety is predominant, it is desirable to schedule harvesting according to the date of planting ratoon initiation or harvesting of plant crop for ratoon. This practice is widely used in Maharashtra and Tamil Nadu.

Harvesting methods and transport

It is advisable to use sharp steel blade mounted on wooden base with a handle. It cuts the cane stalks at an angle. Cane should be cut flush to the ground. The canes should be de-trashed thoroughly after topping with sickle or a stripper. If the transport of the cane is likely to be held up for a period exceeding 48 hours, proper care should be taken as to heap the bundles under shade, cover them with trash and occasionally sprinkle water to prevent fast deterioration.

Ratoon management under specific conditions

Under optimal conditions of input availability:

- At the time of harvest of plant crop, stubble shaving flush to the ground level is essential to promote a uniform sprouting.
- The inter row spacing should receive deep cultivation (off-barring) to improve the soil physical condition and also to prune the stubble roots. It should be irrigated soon after.
- The ridges should be dismantled after harvesting of plant crop.
- Fertilizer nitrogen may be applied in two equal splits within 60 days of ratoon initiation. The requirement is 25 percent higher than for the plant crop. The ratoon crop generally requires phosphorus and potash fertilization at the rate of 60 kg/ha. The actual requirement may, however, better be ascertained by soil test.
- Gap filling, using pre-germinated setts or by utilizing the stubble of the same variety is essential if gaps are more than 15 percent.
- Malathion @ 1 kg a.i./ha is required to protect the crop where black bug incidence is high.

Under conditions of piece-meal harvesting of plant crop

In Uttar Pradesh, Bihar, Haryana and Punjab where the numbers of suppliers are too many and quantity of cane supplied per harvest order is rather small, whole field cannot be harvested in one lot even if it is smaller in size. In such a case stubble shaving may be deferred until the last harvest. This will ensure a uniform crop stand. However, it should not be postponed beyond April.

Ratoon with late shoots

These are called water shoots or late shoots or lalas which are often thick, succelent and appear later when early tillers are fully developed. The retention of such shoots during late harvesting of plant crop give good ratoon crop. Heavy earthing up, fertiliger application and frequent irrigation are essential for satisfactory ratoon yields.

Ratooning under low temperature conditions

Plant crop harvested during very low temperature (below 10^0C) produces less ratoon yield due to poor sprouting. This should be avoided, however, if it is essential, a thick trash blanket (20 cm) may be spread over the stubble to prevent them from sprouting until the season becomes warm (February) when the trash may be removed and spread in the inter-row spaces. Inter-cropping of berseem in winter initiated ratoon also protects the buds from extreme winter and encourages sprouting.

Ratoon Management Device is a viable option and can be tried successfully to minimize manual labor and complete the necessary agronomic practices in one go.

C – CROP PROTECTION MEASURES

Major insect-pests and their control measures: Sugarcane is attacked by at least 125 species of different insect pests. In sub-tropics, root borer, stalk borer, top borer, Gurdaspur borer, pyrilla and scale insect are the common insect pests while in the tropics, shoot and internodes borers are more prevalent. Beast management practices can be adopted to solve the problems.

Major diseases and their control measures

A total of 55 diseases of sugarcane caused by fungi, bacteria, viruses, phytoplasmas and nematodes have been reported from India. The economic importance and causing huge losses caused by them to the crop are red rot, wilt, smut, ratoon stunting, grassy shoot, pokkah boeng and yellow leaf disease. Integrated disease management practices can be adopted to solve the issue.

CONCLUDING

Sugarcane is important cash/industrial crop and grown worldwide. Ratoon crop is lagging behind the sugarcane crop because of poor crop yield and less income. But now days it is changing, and farmers are getting equal or more yield than cane crop. Because, it can be improved by adoption/application sugarcane cultivation practices and insect-pests, diseases and other like water, weed and nutrient management methods. By adopting best technologies with suitable techniques ratoon crop could get maximum benefit by putting minimum efforts.

Chapter No. 26: Soil Testing for Soil quality Parameters

S. R. Singh
Principal Scientist
Division of Crop Production
ICAR-Indian Institute of Sugarcane Research, Lucknow
Email: shivramsingh22@gmail.com.

Crop yields that are high require adequate supplies of all essential nutrients. As soil is the primary source of the majority of the essential nutrients required by crops. Accurate evaluations of nutrient removal and replacement, crop production statistics, and soil analysis results may assist the producer in managing fertilizer applications. A soil analysis is used to determine the nutrient content of a soil sample. As such, it can only be as accurate as the sample taken in a particular field. The results of a soil analysis provide an estimate of the amount of fertilizer nutrients needed to supplement those in the soil. After nutrient analysis, principal component analysis help to sort out the minimum data set or soil quality indicator in a particular region, and crops that can be improved or increased by balance fertilization. Applying the precise dose of needed fertilizer on the basis of soil testing results, provide a more reasonable chance to obtain the desired crop yield and improve soil quality.

Soils are the foundation for life on Earth in the most basic sense. Plants rely on soils as a pedestal to stay erect. It is made up of organic matter (humus), mineral matter, soil water, and soil air. There are seventeen nutrients in the soil required for plant growth. Soil dissolves nutrients and makes them available to plants in conjunction with water content; it acts as a buffer medium for disruptions in biogeochemical processes important to climate change; and it serves as a reservoir for various natural resources. Natural minerals, parent material, amount of organic matter, depth to bedrock, sand, or gravel, permeability, water holding capacity, and drainage of soil all have an impact on nutrient availability. The majority of the carbon (C) and nutritional components that support life are generated and stored in soils, which also serve as the habitat for a tremendous biodiversity and biomass of soil organisms and life itself. As soils reduce the pace of water movement and hold onto the water that plants and soil organisms need to exist and flourish, they also minimize soil erosion and loss. Additionally, soils have a substantial role in both the source and sink of greenhouse gases, which has an impact on temperature and the composition of the atmosphere.The function that soils play in supplying food for human populations and feed for livestock is one of the most evident ways that soil benefits people on a social level. For more than 12,000 years, people have directly manipulated soils for the production of food and feed. Soils have been indirectly controlled for the production of food and feed for decades through hunting and gathering. Currently, crop agriculture accounts for around 12% of the terrestrial land surface, while grazing lands account for about 25% of the total area used for food and feed production. The availability of the materials required for the production of food and feed varies greatly amongst soil types. For instance, due to the high P sorption capacity of residual iron and aluminum minerals, along with deep profiles and the lack of new P inputs from weathering products of primary minerals, old, heavily weathered soils often possess low phosphorus (P) availability. Recently unglaciated areas, newly formed volcanic soils, high latitude regions with low mean annual temperatures, or regions with little temperature seasonality, low mean annual precipitation, low soil clay fractions, or high seasonality in precipitation are all prone to inherent nitrogen (N) limitation. The elements that influence pedogenesis influence how well various crop species can grow and how productively soils can support agriculture.

What is soil testing?

Soil testing is the procedure used to chemically remove elements like phosphorus, potassium, calcium, magnesium, sodium, sulphur, manganese, copper, and zinc from the soil and determine how much of each element is present in the sample of soil. This is a crucial diagnostic tool for identifying plant nutrients.In other words, it is an investigation of farmland for a variety of factors, including chemical content, toxicity, pH level, salinity, earth-dwelling biota, etc. These tests can reveal information on cation exchange capacity, humic or organic content, electric conductivity, chemical contamination, and other physical and chemical characteristics.

Objectives of Soil Testing:

- To assess the soil's inherent ability and nutrient status in order to provide a measure of nutrient supply or availability in a particular soil.
- Identification of issues with acidity, salinity, and alkalinity.
- To make a suggestion for the quantity of manure and fertilizer depending on the results of the soil test and the type of crop.
- To protect the environment and prevent overuse of fertilizer and determination of the soil's suitability for the crop.
- Restoring soil fertility is essential for crop productivity, financial success, and long-term sustainability.
- Crop needs, soil availability, fertilizer use effectiveness, manure contribution, etc. must all be taken into account when planning a fertilization programme.
- A site-specific, balanced fertilization programme must be developed after periodic evaluation of the underlying soil fertility level.

Benefits of Soil Testing

- Soil analysis helps better fertilizer decisions by lowering soil hazards like erosion, soil infertility, and damaged lands, as well as by enhancing long-term agricultural profitability.
- Assess the nutrients status existed in the soil profile as well as identifies key limiting nutrients that might reduce crop yield.
- Keeps track of the qualities of the soil that affect crop yields and profitability, such as pH, EC, and OC.
- Offers a foundation for variable rate application (VRT) based on the crop and soil.
- Aids in decisions on the quantity, timing, location, and type of fertilizer.It also offers a farm management tool with a possible benefit to the farmer of improved awareness of the soil types inside the farm to maximize management possibilities.
- Soil testing also improved crop maturity and quality, higher tolerance to disease and pest damage, and increased, and reduced operating costs, and superior environmental risk management crop growth due to applying precise amount of mineral fertilizers.

What are the Soil Testing benefits for Farmers?

Soil testing provides plenty of benefits for farmers. Healthy soil improves crop growth. Farmers can begin testing their soil before harvest season to get a jump on how they can improve their soil. These benefits can help farmers by:

- Improving yields and profitability because due to providing necessary nutrients to particular crop.
- Increasing consistency of nutrient availability across a field.
- More uniform crop growth. This also helps individual plants stronger against weeds and simplifies other processes like cultivation and spraying.
- More uniform plant maturity. This can help simplify crop harvesting and drying along with improving market quality.
- Allowing fine-tuning of which nutrients are most needed. Helping to allocate fertilizer dollars to those nutrients that will give the greatest profit increase.

Soil sampling procedure and material required

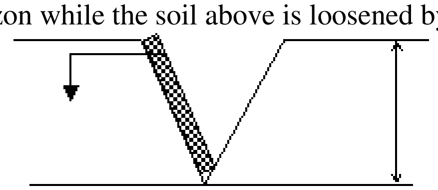
The management of soil resources must include soil testing. Every sample that is taken needs to be an accurate representation of the area being studied. The accuracy of the sampling will determine how useful the results of the laboratory analysis are. In order to obtain a sample of the necessary size through subsampling, it is therefore advised to gather a large number of samples. In most cases, one sample is taken for every two hectares of land. However, a minimum of one sample needs to be taken for each region up to five hectares. In order to conduct a soil survey, samples are taken from a soil profile that is typical of the soil in the surrounding area. Soil sample collection requires a spade or auger (screw or tube or post hole type), khurpi, core sampler, sampling bags, and a plastic tray or bucket.

Points to be considered

1. Take a soil sample while the land is fallow.
2. Take samples collected between the rows of the standing crop.
3. Sampling should be collected in a zigzag pattern across a number of sites assures homogeneity.
4. It is possible to combine fields that are comparable in terms of their look, productivity, and previous management techniques into a single sample unit.
5. Take distinct samples from fields with different colour, slope, drainage, and past management techniques including liming, applying gypsum, fertilizing, cropping systems, etc.
6. Steer clear of sampling near main bunds, trees, manure piles, irrigation channels, moist areas, dead furrows, and wet patches.
7. For crops with shallow roots, take samples up to 15 cm deep. For crops with deep roots, take samples up to 30 cm below the surface. Gather profile samples for tree crops.
8. Whenever possible, collect the soil sample in the presence of farm owner who know the farm in better way.

Soil sampling procedure

1. Divide the land into various homogeneous units based on visual observation and expertise. Clear the sampling site of any surface trash as well.
2. Drive the auger to a plough depth of 15 cm and draw the soil sample.Collect 10 to 15 samples from each sampling unit, and put them in a bucket or tray.
3. If an auger is not available, use a spade to make a "V"-shaped cut in the sampling area at a depth of 15 cm (Table 1). Cut the soil into thick slices (2 cm) and remove them from the exposed face of the 'V'-shaped cut, placing them in a clean container. Prick the surface with a knife or edge of the spade to show up structure, colour and compactness. After the profile has been exposed, clean one face of the pit carefully with a spade and note the succession and depth of each horizon.
4. Collect samples starting from the bottom most horizon first by holding a large basin at the bottom limit of the horizon while the soil above is loosened by a khurpi.



1 inch / 2.5 cm 6 inches (15 cm)

5. Mix the samples thoroughly after removing foreign materials like roots, stones, pebbles and gravels.
6. Reduce the bulk to about half to one kilogram by repeated quartering or compartmentalization.
7. Quartering is done by dividing the thoroughly mixed sample into four equal parts. The two opposite quarters are discarded and the remaining two quarters are remixed and the process repeated until the desired sample size is obtained.
8. Compartmentalization is done by uniformly spreading the soil over a clean hard surface and dividing into smaller compartments by drawing lines along and across the length and breadth. From each compartment a pinch of soil is collected. This process is repeated till the desired quantity of sample is obtained.Mix the sample and transfer to a polythene or cloth bag and label the bag with information like name of the farmer, location of the farm, survey number, previous crop grown, present crop, crop to be grown in the next season, date of collection, name of the sampler *etc*.

Table 1: Guidelines for soil sampling depth

S. No.	Crops	Soil sampling depth (cm)
1.	Grasses and grasslands	5
2.	Rice, wheat, maize, finger millet, groundnut, pearl millet, small millets etc.(shallow rooted crops)	15
3.	Cotton, sugarcane, banana, tapioca, vegetables etc. (deep rooted crops)	22-25

4.	Perennial crops, plantations and orchard crops	Three soil samples at 30, 60 and 90 cm

Processing and storage

1. Assign the sample number and enter it in the laboratory soil sample register.Dry the collected soil samples from the fieldin shade by spreading on a clean sheet of paper after breaking the large lumps, if present.
2. Spread the soil on a paper or polythene sheet on a hard surface and powder the sample by breaking the clods to its ultimate soil particle using a wooden mallet and sieve the soil material through 2 mm sieve.Repeat powdering and sieving until only materials of >2 mm (no soil or clod) are left on the sieve.
3. Collect the material passing through the sieve and store in a clean glass or plastic container or polythene bag with proper labeling for laboratory analysis.
4. For the determination of organic matter it is desirable to grind a representative sub sample and sieve it through 0.2 mm sieve.
5. If the samples are meant for the analysis of micronutrients at-most care is needed in handling the sample to avoid contamination of iron, zinc and copper. Brass sieves should be avoided and it is better to use stainless steel or polythene materials for collection, processing and storage of samples.
6. Moist soil samples should be used for the analysis of NO_3-N and NH_4-N as well as for microbial analysis.
7. Field moisture content must be estimated in un-dried sample or to be preserved in a sealed polythene bag immediately after collection.
8. Estimate the moisture content of sample before every analysis to express the results on dry weight basis.

Soil quality features, analysis methods, range and interpretation

All soil quality attributes are determined by using a specific soil exgtractant that has been suggested by various researchers (Table 2). Soil test results include the amount of macronutrients nitrogen, phosphorous, potassium, calcium, magnesium, sulphur, zinc, copper, iron, manganese, boron and molybdenum. Laboratory methods for soil testing vary, which can affect results and sufficiency ranges. As a result, the sufficiency ranges are only accurate for the test methods listed. Soil tests can measure soil nutrients that are expected to become plant-available but not total nutrient levels in the soil. Because only a small portion of the nutrients are available, total nutrient content measurements are not useful indicators of sufficiency for plant growth. Plant-available nutrients are taken up by roots as positively or negatively charged ions from the soil (Table 2). Soil test results can be viewed in three categories: (1) low or yes, a fertilizer addition will likely increase growth and yield; (2) high or no, a fertilizer addition could not likely increase growth or yield; and (3) intermediate or maybe, a fertilizer addition may increase growth or yield. Categorization of soil test results into “yes,” “no,” and “maybe” assists understanding the limits and benefits of using soil test results for making nutrient recommendations. Most soil test results do not differ significantly from year to year. Some soil and environmental conditions, however, cause fluctuations in measurements like pH and available nitrogen. Changes in test values from one year to the next may indicate an unrepresentative soil sample or a laboratory error. When in doubt, send in a new sample or request that the lab repeat the analysis. Proficiency Testing is included in quality control programmes for agricultural soil testing laboratories.

Table 2. Soil quality characteristics, analytical methods, nutrient range, and interpretation

S. No.	Soil attributes	Method employed	Reference	Soil ratting chart		
				Low	**Medium**	**High**
1.	Sand (%)	Hydrometric method	Bouyoucos (1962)			
2.	Silt (%)					
3.	Clay (%)					
4.	pH	Glass electrode pH meter	Jackson(1973)	<6.5	6.5-7.5	>8.5

		(Soil: Water::1:2.5)				
5.	Electrical conductivity (dS m^{-1})	Conductivity Bridge (Soil: Water::1:2.5)	Jackson(1973)	<1.0	1.0-2.0	>2.0
6.	Soil organic carbon (%)	Rapid titration method	Walkley& Black(1934)	<0.5	0.5-0.75	>0.75
7.	Available N	Alkaline $KMnO_4$ method	Subbiah and Asija(1956)	<2800	280-560	>560
8.	Available P	Olsen's method	Olsen *et al.* (1954)	<10	10-25	>25.0
9.	Available K	Flame photometric method	Jackson(1973)	<120	120-280	>280
10.	Available S (mg kg^{-1})	Tubidimetric method	Chesnin and Yien . (1951)	<10	10-20	>20
11.	Zinc (Zn) (mg kg^{-1})	DTPA method	Lindsay and	<0.6	0.6-1.20	>1.20
12.	Copper (Cu) (mg kg^{-1})		Norvell (1978)	<0.2	0.2-0.4	>0.4
13.	Iron (Fe) (mg kg^{-1})			<4.5	4.5-9.0	>9.0
14.	Manganese (Mn) (mg kg^{-1})			<2.0	2.0-4.0	>4.0
15.	Boron (B)	Hot water method	John et al. (1975)	<0.50	0.50-0.75	>0.75
16.	Molybdenum (Mo)	Ammonium oxalate method	Gupta and MacKay (1966)	<0.10	0.1-0.20	>0.20

The interpretation of soil analysis results is critical for recommending fertilizers for a specific crop. When the analysis resulted in "low" in a category, it meant that the soils were deficient and needed additional doses of a specific nutrient for a sustainable crop yield. Differing fertilizer recommendation philosophies can provide multiple recommendations from the same soil test results. For example, nutrient application recommendations are based on the philosophy that nutrients should only be applied when an economic yield increase is likely. In contrast, another philosophy for nutrient application is soil test level maintenance, commonly used under soil test crop correlation (STCR) concept in which fertilizers applied for fertilizing the crop *V/s* fertilizing the soil. Soil test level maintenance is accomplished by fertilizing nutrients removed by crop harvest. Nutrients are applied even though the soil test level for these nutrients may be sufficient. Nutrient concentrations vary with soil depth, which affects soil test results. To determine the proper sampling depth, you must consider the purpose of the soil test. To estimate fertilizer requirement prior to planting, sample soil to the depth where most root activity will occur, usually a depth of 6 to 12 inches. Shallow sampling, 2 to 3 inches, is sometimes used to evaluate fertilizer need in perennial crops where fertilizers have repeatedly been applied to the soil surface. A combination of sampling depths may be necessary to diagnose problems in orchards.

Soil quality

Soil quality is defined as the soil's ability to perform ecological functions and provide ecosystem services in order to maintain biological productivity and environmental quality while also improving plant and animal health. Resistance to perturbations (natural or man-made) and rapid recovery are characteristics of healthy soil (Schoenholtz et al., 2000). The incorporation of multiple factors such as physical, chemical, biological, and enzymatic activity can result in a more accurate and better soil assessment. These variables should be used in tandem as indicators of soil quality assessment.

Soil quality indicators

Clear goals for ecosystem restoration, as well as effective tools for assessing and monitoring progress, are critical to restoration success. Soil quality indicators can be useful tools for monitoring and assessing ecosystems. Recent advances in the development of soil analysis methodologies, such as sensing techniques or molecular methods, offer unprecedented opportunities to incorporate soil indicators into restoration programmes. Despite the significant potential benefits of using these indicators as tools in ecosystem restoration, calibrating and establishing global soil parameters remains difficult due to the wide range of soil, climate, and ecosystem types. Soil quality indicators use to evaluate how well soil functions since soil function often cannot be directly measured. Soil quality measurement is an exercise in identifying soil properties that respond to management, influence or correlate with environmental outcomes, and can be precisely measured within certain technical and economic constraints. Soil quality indicators can be qualitative (for example, fast drainage) or quantitative (infiltration = 2.5 in/hr). Ideal indicators should:

- Correlate well with ecosystem processes
- Integrate soil physical, chemical, and biological properties & processes
- Be accessible to many users
- Be sensitive to management & climate
- Be components of existing databases
- Be interpretable

Soil indicators are classified into three types: chemical, physical, and biological. Soil tests are typically only concerned with chemical indicators. Soil quality makes an effort to incorporate all three types of indicators. Because the categories do not neatly align with the different soil functions, integration is required. The relationship between indicator type and soil function is shown in the table 3:

Table 3. Soil indicators and relation to soil function

Indicator category	**Related soil function**
Chemical	Nutrient Cycling, Water Relations, Buffering
Physical	Physical Stability and Support, Water Relations, Habitat
Biological	Biodiversity, Nutrient Cycling, Filtering

Organic matter, or more specifically soil organic carbon, is the most widely recognized influence on soil quality and transcends all three indicator categories. All soil functions are linked to organic matter. It influences other indicators such as aggregate stability (physical), nutrient retention and availability (chemical), and nutrient cycling (biological), as well as being an indicator of soil quality in and of itself. Some indicators are descriptive and can be used as part of a health card in the field. Others must be measured in a laboratory setting. Below are some examples of indicators that fall into the three broad categories of chemical, physical, and biological are listed below (Table 4).

Table 4. Potential indicators for soil assessment

S. No.	**Soil parameters**	**Soil parameters**
A.	**Physical indicators**	
1.	Bulk density, infiltration, slaking, soil crusts,	Potential indicator for soil compaction, porosity, microorganisms growth and activity
2.	Texture, structure and macro-pores	Potential indicator for soil quality, growth and activity of microbial biomass
3.	Soil water content	Potential indicator of microorganism's growth and activity
B.	**Chemical indicators**	
1.	Soil salinity	Potential indicator of soil fertility by reducing the growth of microorganisms
2.	pH	Potential indicator for microbial growth and their activity
3.	Cation exchange capacity	Potential and sensitive indicator for determining nutrient holding capacity and fertility of soil, enhancing the microbial activity of soil
4.	Nitrogen	Potential indicator for soil fertility

5.	Phosphorus	Potential indicator for soil fertility causes shifts in the microbial community
6.	Potassium	Potential indicator for soil fertility by affecting nitrogen fixation and increase microbial activity but excess potassium also causes the reduction in microbial activity, plant growth and crop yield
7.	Sulfur	Potential indicator of soil fertility, increase plant productivity by enhancing protein synthesis to combat abiotic and biotic stress, favors nitrogen fixation
8.	Soil organic matter	Potential indicator to monitor soil degradation, erosion, enhance water holding capacity, soil texture, enhancing biological activity and diversity
C.	**Biological Indicators**	
1.	Bacteria	Use as potential indicator to monitor various soil disturbances such as herbicide, wastewater effluent, organic waste and toxic metals contamination such as lead, silver nanoparticle and Uranium.
2.	Actinomycetes	Use as potential indicator against polymetallic, Polycyclic Aromatic Hydrocarbons (PAHs) and copper contamination.
3.	Algae	Use as potential indicator for archeological sites and use as potential indicator for organic rich soil
4.	Fungi	Use as potential indicator for soil disturbances, drought affected soil, nitrogen, phosphorus and potassium treated soil, manure treated soil, soil contaminated with petroleum hydrocarbons, soil organic carbon and total nitrogen
5.	Soil enzymes	Indicator for higher pesticide application and high salinity soil, plays central role in carbon cycling (Amylase), heavy metals contamination, organic and sludge amendment in soil, and sulfur cycling (Arylsulfatase), monitoring soil health, performs a primary role in carbon cycling, detects heavy metal, soil salinity and pH (β-Glucosidase), potential indicator for heavy metals contamination, organic amendment in soil (Cellulases), potential indicator for disturbed soil, act as biopesticides and biocontrol agents (Chitinases), potential indicator of biological activity, heavy metals, crude oil contamination, insecticide and herbicide contamination, sludge amendment in soil (Dehydrogenase), potential indicator for cadmium contamination, organic matter and nitrogen fertilization and tillage (Phosphatase) and potential indicator for petroleum contaminated soil, heavy metal contamination, drilling waste contamination, drought affected soil and pH change in soil (Urease).

Conclusions

The laboratory results usually provide some interpretation as part of a soil analysis, including an indication of whether individual soil tests are low, medium, or high. Based on the analysis, the laboratory may also make fertilizer recommendations, though these are plant and soil-specific. Routine sampling, analysis and sort out of liming nutrient as soil quality indicators can be useful tools for small-acreage management. Keeping track of soil analysis results and sort listing of minimum data set can also provide useful information about long-term changes in soil properties.

References:

John, M. K., Chuah, H. H. and Neufeld, J. H. (1975). Application of improved azomethine-H method to the determination of boron in soils and plants. *Analytical Letters*, 8: 559–568.

Gupta, U. C. and MacKay, D. C. (1966). Procedure for the determination of exchangeable copper and molybdenum in podzol soils. Soil Sci. 101: 93-97.

Lindsay, W. L. and Norvell, W. A. (1978). Development of a DTPA soil test for zinc, iron, manganese, and copper. Soil Sci. Soc. Amer. J. 42:421-428.

Schoenholtz, S.H., Van Miegroet, H. and Burger, J.A. (2000). **A review of chemical and physical properties as indicators of forest soil quality: challenges and opportunities.** Forest Ecology and Management, 138: 335-356

Chapter No. 27: Water management in Sugarcane

M. K. Tripathi, V.K. Singh, A.P. Dwivedi, Shivam Tripathi* and Ankur Tripathi**
Principal Scientist, ICAR-IISR, Lucknow
*Ph.D. Scholar, CSUAT, Kanpur
***Ph.D. Scholor, ANDUAT, Ayodhya

Water is of fundamental importance to human development, the environment and the economy. Access to water and water security is paramount to improving food security, incomes and livelihoods of rural communities. India has 16% of the world's population, 2.4% of the world's land area and 4% of the world's fresh water resources. On an average, every year India receives 4,000 billion cubic meters (BCM, 1 BCM = 1 cubic km) of water by mostly rainfall and some snowfall. However, there are considerable spatial and temporal variations in the distribution of rainfall and hence in the availability of water in the country. It is estimated that out of the 4000 BCM of water, 1869 BCM are "available water resources". Out of this quantity only 1123 BCM (690 BCM from surface water resources and 433 BCM from ground water) can be put to use ("usable water resources"). The water demand in the year 2000 was 634 BCM and demand is expected to be 1093 BCM by the year 2025. In India, water availability per capita has declined from 5000 cubic metres (m3) per annum in 1950 to around 2000 m^3 now and is projected to decline to 1500 m^3 by 2025 leading to far less water availability for agriculture. The water availability for agricultural use has reached a critical level as the country uses more than 80 per cent of the surface water for this sector alone. Agriculture production is highly dependent on water and increasingly subject to water risks. Improving agriculture's water management is therefore essential to a sustainable and productive agro-food sector.

Sugarcane, an important cash crop of the country, requires considerable quantity of water during its entire crop cycle of 12-18 months, depending on agro-climatic regions varying from subtropical to tropical regions. Indeed, sugarcane is one of themostwater-demandingcrops after rice. The annual water requirement of this crop in sub-tropical states like Uttar Pradesh, Punjab, Haryana and Bihar is 1400-1600 mm. In Maharashtra regions having annual rainfall of about 500mm. the water requirement of sugarcane varieties from 2400 to 3000 mm for a crop of 12 months duration whereas 3200-3500 mm. is required for the crop of 16-18 months duration. Number ofirrigationinsugarcanedependsuponthe climatic conditions, type of soil,method of planting and use of manures and fertilizers. The hotweather associated with dry winds and drought increases the water requirement of thecrop.

Waterisauniversalsolventwhereinmanybiochemicalprocessesanddiffusionofsolutestake place in plant cells and regulates temperature inplants.Beingincompressibleitsupportsthe plant structure. Turgidity of thecells, which is main tainedby water, is essential for physiological and biochemical processes to occur and support growth. Water/moisture content (%) in various morphological components is as follows:leaf laminae:68–70;leafsheaths:78–80;stalk:80–85androots:70–75(Shrivastava, 2006). Bringing down the moisture content from 83%to73% in the third, fourth and fifth leaf sheaths and from 84% to 74% in the eighth, ninth and tenth internodes during 2–5monthsbeforeharvest,enhanced accumulationofsugars. Water requirement is the total amount of water needed for raising a crop successfully.In the case of sugarcane, it includes the amount of water for meeting the need so fevapotran spiration and metabolic activities (known as consumptive use), losses during application of water and water needed for land preparation as pre-planting irrigation (Srivastava and Johari, 1979). Water loss from the soil take splace through surface evaporation, transpiration by plants and per collation beyond the rootzone. Under fieldconditions, water requirement is met effectively by rainfall, contribution from groundwater (if thewater table is within the reach of the root system) and irrigation. It varies from place to place depending on weather conditions, texture of soil and development of crop(Verma,2004).

Sugarcane cultivation is mainly concentrated in areas having assured and adequate irrigation as the crop remains in the field for a year or more and undergoes wide fluctuations in weather conditions according to the change in seasons from dry to wet and cold to very hot. Under such conditions, necessary, timely irrigation saves the crop and ensures its growth and development. Contrary to general perception of being a water guzzler, sugarcane is a water-efficient crop as biomass produced against per unit of water used by the crop matches with those of highly water-efficient crops like pearl millet and sorghum. Irrigation requirement of the crop is, however; comparatively higher and depending upon soil and climatic conditions it varies from 500 mm to 3500 mm during the crop season. It is because the formative phase on the crop development called tillering coincides with the dry, hot summer season in almost all the sugarcane growing regions of the country and adequate irrigation is compulsory to get higher tiller numbers that makes the millable cane, the final yield attributing factor of sugarcane. Irrigation water applied during this phase makes up for 75-85 % of total irrigation water requirement of the crop the rusty being needed during germination and grand growth phases. However, water requirement of sugarcane is highest during grand growth phase that is up to 85% of the total water requirement and mostly met through rains as most of the sugarcane growing regions in the country receive copious rains during this phase of the crop. Like other crops, sugarcane too utilizes just 1-2 % of the total water requirement for metabolic needs. Research conducted to economize water use in sugarcane has revealed that for high yield irrigation is required during tillering phase of the crop especially during 45 to 120 days after planting at an interval of 10-15 days with 75 mm depth of each irrigation.

Further, during ripening and maturity phase, 2-3 irrigations are needed at an interval of 15-20 days to support adequate sugar accumulation in the internodes. On average irrigation meets only 30-40 % of total crop water requirement in the sub-tropical region compared to 50-60 % in the tropical area. Practices like alternate furrow irrigation and mulching have been found to reduce the irrigation water requirement by 30 to 40 %. Adoption of furrow irrigation with adjustment of furrow length as per the field slope gradient and wetting of just 80 % of the furrow effectively saves 15-20 % irrigation water. Scheduling of irrigation in sugarcane based on cumulative pan evaporation and crop coefficients at various growth stages results in a significant saving of water that enhances up to 60 % with the use of micro-irrigation techniques like drip and fertigation.

Irrigation quantum is one of the most important abiotic stress factors limiting sugarcane production worldwide. Strong positive correlation exists between the growth rate of sugarcane and the optimum soil moisture regimes, because the vegetative growth is of economic importance in this crop. In India, 89% of the sugarcane area is irrigated, and hence, a suitable water-saving method needs to be practiced, which will result in saving a massive quantity of water. Sugarcane cultivation requires the land to be occupied for about 10 to 18 months and thus requires adequate irrigation to realize its potential yield. Sugarcane tolerates moisture stress to some extent but responds well to irrigation, and it is having a linear relationship between the growth rate and optimum soil moisture. Sufficient water is needed to realize maximum yield. There is a linear relationship between cane yield and actual evapotranspiration. On an annual basis, the total crop evapotranspiration (ETc) / water-use is in the range 1200-2000 mm, with peak daily rates varies 6 to 15 mm/day. The water requirement for sugarcane in India varies widely from 1100 to 3000 mm evenly distributed over the growing season, depending upon soil, climate and crop conditions, Majority of sugarcane farmers irrigate sugarcane with only 35-45% irrigation water use efficiency, leading to significant loss of irrigation water. It is being observed that irrigating sugarcane crop with 0.75 (tillering), 0.75 (grand growth) and 0.50 IW/EPE ratio (Irrigation water/Cumulative Pan Evaporation) at maturity phase, gave the highest cane yield. This showed that moisture stress during juvenile and grand growth phases of sugarcane crop reduces the product significantly. Still, at maturity stage, the crop can withstand moisture stress during juvenile and grand growth phases of sugarcane crop reduces the product significantly. Still, at maturity stage, the crop can withstand moisture stress to some extent. Irrigation at 0.8 IW/CPE is optimum and gave good sugarcane yield. This shows that there is an imperative need to optimize production of sugarcane by efficiently managing the available water resources. The stage, at which the sugarcane crop faces water deficit, will have a direct impact on the reduction of cane yields and ultimately affecting the sugar production, because the water requirement of sugarcane varies with the stage of the crop. In India, farmers must plan their acreage to be planted under cane crop according to the available water at their farm. Irrigation water depth of 7-8 cm is recommended. Since sugarcane is grown throughout the year, some months of a year will experience moisture surplus period (i.e. adequate rainfall will be more than the crop ETc-Monsoon) and some months will face moisture deficits (i.e. sufficient rain will be less than the crop ETc-Summer season). Again the evaporative demand of the climate and the water requirement of the crop are more during the deficit period compared to the surplus period, since these periods will usually be summer months. Under these circumstances, we have attempted to provide the sugarcane crop, the required soil moisture conditions throughout its growing period, to realize good yields and maximize the productivity.

The main reasons for large water requirement of sugarcane crops are therefore not the plant *per se* but the cultivation practices like wide spacing of rows, frequent hoeing to support tillering, flood irrigation and no mulching in plant crop. Water-use efficiency in sugarcane production can be improved and the by implementing more efficient irrigation systems, by covering the soil with a thick mulch cover to limit evaporation, and by implementing effective irrigation scheduling. Indian Institute of Sugarcane Research, Lucknow devised Irrigation water-saving techniques in sugarcane like skip furrow irrigation, irrigation at critical growth stages, trash mulching and ring pit planting methods for enhancing irrigation water use efficiency by 1.5 to 2.5 times (Shukla et al. 2020). The experiments conducted under the All India Coordinated Research Project AICRP(S) showed that surface and subsurface drip irrigation methods effectively saved water (up to 40%) and increased crop productivity to the tune of 20%. Fertigation with drip resulted in a 25% saving of nitrogen compared with surface irrigation. Drip irrigation system, once installed, could be effectively used for five years (up to fourth ratoon crop). The skip furrow/alternate furrow irrigation, a practical and useful approach of saving irrigation water by 30-40% water without reduction in cane yield, has been considered significant in which one row is skipped, and irrigation is applied in alternate furrows, missing one ruffle in between. In alternate furrow method, alternating tracks for irrigation each time have also economized water use, and the technique is recommended under limited water availability conditions.

The average quantity of water requirement per ton of sugarcane in India was estimated 565.27 m^3 / tonand for the Uttar Pradesh it was 207.81 m^3 / ton. Indian Sugar Mills Association (ISMA, 2013) estimated the total water requirement for sugarcane in India 80-100 BCM/year. Out of this 80 per cent of the irrigation requirements of sugarcane in India are met through groundwater sources. On an average about 88 kg water / kg of cane and 884 kg of water / kg of sugar is required for planted crop and about 118 kg water/kg of cane and 1157 kg water / kg of sugar for ratoon crop (NABARD, 2018). A study made by NASA on gravity recovery revealed fast depletion of groundwater (18 BCM/ year) in India, especially in the north and north western parts of the country, where 96% of crop area is irrigated(Sharma et al. 2018). During the last four decades, groundwater levels shrunk from 8 m below ground level to 16 m below ground level in north western India and have lost 109 km3 of groundwater between 2002 and 2008 (Rodell et al. 2009; Aeschbach-Hertig and Gleeson 2012). Considering the declining trend of annual precipitation and rising minimum temperature in the region (Srivastava et al 2021), further drop in groundwater table is very likely that will reduce the availability of irrigation water and raise the cost of irrigation leading to lower cane productivity. Sugarcane requires 6-8 irrigations in the northern part and 30-40 irrigations in the southern part of the country (Shukla et al. 2019). Majority of the sugarcane area is under surface method of irrigation having very low water use efficiency, therefore, efforts are needed to adopt different water saving strategies for better water management in sugarcane.

Ring pit method of planting:

The field is marked at a regular distance of 105 cm, leaving 65 cm space in the beginning, both length and width wise. Nearly, 9000 pits per ha of 75 cm diameter and 30 cm depth are made by pit digger. The soil dugged up from the pit is kept in the periphery of the ring in 30 cm space left in between the two pits. In every pit, organic manure and chemical fertilizers are added. Twenty setts (twobudded) are placed in each pit like spokes in a cycle wheel. The chlorpyriphos solution is applied on the setts and2-5 cm soil cover is made over the setts. One irrigation just after planting and blind hoeing prompt germination. Thirty days after germination, required urea is applied in each pit and half of the soil remaining at periphery is filled back in the pit. The filling of soil is completed when all the mother shoots have emerged. Interconnect each pit with narrow channel manually for irrigating the pits. As the irrigation water is applied in the pits only, more than 40 per cent surface area remains dry. For this reason, with the ring planting 25-30 per cent irrigation water is saved. Higher sugarcane yield and reduced quantity of irrigation water results in 30-40 per cent higher irrigation water use efficiency.

Figure1: Ring Pit method

Figure 2: Ring Pit Digger

Skip furrow method of irrigation:

In this method of irrigation, instead of irrigating all the rows and inter-row spaces, one row is skipped and irrigation is given in alternate rows. With this technique, limited water may be used to irrigate larger area. In this method, sugarcane is planted in flat bed as usual and after germination, 45 cm wide and 15 cm deep furrows are made in alternate inter-row spaces. At the time of irrigation, the furrows thus made are irrigated. Irrigating sugarcane with this method results in 36.5 per cent water saving and 64 per cent increase in water use efficiency.

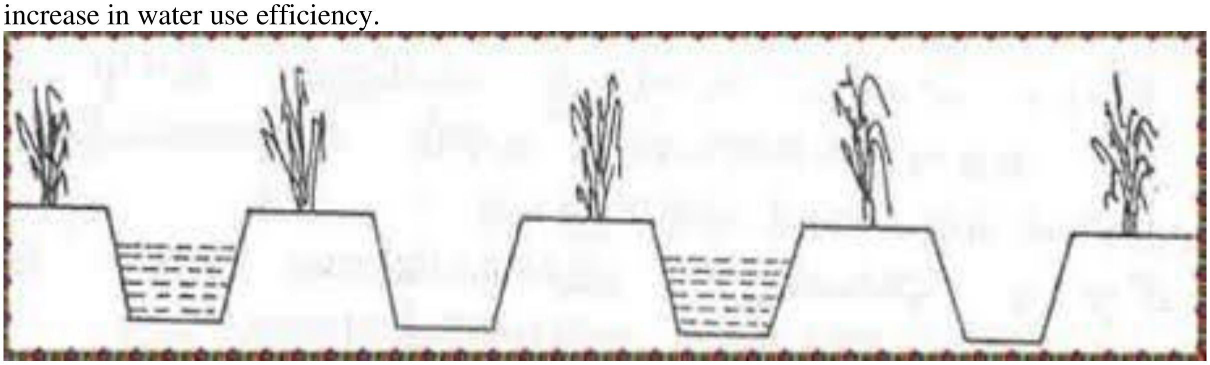


Figure 3: Skip Furrow Method

Trash mulching:
Sugarcane trash is a waste material available after harvesting of the crop. Trash is spread @ 10 t ha^{-1} in the alternate inter-row spaces in ratoon crop at the time of its initiation. Because of trash mulching, effectiveness of irrigation is increased as the evaporation losses of moisture from soil surface reduced considerably. Sugarcane crop yield and water use efficiency increases by 26 and 40 per cents, respectively, due to trash mulch as the trash mulch keeps the soil moisture at a higher level for a longer time as compared to uncovered soil surface. Increase in sugarcane yield due to trash mulch is attributed to favourable moisture condition, increased microbial activities and addition of water-soluble nutrients from the trash. In the long run, soil organic carbon content is also improved. Organic matter in the soil maintains the porous structure of the soil and improves its water holding capacity. To sustain sugarcane production under multiple ratooning system where the soil gets compacted by the movement of heavy farm machineries such as tractor and harvester, the organic matter content of the soil must be maintained either by recycling of organic farm wastes or by trash mulching.

Figure 4: Trash Mulching

Irrigation at critical growth stages:
In the areas of limited water supply, ensuring irrigation at critical period of water need of the crop and deferring the same at somewhat less critical period, improves yield and irrigation water use efficiency. These critical stages for sugarcane are emergence, first order of tillering, second order of tillering and third order of tillering. Depending upon the availability of water, the crop is irrigated at these stages. If two irrigations are available, then the irrigations are provided at second and third order of tillering. If three irrigations are available, then the irrigations are provided at all three orders of tillering. If four irrigations are available, then the irrigations are provided at all the four critical stages.

Drip Irrigation:
Drip irrigation is defined as the precise, slow and frequent application of water through emitters on or below the soil surface at a pressure of 20-200 kPa and at a low discharge rate of 0.6-20 litre per hour.Drip irrigation in sugarcane is a relatively new innovative technology that can conserve water, energy and increase profits.

Surface Drip:
The application of water to the soil surface as drops or a tiny stream through emitters placed at predetermined distance along the drip lateral is termed as surface drip irrigation.
It can be of two types - online or integral type surface drip system. Integral drip line is recommended for sugarcane.

Subsurface Drip (SDI):
The application of water below the soil surface through emitters molded on the inner wall of the drip line, with discharge rates (1.0 - 3.0 LPH) generally in the same range as integral surface drip irrigation.The integral drip line (thin or thick-walled) is installed at some predetermined depth in the soil depending on the soil type and crop requirements.There are two main types of SDI - "one crop" and "multi

crop".Subsurface irrigation saves water and improves yields by eliminating surface water evaporation and reducing the incidence of disease and weeds.

The drip irrigation saves the water to the tune of 25-50 % and the water loss through evaporation is minimized. With use of low quantity of water more yield may be achieved. In this method of irrigation problem of weed is also reduced and the growth of crop is homogeneous.

Figure 5: Drip Irrigation

Rain Gun:

The name itself is self-explanatory an irrigation system which showers like rain. Rain gun is also known as big sprinkler or water gun. Itis a high-performance micro-irrigation device.Rain gun can be moved in half or full circle at the same speed due to the use of gear technology in it. Normally sugarcane crop is irrigated by flood irrigation method. In flood irrigation much more water needs for one irrigation. When compared to flood irrigation method in sugarcane cultivation rain guns saves considerable amount of water, labour and time for irrigation to the same area.Rain gun sprinkler is available with an operating pressure of 2.0 to 7.5 kg/cm2 and flow of 3 to 30 lps. Most of them have nozzle diameters ranging from 10 to 30 mm and a wetting radius of around 27- 60 meter.

Figure 6: Rain Gun

Laser Land Leveller:

Laser leveling reduces the water and time required to irrigate the field as it increases the distribution efficiency, creates a uniform water regime, decreases the water loss and avoids over irrigation in the head. The use of laser technology in the precision land levelling is of recent origin in India. It does not only minimize the cost of levelling but also ensures the desired degree of precision. Land levelling of farmer's field is an important process in the preparation of land. It enables efficient utilization of scarce water resources through elimination of unnecessary depression and elevated contours (Naresh et al., 2011). It has been noted that poor farm design and uneven fields are responsible for 30% water losses (Asif et al., 2003). Precision land levelling (PLL) facilitated application efficiency through even distribution of water and increased water-use efficiency that resulted in uniform seed germination, better crop growth and higher crop yield (Jat et al., 2006). It was estimated that around 25 to 30% of irrigation water could be saved through this technique without having any adverse effect on the crop yield (Bhatt and Sharma, 2009). The land levelling have resulted smoother soil surface, reduction in time and water required to irrigate the field, more uniform distribution of water in the field and more uniform moisture environment for crop.

Figure 7: Lase Land Leveller

Hydrogel:

Hydrogel is three-dimensional, hydrophilic polymer, loosely cross-linked networks capable of imbibing large amounts of water or biological fluids. These synthetic polymers found in form of crystals and available under several trade names viz., Super Absorbent, Pusa Hydrogel *etc.* are collectively called hydrogel. Hydrogels have great potential in areas where opportunity for irrigation is limited and can increase the water availability during crop establishment. The capacity of the hydrogel to absorb and retain water is as much as 80-180 times its original volume (Bowman *et al.,* 1991) while on weight basis it can absorb as high as 400 times its original weight (Kalhapure *et al.,* 2016). It enhances the crop productivity per unit available water and nutrients, particularly in moisture stress condition. It improves physical properties of soil, water holding capacity, water use efficiency and enhances soil permeability and infiltration rate.

Figure 8: Hydrogel

Fertigation:

Fertigation is the judicious application of fertilizers by combining with irrigation water.This can be achieved through fertilizer tank, venturi system, injector pump, Non-Electric Proportional Liquid Dispenser (NEPLD) and automated system. It ensures a regular flow of water as well as nutrients to crop resulting in better growth and development. Proper distribution of plant nutrients throughout the wetted root zone ensures increased nutrient availability & uptake contributing to higher cane yield. Fertigation supplies nutrients incrementally according to the crop developmental phases throughout the season to meet the actual nutritional requirements of the crop.

Since the quantity of water to produce sugarcane is considerably high, there is need to adopt efficient surface water application techniques, drip irrigation, rain gun, mulching, fertigation, use of laser land leveler and super absorbent molecules (Hydrogel) to improve the water use efficiency and water productivity of sugarcane crop.

References:

Aeschbach Hertig, W. and Gleeson,T. 2012. Regional strategies for the accelerating global problem of groundwater depletion. Nature Geoscience 5: 853–861. https://doi.org/10.1038/ ngeo1617.

Asif, M., Ahmed, M., Gafool, A. and Aslam, Z. 2003. Wheat productivity Land and Water Use Efficiency by Traditional and Laser Land-leveling Techniques. On line J. Biol. Sci. 3(2):141-146.

Bhatt, R. and Sharma, M. 2009. Laser leveler for precision land levelling for judicious use of water in Punjab,Extension Bulletin, Krishi Vigyan Kendra, Kapurthala, Punjab Agricultural University, Ludhiana.

Bowman, D. C. and Evans, R. Y. 1991. Calcium inhibition of polyacrylamide gel hydration is partially reversible by potassium. *Hortic. Sci.,* 26 (8): 1063–1065.

ISMA. 2013. https://www.indiansugar.com/. Accessed 30 Nov 2021.

Jat, M.L., Chandna, P., Gupta, R.K., Sharma, S.K. and Gill. M.A. 2006. Laser land levelling: A precursor technology for resource conservation, Rice-Wheat Consortium Technical Bulletin Series 7, Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi. P. 48.

Kalhapure, A., Kumar, R., Singh, V.P. and Pandey, D.S. 2016. Hydrogels: a boon for increasing agricultural productivity in water stressed environment. *Current Sci.,* 111(11): 1773–1779.

NABARD.2018.https://www.nabard.org/demo/auth/writereaddata/File/11%20_Sustainable_Sugarcane_Initiative. Accessed 30 Nov 2021.

Naresh, R.K., Gupta, R. K., Kumar, A., Prakash, S., Tomar, S.S., Singh, A., Rathi, R.C., Mishra, A.K. and Singh, Madhvendra.2011. Impact of laser leveler for enhancing water productivity in Western Uttar Pradesh. Int. J. Agric. Eng. 4(2):133-147.

Rodell, M., I. Velicogna and J.S. Famiglietti. 2009. Satellite-based estimates of groundwater depletion in India. Nature 460: 999–1002. https://doi.org/10.1038/nature08238.

Sharma, B.R., Gulati, A.,Mohan, G.,Manchanda, S.,Ray, I. and Amarsinghe,V. 2018. Water productivity mapping of major Indian crops. New Delhi: NABARD & ICRIER. https://www. nabard.org/auth/writereaddata/tender/1806181128 Water%20Productivity%20Mapping%20of%20Major%20Indian%20Crops, %20Web%20Version %20(Low%20Resolution%20PDF).pdf. Accessed 30 Nov 2021.

Shrivastava, A.K. 2006. Sugarcane at a Glance, *International Book Distributing* Co., Lucknow, Pp. 257.

Shukla, S.K., Nagargade, M., Pathak, A.D. and Blessy, V.A. 2020. Water footprint in sugarcane. Technical bulletin, Pp. 10.

Shukla, S.K., Solomon, S., Sharma, L., Jaiswal, V.P., Pathak, A.D. and Singh, P. 2019. Green technologies for improving cane sugar productivity and sustaining soil fertility in sugarcane – based cropping system. Sugar Tech. 21 (2): 186-196.

Srivastava, S.C. and Johari, D.P. 1979. The irrigated sugarcane in India. AICRP (Sugarcane), Indian Institute of Sugarcane Research, Lucknow, Pp. 36.

Srivastava, T.K., Singh, P. and Verma,R.R. 2021. Weather variability trends in Gangetic plains of Uttar Pradesh, India: Influence on cropping systems and adaptation strategies. Environment Development and Sustainability. https://doi.org/10.1007/s10668-021-01578-8.

Verma, R.S. 2004. Sugarcane Production Technology in India, International Book Distributing Co., Lucknow, Pp. 628.

Chapter No. 28: Crop residue management (CRM) for soil carbon sequestration and sustaining crop yield

V.K. Singh[1], C. Gupta[1], M.K.Tripathi[1], Ankur Tripathi[2], Shivam Tripathi[3] and Abhinav Singh[1]
[1]Principal Scientist, ICAR-IISR, Lucknow
[2]NDUAT, Ayodhya
[3]CSAUAT, Kanpur

In the second half of the twentieth century, inorganic fertilizers largely replaced organic amendments, both in developed and developing countries, but there is now renewed interest in the application of organic residues to the soil as a means of improving its quality and thus sustaining its fertility and productiveness. Organic matter plays a key role in maintaining the fertility of soils. Soils in many developing countries have low inherent fertility, are old and highly weathered, and have lost their capacity to retain and exchange nutrients. Furthermore, more importantly than focusing only on nutrient additions, one should be aware that nutrient losses must be drastically reduced. In the case of nitrogen (N), losses can occur through leaching, gaseous conversions, and run-off. The organic matter present in soil (SOM) strongly influences several properties. It is well known that it enhances soil structure and stability, thus improving root development (reducing soil density and increasing aeration and water-holding capacity), and minimizing risks of erosion. The presence of organic matter is also essential for a soil to be able to capture, store and recycle nutrients. Soil organic matter serves as a temporary storage place of energy and nutrients. When soil microorganisms use the stored energy, nutrients may be released and become available for plant uptake. One of the most important factors to be dealt with is synchrony of nutrient release by different SOM pools and nutrient demand by the crop. Continuous cropping of the land causes declines in soil organic matter and loss of inherent fertility. Large inputs of chemical fertilizer are necessary to sustain crop yields. Rotations with legumes that are efficient in fixing atmospheric N2 and in returning N to the soil through crop-residue incorporation have been widely studied elsewhere. Agricultural dependent economy like ours produces plenty of crop residues i.e., over 500 million tons (MT) every year (MNRE, 2009). Cereal crops such as rice, wheat, maize and millets contribute 352 MT crop residues (70%) of the total crop residue. While, among the cropping systems, rice-wheat system accounts for nearly one-fourth of the total crop residue produced in India. It was reported that surplus crop residue of about 141 MT is either burnt or remain unutilized which is detrimental to soils, crops, human being and overall environmental health. The practice of rice and wheat stubble burning as a method of field cleaning for the next season crop sowing have adverse impact on environment and also threatens the socio-economic as well as agricultural activities. While most of the wheat residue is removed from the field and used as animal fodder, 82% of rice residue is burnt in the field (Beri et al. 2003). Burning of rice residue besides resulting in loss of C and N adds to the greenhouse gas load of the environment (Samra et al. 2003).

It is not only a cost-effective method but it acts as an effective practices incest pest control (Dobermann and Fairhurst, 2002). Crop residue means any vegetative material left in an agricultural field or orchard after the crop has been harvested. These residues include stalks and stubble (stems), leaves, and seed pods. Crop residue management, a cultural practice that involves fewer and/or less intensive tillage operations and preserves more residue from the previous crop, is designed to help protect soil and water resources and pro- vide additional environmental benefits. The residue can be ploughed directly into the ground, or burned first. In contrast, no-till, strip-till or reduced-till agriculture practices are carried out to maximize crop residue cover. Good management of field residues can increase efficiency of irrigation and control of erosion. Simple line-transect measurements can be used to estimate residue coverage.It is a substance that is not the end product (s) that a production process directly seeks to produce; it is not a primary aim of the production process and the process has not been deliberately modified to produce it. “Agricultural residuals” means materials generated by the customary and generally accepted activities, practices, and procedures that farmers engage in during the production and preparation for market from the production and harvesting of agricultural crops, which include agronomic, horticultural, and silvicultural crops; and materials resulting from aquacultural production. CRM is not only a cost-effective method but it acts as an effective practices incest pest control (Dobermann and Fairhurst, 2002).

Crop residues, the byproduct of crop production, are valuable natural resources that can be managed to maximize different input use efficiencies. Crop residue management is a well-known and widely accepted practice, and is a key component of conservation agriculture. The rapid shift from conventional agriculture to input-intensive modern agricultural practices often leads to an increase in the production of crop residues. Growing more food for an ever-increasing population brings the chance of fast residue generation. Ecosystem services from crop residues improve soil health status and supplement necessary elements in plants. However, this is just one side of the shield. Indecorous crop residue management, including in-situ residue burning, often causes serious environmental hazards. This happens to be one of the most serious environmental hazard issues witnessed by the agricultural sector. Moreover, improper management of these residues often restrains them from imparting their beneficial effects. In this paper, we have reviewed all recent findings to understand and summarize the different aspects of crop residue management, like the impact of the residues on crop and soil health, natural resource recycling, and strategies related to residue retention in farming systems, which are linked to the environment and ecology. This comprehensive review paper may be helpful for different stakeholders to formulate suitable residue management techniques that will fit well under existing farming system practices without compromising the systems' productivity and environmental sustainability.

A cultural practice that involves fewer and/or less intensive tillage operations and preserves more residue from the previous crop, is designed to help protect soil and water resources and provide additional environmental benefits. CRM is generally cost effective in meeting conservation requirements and reducing fuel, machinery, and labor costs while maintaining or increasing crop yields. However, improved managerial skills are often needed to capture the full economic benefits of CRM. Crop residue management practices include reduced tillage or conservation tillage, such as no-till, ridge-till, and mulchtill, as well as the use of cover crops and other conservation practices that provide sufficient residue cover to significantly reduce the erosive effects of wind and water. These practices can benefit society through an improved environment and can benefit farmers through enhanced farm economic returns. Conservation tillage equipment designs have improved over the last decade and these improvements enhance the opportunity for successful conversion to a CRM system. Farm equipment manufacturers are now producing a wide range of conservation tillage equipment suitable for use under a variety of field conditions. Reducing the intensity or number of tillage operations also results in lower fuel and maintenance costs. conservation tillage practices become relatively more profitable.

Carbon sequestration

Carbon sequestration is the process of capturing and storing atmospheric carbon dioxide. It is one method of reducing the amount of carbon dioxide in the atmosphere with the goal of reducing global climate change. Carbon is crucial for life on earth. For plants to thrive, carbon is derived from the soil where they get to retain it even after harvest. Burning residue means carbon escapes into the atmosphere instead of keeping it in the soil where it is beneficial for cultivation and soil properties**.** Carbon sequestration is the process of removing carbon from the atmosphere and storing it in another form that cannot immediately be released, like wood whereas the total amount of carbon contained in a forest or a part of the forest (trees, soil) is called carbon storage Carbon sequestration sustains biological activity, diversity, and ecosystem productivity. Humans and animals release carbon dioxide (CO_2), while plants take it in and release oxygen, returning carbon to the soil when they die. It's generally accepted that the carbon cycle flowed more or less in balance until the late 1880s. Crop residue incorporation/retention is a promising option to increase soil organic carbon (SOC) storage, which is linked to crop yield promotion, ecologically sustainable agriculture, and climate change mitigation. Carbon cycles globally among three distinct pools: the atmosphere, the ocean and terrestrial ecosystems. The atmosphere contains 762 Pg C with nearly all of it as CO2 (Denman et al. 2007). Over the last 250 years the atmospheric concentration of CO2 has increased globally by more than 100 ppm (40%) from about 275 ppm in the pre-industrial era to 385 ppm in 2008 (NOAA 2009). Soil is the largest organic carbon (C) pool on earth (Paustian, K. et al 2016). The dynamics of soil organic carbon (SOC) can be used to indicate changes in SOC sequestration capacity and crop productivity. Due to the large SOC stock, small fluctuations may cause large changes in atmospheric CO_2 concentration, finally affecting global climate changes. In this sense, increasing SOC sequestration is one of the most important strategies to reduce atmospheric CO_2 concentrations and to mitigate the greenhouse effect, with a significant potential to mitigate climate change.The adoption of appropriate farming managements can reduce the mineralization and decomposition of organic matter (OM) and increase SOC storage. Thus, increased C sequestration and reduced greenhouse gas emissions can be attributed to improved soil fertility, ultimately promoting crop production and economic viability.Crop residue management, which means to return the aboveground and belowground biomasses into field after harvesting, is a worldwide recommended management practice due to the benefits in enhancing soil quality and productivity. CRM can improve soil structure, increase systematic biodiversity, enhance SOC sequestration capacity, and partially replace fertilizer input, thereby increasing crop yield and farmland system production capacity in a sustainable manner. Therefore, scientific and rational implementation of CRM is critical to maintain soil quality, high crop production, and sustainability.

Impacts of CRM on SOC Storage

Improved soil quality and more C inputs may be the most important reasons of SOC sequestration by CRM. As a C source, the decomposition of newly added residue can increase the soil C pool. However, the various methods of CRM can alter the effects on SOC storage. Mulch retention can reduce the contact between the soil and the environment, protect soil from rainwater erosion, and prevent soil moisture loss, facilitating the growth of the root system and therefore resulting in higher grain yields.Mulch residue may lead to an increase in the number of pests in the cropland. Residue floating on the soil surface also affects the contact with soil microorganisms and reduces the decomposition rate of the residue. Regarding the different return patterns, increases in SOC storage were observed with increased duration and decreased with cropping intensity within 1 yr. Generally, because of the priming effects of CRM, interactions between dead and living organic matter and different qualities of biomass would be strengthened, thereby accelerating residue decomposition. Tillage practices affected soil aeration and nutrient exchange in the field, and selecting appropriate tillage practices could help improve soil quality and crop yields (Zhang, H.L. et al 2014). The ocean, soil and forests are the world's largest carbon sinks. A carbon source releases carbon dioxide into the atmosphere. Examples of carbon sources include the burning of fossil fuels like gas, coal and oil, deforestation and volcanic eruptions. The largest reservoir of the Earth's carbon is located in the deep-ocean, with 37,000 billion tons of carbon stored, whereas approximately 65,500 billion tons are found in the globe. Carbon flows between each reservoir via the carbon cycle, which has slow and fast components.

Types of Carbon Sequestration

- Biological Carbon Sequestration- Biological carbon sequestration is the storage of carbon dioxide in vegetation such as grasslands or forests, as well as in soils and oceans.
- Geological Carbon Sequestration- Geologic carbon sequestration is the process of storing carbon dioxide (CO2) in underground geologic formations. Geologic carbon sequestration is a method of securing carbon dioxide (CO2) in deep geologic formations to prevent its release to the atmosphere and contribution to global warming as a greenhouse gas. The CO2 is usually pressurized until it becomes a liquid, and then it is injected into porous rock formations in geologic basins. Capture of carbon dioxide (CO_2) emissions from industrial processes, such as steel and cement production, or from the burning of fossil fuels in power generation. This carbon

is then transported from where it was produced, via ship or in a pipeline, and stored deep underground in geological formations.

Soils contain more carbon than is contained in vegetation and the atmosphere combined. Agricultural carbon sequestration has the potential to substantially mitigate global warming impacts. At the same time, employing methods to enhance carbon sequestration in soil will increase soil quality**.** Carbon is stored within soil organic matter (SOM)**.** SOM is a complex mixture of carbon compounds, consisting of decomposing plant and animal tissue, microbes (protozoa, nematodes, fungi, and bacteria), and carbon associated with soil minerals. Methods that significantly enhance carbon sequestration in soil include-

Conservation tillage (low till / no-till farming) – minimizing or eliminating manipulation of the soil for crop production. This includes the practice of mulch tillage, which leaves crop residues on the soil surface. These procedures generally reduce soil erosion, improve water use efficiency, and increase carbon concentrations in the topsoil. Conservation tillage can also reduce the amount of fossil fuel consumed by farm operations

Cover cropping – the use of crops such as clover and small grains for protection and soil improvement between periods of regular crop production. Cover crops improve carbon sequestration by enhancing soil structure, and adding organic matter to the soil.

Crop rotation – planting different crops on a rotating pattern of years (e.g. corn-oats-clover) will reduce the loss of carbon from the soil and with some additions (e.g. manure-lime-phosphorous) will add carbon to soils

Grasslands - Grasslands contribute to soil organic matter, mostly in the form of their extensive fibrous root mats. A large proportion of the world's grasslands have been tilled and converted to croplands, allowing the rapid oxidation of large quantities of soil organic carbon. Livestock producers can enhance carbon sequestration on their operations by converting from continuous grazing to rotational grazing. This keeps the plants in an actively growing state and keeps photosynthesis rates high. This improves the quality of the forage and allows the plants to sequester more carbon.

SOC Sequestration Rate under CRM

The SOC sequestration rate of CRM was generally positive.CRM effectively improved the function of ago-ecosystems, production, and the environmental benefits. Increased SOC sequestration rates and SOC storage could sequentially improve crop yield.Lu, F. et al. 2009, found that CRM had a higher SOC sequestration rate in single-cropping than in double-cropping fields. On the one hand, this may be related to discrepancies in climatic conditions, soil types, and cropping systems in different regions (Lu, F. et al. 2010). On the other hand, increases in residue species may be beneficial for microorganisms using the C substrates of the soil, thus accelerating the depletion of SOC(Vivanco, L. et al 2008). As an environmentally friendly and ecologically sustainable practice, CRM improved crop yield and soil fertility by increasing SOC storage and sequestration rate. CRM can be used as an efficient and climate-smart management practice for sustainable crop production.

Benefits of crop residue management:

Enriching the soil health and quality : Generally, the incorporation of crop residues increases soil porosity especially the large pores of soil and reduce soil bulk density, regardless of tillage operations. It is clear that residue retention has a positive effect on long-term soil quality but it is not suitable for all agro-ecosystems in terms of its effects on crop production. Soil type, crop rotation and weather conditions have a great bearing on the effect of crop residue management for crop production. Residue mineralization leads to more nutrients availability for the crop plants besides, it also supplied organic matter to the soil, which modify the soil structure and thereby development of root system. CRM reduce soil erosion, increase soil organic matter, improve soil tilth, increase soil moisture, and minimize soil compaction. These changes can maintain or increase the productivity of many soils, especially those that are fragile and subject to damage from soil erosion or compaction.

Role in water conservation: Crop residue acts as mulch, which reduces erosion and runoff losses and increases the permeability of soil thus helps in conserving soil moisture. In the drier parts of country, crop residues can serve as good mulch material to moderate the soil temperature, better penetration and conservation of rain water for growing crops with better yields. CRM practices keep more nutrients and pesticides in the soil where they can be used by crops and help to prevent their movement into surface or ground water. Surface residues intercept nutrients and chemicals and hold them in place until they are used by the crop or degrade into harmless components (Dick and Daniel, 1987; Helling, 1987; Wagenet, 1987).

Crop residue as a potential source of energy as well as amendments: Crop residues could be used as an alternative fuel and a potential source of energy production. Besides, its energy potential it can also be used as a source of soil amendment, biomass feedstock for livestock and an alternate to chemical fertilizers. Such beneficial effects could have lost under field burning practice of crop residues.

Enriching the environmental health and quality : Crop residue retention offers several environmental and ecological benefits for the soil-water-plant system, including improved soil structural quality. Crop residues management with its potential ability to offset the fossil fuel demands and consequent reduction in carbon-di-oxide emission due to proper in-situ incorporation of residue improves the environmental quality, would have otherwise severely affected under field crop residue burning practice. The recycling of crop residues has the great potential to return a considerable amount of plant nutrients to the soil. The yield of crops stagnation consequently upon due to declining soil organic carbon is a major threat to this system. Therefore it is a great challenge to the agriculturists to manage crops residues effectively and efficiently for enhancing sequestration of carbon and maintaining the sustainability of production. Crop residues management practices are also important as machines are being increasingly used for harvesting of grains and this mechanical harvesting leaves huge amount of crop residues in the field. There are several options for management of crop residues: mulching, incorporation in the soil and surface retention.

Conclusion:

The recycling of crop residues has the great potential to return a considerable amount of plant nutrients to the soil. The yield of crops stagnation consequently upon due to declining soil organic carbon is a major threat to this system. Therefore, it is a great challenge to the agriculturists to manage crops residues effectively and efficiently for enhancing sequestration of carbon and maintaining the sustainability of production. Crop residues management practices are also important as machines are being increasingly used for harvesting of grains and this mechanical harvesting leaves huge amount of crop residues in the field. There are several options for management of crop residues: mulching, incorporation in the soil and surface retention etc. All management options have its advantages as well as disadvantages. Now it is the location, soil and situation, which will govern the practice to be selected. Of course, intensive research is required to solve this problem of managing rice residues. Sometimes surface retention may be the best option for sustainable agriculture. For sowing/ planting of subsequent crops having rice residues, both stubbles and loose straw in the field needs to be managed, for that intensive investigation in different crops growing areas is required. In long term incorporation of crop residue increase the soil physical, chemical and biological properties. No tillage technology may be adopted which is fitted to the location and soil condition. Incorporation of crop residues in soil is the best option as well as ecofriendly management practices for sustainable agriculture. Thus, it may be concluded that incorporation of crop residues in soil improved the hydro-physical environment and fertility status of the soil, which led to the enhancement of crop yield.

References :

Beri V, Sidhu BS, Gupta AP, Tiwari RC, Pareek RP, Rupela OP, Khera R, Singh J (2003) Organic resources of a part of Indo-Gnagetic Plain and their utilization. Department of Soils, Punjab Agricultural University, Ludhiana 93.

Beri, V., Sidhu, B.S., Gupta, A.P., Tiwari, R.C., Pareek, R.P., Rupela, O.P., Khera, R. and Singh, J. (2003). Organic resources of a part of Indo-Gangetic Plain and their utilization. Department of Soils, PAU, Ludhiana, India, p. 93.

Cherubini, F. and Ulgiati, S. (2010). Crop residues as rawmaterials for biorefinery systems-A LCA case study. Appl. Energy, 87 : 47-57.

Denman KL, Brasseur G, Chidthaisong A, Ciais P, Cox PM, Dickinson RE, Hauglustaine D, Heinze C, Holland E, Jacob D, Lohmann U, Ramachandran S, da Silva Dias PL, Wofsy SC, Zhang X (2007) Couplings between changes in the climate system and biogeochemisry. In: Solomon S, Qin M, Manning D, Chen Z et al (eds) Climate change 2007: the physical science basis. Contribution of working grop I to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, UK and New York, USA, pp 499–587.

Dick, W. A. and T. C. Daniel (1987). "Soil Chemical and Biological Properties as Affected by Conservation Tillage: Environmental Implications," in T. J. Logan, J. M. Davidson, J. L. Baker, and M. R. Overcash (eds.), Effects of Conservation Tillage on Groundwater Quality: Nitrates and Pesticides. Lewis Pub., Chelsea, MI, pp. 125-147.

Dobermann, A., and Fairhurst, T. H.,(2002). Rice straw management. Better Crops International, Special supplement publication: Rice Production., pp: 16.

Helling, C. S. (1987). "Effect of Conservation Tillage on Pesticide Dissipation." In T. J. Logan, J. M. Davidson, J. L. Baker, and M. R. Overcash (eds.), Effects of Conservation Tillage on Groundwater Quality: Nitrates and Pesticides. Lewis Pub., Chelsea, MI, pp. 179-187.

Ji, S.; Unger, P.W. Soil Water Accumulation under Different Precipitation, Potential Evaporation, and Straw Mulch Conditions. *Soil Sci. Soc. Am. J.* **2001**, *65*, 442–448. [Google Scholar] [CrossRef][Green Version]

Lu, F.; Wang, X.K.; Han, B.; Ouyang, Z.Y.; Duan, X.N.; Zheng, H.; Miao, H. Soil carbon sequestrations by nitrogen fertilizer application, straw return and no-tillage in China's cropland. *Glob. Chang. Biol.* **2009**, *15*, 281–305. [Google Scholar] [CrossRef]

Luo, Z.; Wang, E.; Sun, O.J. Can no-tillage stimulate carbon sequestration in agricultural soils? A meta-analysis of paired experiments. *Agric. Ecosyst. Environ.* **2010**, *139*, 224–231. [Google Scholar] [CrossRef]

Mandal, K.G., Misra, A.K., Hati, K.M., Bandopadhyay, K.K., Ghosh, P.K. and Mohanty, M.(2004). Rice residue: management options and effects on soil properties and crop productivity. Food, Agric. & Environ., 2 (1): 224-231.

Maurya R., C. Bharti, T. D. Singh and Vijay Pratap, (2020) Crop Residue Management for Sustainable Agriculture *.Int.J.Curr.Microbiol.App.Sci* (2020) 9(5): xx-xx (1-8).

MNRE (2009). Ministry of New Renewable Energy Report 2009. www.nicra.iari.res.in UNEP (2009). Converting Waste Agricultural Biomass into a Resource. Compendium of technologies. United Nations Environmental Programme, International Environmental Technology Centre Osaka/Shiga, (Japan), Division of Technology, Industry and Economics, Osaka/Shiga, (Japan).

NOAA (2009) NOAA- ESRL data available online www.noaa. gov/gmd/ccgg/trends.

Paustian, K.; Lehmann, J.; Ogle, S.; Reay, D.; Robertson, G.P.; Smith, P. Climate-smart soils. *Nature* **2016**, *532*, 49–57. [Google Scholar] [CrossRef] [PubMed][Green Version]

Rathore, A.L.; Pal, A.R.; Sahu, K.K. Tillage and Mulching Eþects on Water Use, Root Growth and Yield of Rainfed Mustard and Chickpea Grown after Lowland Rice. *J. Sci. Food Agric.* **1998**, *78*, 149–161. [Google Scholar] [CrossRef]

Samra JS, Bijay-Singh JS, Kumar K (2003) Managing crop residues in the rice-wheat system of the Indo-Gangetic plain. In: Ladha JK, Hill JE, Duxbury JM, Gupta RK, Buresh RJ (eds) Improving the productivity and sustainability of Rice–Wheat systems: issues and impact ASA, spec. Publ. 65. American Society of Agronomy, Madison, WI, pp 173–195.

Vivanco, L.; Austin, A.T. Tree Species Identity Alters Forest Litter Decomposition through Long-Term Plant and Soil Interactions in Patagonia. *Argent. J. Ecol.* **2008**, *96*, 727–736. [Google Scholar] [CrossRef]

Wagenet, R. J. (1987). "Processes Influencing Pesticide Loss with Water under Conservation Tillage," in T. J. Logan, J. M. Davidson, J. L. Baker, and M. R. Overcash (eds.), Effects of Conservation Tillage on Groundwater Quality: Nitrates and Pesticides. Lewis Pub., Chelsea, MI, pp. 190-204.

Zhang, H.L.; Lal, R.; Zhao, X.; Xue, J.F.; Chen, F. Opportunities and Challenges of Soil Carbon Sequestration by Conservation Agriculture in China. *Adv. Agron.* **2014**, *124*, 1–36. [Google Scholar]

Chapter No. 29: Organic farming for sustaining soil carbon and crop yield

A.P. Dwivedi, S.K. Shukla, L.P. Awasthi#, Ankur Tripathi* and Shivam Tripathi**
Principal Scientist, ICAR-IISR, Lucknow
#Former Prof. & HoD, ANDUAT, Ayodhya
*Ph.D. Scholor, ANDUAT, Ayodhya
**Ph.D. Scholor, CSUAT, Kanpur

Organic Farming appealed to me because it involved searching for and discovering nature's pathway's, as opposed to the formulaic approach chemical farming .The appeal of Organic Farming is boundless; this mountain has no top, this river has no end.

………..Eliot Coleman

Introduction-

Excessive use of agro-chemicals and their hazardous nature generates the need of alternative ecofriendly farming approaches in terms of organic management. Organic Farming practices are traditionally come from our four fathers. Sustainable agriculture is important to reach the core of sustainable development. Organic Farming is one of the crucial approaches which meets the objective of sustainable agriculture. Various techniques are applied in Organic Farming like mulching, inter-cropping, mixed cropping, integration of new crops etc. Organic Farming is associated with various laws and certification programmes, which prohibit the enormous use of synthetic agrochemicals.Adverse effect of modern agricultural practices are on,habitate,human health and environmental health. Hazardous effects on the environment are manifestedthrough soil toxicity and erosion,water scarcity and salinity,soil contamination and genetic erosion. Organic Farming is one of the best methods of neutralize negative effects of toxic hazardous chemicals. Organic Farming is productive system which totally prohibits the use of synthetic agro-chemicals and gives us eco-friendly management strategy. Agricultural practices rely to the maximum extent to the crop residues,crop rotation,mixed cropping,animal manures,mulching biofertilizers etc.

Kind of Organic Farming-

1. Natural Farming- In this technique, natural ingredients or components are use to make consortia or colloidal paste as natural plant growth enhancer.Two different components-bijamruta-for seed treatment and jivamruta-for soil treatment and foliar spray are found to be most effective.

2. Vedic Farming- In this system,use of chemical pesticides,fertilizers and chemical plant growth regulators are restricted. It is the most ancient traditional farming system,which prefers the use of natural ingradients. Vedic Farming provides healthy soils,healthy food and healthy environment,sustainable farming land.

3.Homa Farming- These types of eco-friendly farming practices are very unique.It involves burning of rice grain

PRINCIPLES OF ORGANIC FARMING

Organic farming is an important eco-friendly approach. It has several dimensions:

- By using natural products in organic production it organizes along with livestock and the management of other resources.
- Appropriate technologies are crucially important under the biological system.
- Soil fertility is maintained through organic farming using renewable resources.
- Diversification is applied for optimum reduction.
- Increases the nutritional value of the food.
- Applying and use decentralized structures for distributing, marketing and processing of products.
- Sustainable ecofriendly approach and relationship between manmade activities and soil or land.
- Balance between wildlife and habitats through its multidirectional approach.

SIGNIFICANCE OF ORGANIC FARMING Organic farming is significant in terms of:

- maintaining high nutritional quality of food and sufficient production,
- balancing socio-ecological impact on organic production,
- maintaining soil fertility on a long-term basis,
- maintaining genetic diversity of the production system and its surroundings including natural wildlife biodiversity,
- promoting proper care of waterbodies and underground water, recycling of renewable resources under localized production system,
- providing all livestock conditions of life that help to moderate their behaviour,
- lowering all kinds of pollution and maintaining ecological balance and sustainable land for future farming, and
- Improving the production, processing and distribution chain.

As per latest statistics near about 30-35% agricultural needs are fulfilled by organic farming. Role of hazardous, toxic, non-ecofriendly inorganic fertilizers needs to be revised, Organic farming policies also need to be revised.Organic farming gives us more safe and nutritious food. Day by day increased food demand makes the organic food market high. Organic farming is ecofriendly. It maintains soil health and environmental integrity. Organic import-export and new markets are growing faster. According to Willer and Lernoud, 2019 India is the largest organic producer and in near future will compete with any developing country through nation building in terms of ecological, nutritional and economical aspects.

Initiatives Taken By Goverment (Central/State), NGOs and other Organizations for Promotion of Organic Agriculture

1. Rastriya Krishi Vikas Yojna
2. National Mission for Sistainable Agriculture
3. The Paramparagat Krishi Vikas Yojna
4. Organic Value Chain Development in North-Eastern Region Scheme
5. The Mission for Integrated Development of Horticulture
6. National Programme for Organic Production
7. National Project on Organic Farming

ROLE OF NGO AND OTHER ORGANIZATIONS TO PROMOTE ORGANIC FARMING - The emerging role of NGOs in rural development and for promotion of organic agriculture was described by Ramakrishna (2013). This intervention with high priority for organic agriculture, waste recycling, watershed management and value addition of agricultural/ horticultural products need to be promoted gains significance in the present scenario where we need to invigorate agricultural production and farmers livelihood in a sustainable manner (Surudhi and Jayakumar, 2016). This strategy may also help in organic agriculture. Various NGOs and self-help groups reach there where state/central government projects can't reach. Awareness camps, training, seed distribution, village fairs are the alternatives to promote organic agriculture. Overall allotment of revised budget, establishment of new laws for farmers' welfare and chemical pesticide restriction can bring sustainable faming and agricultural practices.

Organic Ecosystems -

Effect organic farming on soil ecology and environment

Soil is one of the most crucial resources and plays an important role in agriculture. Healthy soil is essential for better plant growth and nutrition. Additionally, soil has multidimensional functions like buffering, filtering and transformation and aside it's a hub of beneficial microorganisms. Some of the positive changes in soil are mentioned below:

(i) More than 30% organic carbon content in soil organic matter.

(ii) By using organic amendment soil biological activity can increase by 30-100%, which is a biomass decomposition indicator.

(iii) Edaphon biomass can increase up to 50-80%.
(iv) Higher saprophytic fungi colonized at the roots of higher plants and makes mycorrhizal association.
(v) Soil microorganisms use soil organic components more efficiently.
(vi) Soil physio-chemical property and soil structure, porosity will improve.
(vii) Improved hydroscopicity and reduction in soil erosion level.

Research on soil organic matter concentrates on the organic carbon content and its changes during conversion to organic farming. Several studies have confirmed that areas under organic cultivation have a higher amount of organic carbon content as compared to areas under conventional cultivation. However, in some researches, there was a higher decomposition of organic matter. More intensive soil cultivation helps in mechanical weed control. However, long-term experiments have confirmed the hypothesis that organic farming methods better protect the soil organic matter. The research also points to a larger amount of humic substances. Soil organic matter protection can only be possible through soil cultivation. In accurately designed crop structure, fertilizers have the equal importance. It is found that structural soil is more resistant to erosion (Siegrist et al., 1998).

Higher supply of organic matter and organic fertilizers create favourable living conditions for soil fauna. The soil provides a habitat for a large number of microorganisms. Crucial role of microorganisms is decomposition of organic matter and transformation of inorganic substances where nutrients are more accessible for plants along with synthesis of complex organic substances enriching humus reserves in the soil biota. In organic farming, the main role for nitrogenous nutrients comes from papilionaceous plants. In case of nonsymbiotic fixation, e.g., by the soil-free living heterotrophic aerobic bacteria. Rhizosphere is a zone where the main part of nutrient cycle takes part due to the interaction between soil, roots and microorganisms colonizing the plant root environment. In organically cultivated soils, more than 40% mycorrhizal association is found (Mader et al., 2002).Predominantly, the farming systems have still been considered production systems. The typical conventional agro-ecosystem are characterized as very open, as systems based on technological processes substituting the ecological ones, systems with high labour productivity but with lower biodiversity, flexibility, stability and sustainability on the other hand. On the contrary, the organic farming systems are based on sustainable development principles and the holistic world approach. It is a production system focused on preservation and improvement of natural resources and the environment at the same time. As for the system concept, there is an effort to balance the economic, environmental and social aspects and relations on global and local level. Agricultural activity itself is considered a process of reasonable ecosystem exploitation with respect to its stability and sustainability. Just this divergence between the both approaches, the intensive industrial agriculture on one hand and the sustainable organic farming systems on the other, makes them very different from the environment point of view. In the organic farming systems the soil quality remains the main interest. Soil erosion control measures include cover crops, mulching, limited soil cultivation, windbreaks planting, use of lighter and smaller machinery, keep an optimal soil structure and looseness. These soil cultivation principles are combined with lower need of pesticides. Thus, there is a sufficient nutrient cycle and organic matter content in the soil leading to an optimal soil's biological activity and fertility. Generally, the principles of organic farming ensure protection of water sources and soil moisture, prevent the underground and surface waters from pollutants and sediments as well. Water preservation is the priority, there are used terraces, environmental corridors and border zones and other measures. There are also considerable differences in biodiversity, which, in the conventional farming, markedly suffer not only due to crop range reduction leading to monocultures in fact, but also thanks to reduction of associated fauna and flora thought as harmful and thus systematically eliminated or suffering from pesticides or other biocides at the same time. By contrast, organic farming purposefully supports biodiversity, takes advantage of more adaptable animal and crop species and varieties to the habitat conditions, uses varied crop rotations, species and variety of mixtures, applies technical and organizational measures friendly to the organisms and the environment. Organic farming systems are also more environment- friendly with regard to the greenhouse gas emissions. Above all, this emission reduction is achieved thanks to the limited use of synthetic fertilizers and pesticides and lower livestock production intensity.

Organic Nutrient Resources and Their Fortification-

CARBON TO NITROZEN RATIO (C:N)-

The carbon to nitrogen ratio (C:N) may be used as an indicator of compost stability and nitrogen availability. Compost C:N ratios typically decrease during composting if the starting C:N ratio is >25 but may increase if starting C:N ratios are low (<15) and nitrogen is lost during the composting process. Composts with high C:N ratios (>30) will likely tie up (immobilize) nitrogen if applied to soil, while those with low C:N ratios (<20) will mineralize organic nitrogen into inorganic (plant-available) nitrogen.Micronutrients are very important for plant growth. Although, micronutrient deficiency is considered to be a big problem for sustainable agriculture and organic farming. Micronutrients are so far used as fertilizer to increase productivity. Especially when the application of conventional NPK fertilizers is not efficient. Gradual reduction of micronutrients level decreases soil fertility. To maintain soil fertility there needs to be a periodical source of various micronutrients. A single fertilizer will not fulfil all the micronutrient deficiency. Various combinations of micronutrient products can develop a new fertilizer. But always remain careful before soil treatment because soil analysis and plant specific micronutrient deficiency is important. By thinking about all classes of farmers, the product should be affordable to purchase. Micronutrients have an immense role in crop biomass production, enhancing yield, suppressing crop diseases and fortifying crops. Development of soil health card is a good initiative from Indian Government. Various soil testing laboratory and agencies help under this government project. Farmers education programme based on plant diseases and disorders linked with micronutrient deficiency is highly appreciating.

Restrictions to Nutrient Use in Organic Farming-

The data presented here suggest some cause for concern over the sustainability of organic systems because of their dependence on feedstuffs and bedding for inputs of P and K, and on the very variable fixation by legumes or imports of manure or compost for N. Air pollution and net mineralization from soil reserves appear to comprise a large part of the N supply on some organic farms. Losses of N from organic systems can also be as large as those from conventional systems. Being dependent on cultivation and the weather, they are even more difficult to limit than those from fertilisers applied to conventional farms. There is some evidence of P deficiency in soils under organic production. However, with careful management of manure and the effective use of legumes and by using permitted inputs for P and K, organic farms can be managed sustainably.

Organic Production Requirements-

The certification and inspection agency set the standards parallelly with the minimum requirements by the central government. The grower should follow all these standards and the procedures. After fulfilling all the criteria, the producer and its product will get an organic certificate for marketing. The grower should gain basic knowledge on the organic crop requirements, the restricted and allowed substances, the soil and water quality, etc. By knowing and following all these regulations, he can be an organic certified grower (Nanda et al., 2003).

Choice of Crops and Varieties in Organic Farming-

Many farmers and growers are now considering organic farming as an interesting and trendier one. Likewise, the consumers for organic products are increasing day by day. Therefore, to maintain the continuity of supply chain in the market, the growers should make a proper strategy and do accordingly. He must have back-up plans for all type of risk factors. Selection of crop and variety is the most important step which is dependent on a wide range of factors. Therefore, proper measures should be taken by the grower.

Biological Intensive Nutrient Management: Organic Manures, Vermicomposting, Green Manuring, Recycling of Organic Residues.

Intensive nutrient management by altering or recycling the various waste materials of our surroundings is one of the best ways to sustainable agriculture. It uses different microorganisms, earthworms and crops which increase the nutrient and mineral uptake in an eco- friendly way (Curry 2002). But still more research is needed to increase the amount of nutrients and more microorganisms should be identified to use them in this novel procedure. Awareness among farmers is still lacking. Therefore, government should take steps to increase the knowledge of sustainable nutrient management by the help of NGOs and other organizations.

Soil Improvement and Amendments-

The application of organic soil amendments has several benefits over synthetic chemicals. These soil amendments should not contain any harmful substances which hamper our environment and livestock. The repeated use of these organic products modifies the microclimatic condition of soil and improves the soil physical and chemical structures which help in growth of the plant and boosting the yield. In organic agriculture, inorganic fertilizer can also be used but only the certified one to a limited extent. The use of organic soil amendments and their benefits are still unknown to many rural farmers. So, more emphasis requires on-training and awareness programmes by which will lead to a sustainable organic agriculture in near future.

Role of Biofertilizers in Organic Farming-

Biofertilizers are one of the major items for organic agriculture and sustainable agriculture. They not only increase the soil nutrient level but also promote growth, increase yield, defend the plant from pathogens, improve soil health, etc. Microorganisms such as *Rhizobium, Frankia, Azotobacter, Azospirillum, Acetobactor,* VAM, etc., play a crucial role in nutrient enrichment in soil. They can show their potential effect in a wide range of plants, various geographic areas and different types of soil. Their multiple potential effects have made biofertilizers more demanding in recent days to build up for a better environment through sustainable farming.

Integrated Diseases and Pest Management: Use of Biocontrol, Pheromones, Trap Crops, Bird Perches-

Day by day growing interest in organic farming and its different tools is a positive approach for us. Research on the present scenario revealed that farmers gained more advantage from organic agriculture in the less rainfall, low soil fertility level area. Integrated disease management is an important tool of organic farming. By adopting such tools farmers gain new techniques and skills to continue their farming within farming budget. IDM practices not only protect our crops but also give more production. From this point of view we can conclude the following points.

1. Large-scale conversion from inorganic to organic agriculture enhances crop production, future security and sustainable environment-friendly approaches.
2. Organic manure is the best alternative renewable source among all types of market based inorganic products enriched with high nutrient.
3. For proper utilization of IDM strategies, knowledge should be distributed among economically poor and illiterate farmers who are not aware about this techniques.
4. Skill transfer is needed in terms of organic products certification and uses.
5. Knowledge about destructive insect-pest-pathogens is highly needed. Crop calendar and their alteration in terms of management is also an important aspect. Epidemiological knowledge and behavioural characteristics of insect-pest- pathogen is necessary for better security of crops.
6. Government help and subsidiary is required to encourage organic growers.
7. Meeting, leaflet, workshop or digitalized app based skill transfer on IDM strategies makes the organic movement more fruitful.

8. Distribution of disease-resistant and stress-resistant seeds from government is a good approach to encourage farmers in developing countries.
9. Use of biopesticides on the cropland and recommended doses should be strictly followed.
10. For more successful IDM strategies, selection of farming land, proper irrigation, time to time weeding and cleaning is a good farming practice.

Weed Management in Organic Farming-

Mulching

Mulching or covering of the main field is utmost important as it blocks the sunlight and secrets some allelo chemicals. This reduces the germination of weed seeds. Mulching is normally of two types: one is live mulch and another is organic mulch.

Live mulching: This type of mulching includes plant species which normally grow near the soil zone such as Portulaca olerasia. The principal purpose of growing this type of plants is to conserve water, minerals and nutrients and to stop pest as well as weed infestation. These crops should be grown just before planting of the main crop or after harvesting. It should not be grown with the main crop simultaneously as it may compete for water minerals and nutrients. It was identified that broccoli can act as mulching crop without competing with the main crop.

Organic mulching: Organic mulch mostly includes woods, barks, crop residues, fallen leaves, straw and any other composting material. Mulching by these materials helps to keep the farmland weed free because proper light cannot penetrate in the soil. It is advised to grow all the composting material in own farmland which will be cost effective. organic mulches available in market have exorbitant price. Organic mulching can be done by using newspapers and straw. In this method, two layers of newspaper and straw cover the soil which keeps the soil cool, light free and hence, weed free. Black polythene mulch which is normally available in market is also an alternative of composting material. This black polythene mulch doesn't penetrate any photosynthetic radiation but lets infrared light to go in which keeps the soil warm ad kills all type of weeds and weed seeds

Tillage-The tillage operation helps to control the weeds by changing the soil seed bank and also modifying the depth of the seeds. It was observed that tilled fields are less infested by weeds as compared to untilled fields.

Field Sanitation-Field sanitation is one of the important factors to control the weeds. For this purpose, we have to use weed-free seeds. Proper monitoring is required to eradicate the weeds and its seeds which will prevent any future weed infestation. The weeds should be removed from the land as well as outside of the land. Movement of animals should not be allowed because they act as carriers of weed seeds. Hand weedings is also required. The machinery or implements used in the land should we cleaned properly before using in a new field.Weed management through organic ways is one of the best effective methods to sustainable agriculture. Though chemical is restricted to some extent in organic weed management, but cultural, thermal and biological management help to control the weed successfully. More awareness programme is still required to deliver this methods to all rural farmers.

Operational Structure of National Programme on Organic Product under Organic Farming-

In organic production system, certification is one of the major steps and it is the mandatory stage for marketing of the products. Without certification, the whole produce will not be sold as organic. Proper Therefore, all the procedures should be known by the farmers. Proper measures should be taken by the government to deliver the information about certification process, rules and regulations of certification so that both growers and consumers are benefitted.

Quality Considerations, Processing, Labelling, Economic Considerations, Viability and Accreditation Processors-

Growing of any farm produce or product is not the only factor to refer it as organic. For proper marketing of an organic product, certification is needed. Customers should trust this as purely organic and for this reason, NAB is formed to accredit several agencies as a certified body. These certified agencies follow all the standards, do surprise visit, and check the quality to give certification. Therefore, all the regulations should be properly delivered to the farmers by the government through training, workshops or through NGOs. Otherwise, the whole effort will go in vein.

Certifications Process and Standards of Organic Farming-

Certification is an unavoidable major step to be followed by the operator to market his product as organic. After fulfilling all the criteria and standards, a certification will be issued to the operator and he can use it for advertising the product. The inspection and certification agency should properly monitor all procedures, techniques and reports before announcing final decision. In case of expiry, it can be applied for renewal. Certification is not only a key factor for marketing but it also increases the market value by advertising as organic as per the norms. Proper measures like workshop, training manuals should be distributed to farmers and operators to gain the idea about certification process.

Marketing and Export Potential of Organic Products-

Though India stands among the top leaders in export and production of organic products, still it needs more attention to develop more interest for more production and use in our country. The traders, government and estates have major role in the marketing of organic products. More promotion and advertisement of organic products can result in the vertical growth of farming as well as reduction of health risk of people. The certification process and information regrading this must reach to rural villagers so that they can adapt this system. Implementation of flexible regulations, consumer-oriented follow-up, easy payment methods, transparent marketing, etc., can develop the organic production market in near future in India.

Indigenous Technology Knowledge (ITK) for Nutrient, Insect, Pest Disease and Weed Management under Organic Farming

- Soaking of paddy seeds in milk can reduce the incidence of rice tungo virus and stunt virus disease.
- Soaking of paddy seeds in cow urine and acornscalms mixed in the boiled water after cooling. The floating seeds should be removed and the dipped seeds used for sowing. This reduces the incidence of seed-borne diseases.
- Sun drying of cow urine treated sorghum seeds can control head smut disease.
- Dusting of dried neem fruits powder at 200 kg/ha can control stem borer and fungal disease.
- Soaking of maize seeds in warm water for 3-6 hours can be effective in control of shoot borer incidence.
- Ash is dusted in the pearl millet fields can reduce the incidence of green leaf hopper.
- Pouring of neem cake extract near the shoot region of sorghum can reduce the shoot borer attack.
- Red gram seeds coated with red earth slurry followed by drying can reduce the incidence of storage insects.
- Coriander and sorghum mixed cropping can reduce the incidence of witch weed.
- Dipping of banana suckers in neem oil and water solution (1 litre neem oil/100 litre of water) can reduce the rhizome rot incidence.
- Intercropping of sunflower in between mango plants can increase honeybee population which ultimately increases pollination.
- To get rid of damping off disease in nursery, tomato seeds are soaked with the leaf extract of bougainvillea for 6 hours.
- Growing onion or garlic as a border crop of tomato prevents from fruit borer attack.
- Aspray solution of 8 crushed leaves of aloe vera plant with one litre of water can prevent the fruit rot disease in brinjal.
- An equal proportion of ash and turmeric powder can be dusted to control aphid in brinjal field.

- A mixture of tobacco waste and neem cake extract can be supplied in field to get rid of thrips and stem borer.
- A solution of milk and water in 1:20 ratio when sprayed in tobacco filed, it reduces the incidence of tobacco mosaic virus.
- Application of lime can reduce the coffee wilt in orchard.
- Insect pest population in rice field can be minimized by application of leaves or seeds of custard apple by broadcasting method.
- To prevent the attack of BPH, rice bran, kerosene and molasses or jaggery in 7:1.5:1.5 ratio mixed properly and placed near BPH infected plant which act as a BPH repellent.
- Fresh cow dung application near the collar region of chili plant can prevent damping off disease.
- Leaves of acacia plant can be used in water channels to control brown spot disease.
- Mixing of dried neem leaf powder at 1% can control stored grain pests.
- Garlic and crushed green chili in equal quantity with 200 litres of water can control jassid and aphid attack (Shailaja et al., 2012).
- A mixture of whey (2 litres), tobacco powder (200 gm), Aloe barbadensis (2 leaves) with 15 litres of water is kept undisturbed for 15 days. After that, it is filtered and the filtered solution spray can effectively control pod borer in gram crop.
- In the rice growing regions of Himachal Pradesh, farmers sweep the field with the Nirgundi (Vitex negundo) branches to reduce the insect population.
- In Rajasthan and Arunachal Pradesh, several traditional storage structures like stone bins, mud bins or bamboo bins are used for storing of food grains to prevent the attack from insect pest. A solution of water (1 litre), tulsi (100 g) and soap solution of 1 mL can effectively use to control wide range of insects like bug, aphid, mosquito etc.
- Application of botanicals mixture of parthenium, segun and akand leave powder extract at 100 mL per litre of water can reduce the weed incidence.
- Inclusion of more legume crops in crop rotation can also effectively control the disease incidence.
- To recover the soil fertility, FYM or sheep penning can be done in the field.
- Groundnut cake can be applied in the field to increase the yield. Coconut milk solution of 5% concentration can be used as a growth booster.
- Use of animal urine, sheep manure, wood ash, cow dung, camel feacal in field can increase the soil fertility.
- Growing of certain local weeds like fog *(Calligonum polygonoids),* bordi *(Zizyphus mauritiana),* bui *(Kochia indica)* can also increase the nutrient content in soil (Shreth et al., 2009).
- Use of ants, frogs and earthworms can increase the soil health and soil physical property.
- Zal technique, one traditional method, a combined irrigation and application of organic amendments in small pits can increase the nutrient and water retention capacity.
- To increase the germination process, radish seeds are soaked in buttermilk overnight.
- A solution of 5 kg fresh Bilb powder, 1 kg jaggery and 20 litres water is kept for one month followed by applying in root zone to increase the potassium content.
- Pusp Rasayan: Mixture of flowers and cow urine in 1:1 ratio kept for 7 days. Application after 7 days can increase boroncontent.
- Solution of 2 kg Harada in 10 litres of water followed by fitkiri (20 g) is kept for 6 days. Application after 6 days can increase the iron content in soil.
- Application of 2 kg Gaajar Ghaas Svaras in 20 litres of water followed by adding Fitkiri powder (20 g) to be kept for 15 days. This application can increase nitrogen content in soil.

Raising of Vegetable Crops Organically Through Nutrient, Disease and Pest Management

1. **Healthy planting material:** Planting materials having disease- and weed-free propagules and a certified source is recommended (Latifian 2017).

2. **Resistant varieties:** Resistant varieties which have already adapted to the local environment can prevent the plant from several pests.
3. **Cropping system:** Suitable cropping system like crop rotation, mixed cropping or green manuring plays a major role in organic crop production. Crop rotation prevents the soil-borne pathogen to attack due to lack of host plant. Green manuring can help in increasing the biological activity in soil which increases the beneficial organism population.
4. **Water management:** Proper drainage and irrigation facility should be there which prevents many weed and pathogens to grow in the field. Waterlogging can lead to severe disease infection. Moisture in any plant parts for long time should be avoided.
5. **Soil solarization:** Expose the soil against the hot sunny rays to get rid of harmful microorganisms, weeds and insects is a major practice in organic agriculture. It is normally done in hottest part of the year for a period of four to six weeks. A plastic sheetis covered to increase the temperature of soil.
6. **Field sanitary measures:** Plant residues, stubble, left-over plant materials and infected plant parts should be thrown far away from the field. If not, it may facilitate the pathogens to grow andcause disease.
7. **Animal grazing:** This is an effective method to prevent weeds. Grazing of animals before planting of a new crop makes the field free of various weeds.
8. **Planting time and space:** Proper plant population limits the pathogen to spread from one plant to another plant. It helps in proper aeration which prevents moisture to stay for long term. The time of planting also plays a crucial role as the life stage of pest if coincides with critical stage of the plant then severe disease infection occurs.
9. **Natural enemies:** Conservation of natural enemies is one of the crucial step. Proper habitat should be provided to grow predators (Matyjaszczyk 2015).
10. **Trap crops:** Some crops other than the main crop can be used as trap crop for diverting or trapping of insects, nematodes and pathogens from the main crop. For example, Marigold (Tagetes spp.) can be used as a trap crop for nematodes as it traps the nematodes by secreting root exudates.
11. **Roguing:** Physical removal of diseased plants or any other unwanted plants is known as roguing. It is normally profitable in high value crops as it is labour intensive.
12. **Regular monitoring:** Field inspection and regular monitoring is an effective practice for pest prevention through which harmful insects, weeds or diseases symptoms can be identified in early stage. For easy monitoring, light traps, yellow sticky traps, bait traps, water traps, etc., can be used (Hill 2008).
13. **Mechanical pest control:** This method can be applied for insects and weeds which are visible easily. Hand picking of insects and hand weeding through soil solarization, mowing, flaming, tilling or washing is one of the effective alternative of chemicalcontrol.
14. **Biocontrol agents:** Using of several potential biocontrol agents is a path towards sustainable agriculture. Biocontrol agents such as *Tricoderma* spp*.*, *Psudomonas* spp*, Agrobacterium* spp., etc.,can be used to get rid of a wide range of pathogens as well as nematodes. Nuclear polyhedral virus (NPV), natural enemies, predators, etc., can control many major insects in field (Olson, 2008).
15. **Plant protection products in organic farming:** Properly authorized plant protection products of various category such as botanicals, oils, soaps, inorganics can be used for controlling pests. These products can be used directly or diluent. The list of products is given in Table 20.1.

ORGANIC NUTRIENT MANAGEMENT

1. **Vermicomposting:** The application of vermicomposting depends on the crop. For fruit crops, it is applied near tree basin. For potted plant, it is applied in pot mixture. For nursery or field crops it is applied with soil. For field crops, 5-6 t/ha and 3-5 kg/ plant is applied.
2. **Application of green manure:** If the green manure crop is grown in intercropping system, then harvesting of green manure crop must be done before the sowing of main crop. Green manure

crops are if hardy and tall, go for chopping into small pieces and then incorporate in soil for easy decomposition. Incorporation should be done before 2 to 3 weeks of sowing of the next crop to prevent nutrient loss. These crops should not be ploughed deep in soil and is better to apply in surface level only.

3. **Animal manure:** Farm yard manure is one of the best practices to enrich the soil with nutrients. Mixture of dung and cow urine makes a well-balanced nutrient solution. The amount of phosphorus available in soil is equal to the amount present in chemical fertilizers. Nutrient content can be stored properly by focusing on the humidity content of FYM. It should not be morehot or more wet.
4. **Crop rotation:** Rotation of crops like N-fixing crops, or leguminous crops or green manuring crops enrich the nutrient in soil organically in the same land. A proper sequence of crops such as heavy feeder, heavy giver and light feeder should bemaintained.
5. **Cover cropping:** These are very important to prevent soil erosion as well as nutrient management. Non-leguminous crops like weeds or grasses recover the mineralized N from soil. Incorporation of these cover crops decomposes in soil with the help of microorganisms and enrich it with several minerals and nutrients.
6. **Application of crop residue:** The nutrient enrichment of soil by crop residue mainly depends on the type of crop residual. For example, cereal straw can enrich 35 kg N/ha while some vegetable crops can add up to 150 kg N/ha.
7. **Biofertilizer:** The microbial biofertilizers play an important role in enriching of soil nutrient. They majorly fixes up N, P and K in soil and makes them available to the plant. It is advised to sow the biofertilizer applied seeds in the evening so that the microorganisms are not be exposed to hot sun radiation.
8. **Organic soil amendments:** Soil amendments such as compost, sphagnum peat moss, alfalfa pellets, wood ash, leaf mould, shredded tree bark can be used to increase soil nutrient. Some other certified soil amendments approved by authorized bodies can also be used for organic nutrient management.
9. **Mineral fertilizer:** These are based on ground natural rock and can only be used as supplement. Sometimes these fertilizers Isoils while for alkali soils gypsum is used. Some mineral destroy the natural habitats. Normally, lime is used for acidic fertilizers used in organic agriculture are listed in Table 20.2.

Cost of Organic Production-

The return or profit will be higher in organic system as compared to conventional agriculture. The cost of chemicals used in conventional system will be always higher as compared to organic system. Because in organic system, the substances for plant protection are mostly available in local area or prepared at home.

Role of Nutrients in the Management of Crop Disease through Biopesticides under organic farming-

Organic farming system is most acceptable in present scenario of sustainable agriculture. To obtain optimum crop production bioresources provide various macro and micro essential nutrients in the soil, they must be available in sufficient quantity for plant's absorption. The protection of plants from various pathogenic diseases is also very important. The amendment of organic residues in fully decomposed form, use of bioresources, bioagents and biological practices can provide solutions for both nutrition and disease protection for plants. Nutrients when present in their normal critical range in soil-plant system are very helpful for plant protection from incidence and development of diseases in various ways. The development of model for balancing nutrients and applications of bioagents and bioresources to achieve uncontaminated environment, agriculture and human health is an urgent need for future prospects.

Zero Budget Natural Farming: Where Healthy Soil Makes Healthy Crop- An Eco-friendly Approach to Manage Insect Pests and Disease under Organic Farming-

Zero budget natural farming (ZBNF) is an alternative farming system to present high cost chemical agriculture. It addresses soil degradation, pollution, human health and climate change issues. 365 days green cover which is a new paradigm in natural farming is discussed in this chapter. ZBNF core principles by emphasizing four wheels, viz., Beejamruth, Jeevamruth, Achadan and Waphasa are described scientifically. The role of healthy soils in producing healthy crops is the core subject of this chapter. How natural farming practices improve the soil microbial diversity, humic substances and the role of useful microbes in inducing systemic resistance is mentioned by quoting research evidence. As ZBNF is similar to agroecosystem principles, the cropping systems with poly crops intercrops, trap crops and boarder crops effectively manage pests and diseases. The list of botanical pesticides and cow based solutions is provided along with non-negotiables for plant protection.

Agro-Nanotechnology: An Eco-friendly Approach in the Management of Plant Disease and Mycotoxins under Organic Farming-

Nanotechnology is a scientific field dealing with the understanding and study of material at a distance of about (1-100) nm as defined by the United States Environmental Protection Agency (USEPA), which includes building and restructuring physical, chemical, and biological properties of materials at the nanolevel, i.e., at the scale of atoms and molecules. In the twenty-first century, nanotechnology has emerged with a major impact on the global economy, industries, and public life. Historically, the agricultural nanotechnology researches were started since mid of twentieth century, but the real applications of this technology can be seen nowadays."Nano" is originally a Greek word means "a dwarf "and was used in mathematics to express the unit of length measurement (1 nanometre = 10-9 m, i.e., one part per billion of metre). It is used as a unit for measuring the length of small things that are only seen by an electron microscope, such as measuring the dimensions of atoms, molecules, and cells, as well as measuring the dimensions of microorganisms such as bacteria and viruses. Numerous studies have been conducted in recent years on the use of nanotechnology in agricultural production, which is called agro-nanotechnology. It is one of the most important tools in modern agriculture and includes employment of nanoparticles properties. Indeed, nano-molecules are absorbed efficiently by plants due to their small size that highly facilitates the penetration of the membrane of plant cells. Additionally, it enhances the crop productivity, protects the plant from insect pests and diseases, reduces agricultural crop losses and control of soil pollution due to heavy metals that impede plant nutrients and water absorption. Furthermore, it helps to purify water from organic and inorganic pollution. A great effort is being done to implement nanotechnology in food production, as it is believed that traditional agricultural systems will not have the capabilities to increase food crops. The rapid developments in nanotechnology have a major impact on agricultural practices, as some Nanomaterials have been implemented in plant diseases control, thus the mechanism for controlling plant diseases and reduction of mycotoxins with less side effects on crops or environment, which was the major concern of the researchers in the management of plant diseases. Therefore, it is necessary to search for alternative solutions and/or protocols to control plant diseases considering the environment safety. In recent years, the use of nanomaterials has expanded and become an alternative to control plant pathogens.

Management of Fungal Diseases of Crops through Plant-Based Natural Products under Organic Farming-

Most of the phytopathogenic diseases caused by the fungi that they have gigantic reproductive capability and hold the metabolic mechanisms which are able to cultivate resistance to marketable fungicides. The mycotoxins on crops produce phytopathogenic fungi *Aspergillus, Alternaria, Botrytis, Colletotrichum, Fusarium, Phytophthora, Penicillium* and *Pythium,* among others. Several plants belonging to the families of Anacardiaceae, Asteraceae, Caprifoliaceae, Lamiaceae, Liliaceae, Papilionacea, Poaceae, Verbenaceae are gorgeous sources of bioactive secondary metabolites of wide spread diversity such as tannins, terpenoids, saponins, alkaloids, flavonoids, essential oils and other compounds, reported to have in vitro antifungal properties. So, the secondary metabolites with antifungal activity signify an alternative for succeeding a sustainable control of phytopathogenic fungi and to reduce the heavy reliance of synthetic pesticides used to control them.

The naturally produced fungicides are considered more eco-friendly than the man-made herbicides, because of their short environmental half-life. The phytochemicals of plants have inhibitory effects on all types of microorganisms in vitro. Approximately 600 plants showing antifungal properties have been reported till date. The extraction of phytochemicals profile may vary on the bases of climatic, geographical condition or genetic factors. Finally, the sustainable food security cannot rely on the use of synthetic pesticides; endemic resources of biopesticides must be utilized in the production and post-harvest protection of food products in developing countries, in order to ensure that the populations will have access to sufficient and healthy food

Scope of Botanical Pesticides in Storage Insect Pests Management under Organic Farming-

Losses of food grains due to insects infestation during storage is a serious problem, particularly in the developing countries. In general, the major pests of stored grain are classified into primary pests, which are capable of penetrating and infesting intact kernel of grain and have immature stages development within kernel of grain, and secondary pests, which cannot infest the whole grain but feed on broken kernels and grain damaged by primary pests and their immature stages are found external to the grain. A high percent infestation of grains due to various insect pests during storage causes loss of germination capacity of seeds making them unfit for human consumption. Insect induced changes in the storage environment may cause warm, moist 'hotspots' that are suitable for the development of storage fungi which cause further losses. The use of synthetic chemical insecticides is either not permitted or these are used restrictively because of the residue problem and health risks to consumers. Such constraints pave a way to use need based plant derived products as alternatives to current chemical pesticides. A high volume of reports has shown plant- derived products to possess great insecticidal potential. Moreover, the biosafety studies of various plant based insecticides should be carried out to ascertain their toxic effects on humans, animals and agricultural crops. This chapter includes various aspects like storage losses by insect pests, plant products as alternative to synthetic compounds, and classification of plant based compounds, powder and oil formulations as grain protectants.

Microbial Control of Storage Insect Pests under Organic Farming-

Many smart methods of insects control depend on microbes, and the more we understand insect-microbe interactions, the more these can be exploited to develop targeted interventions with reduced environmental footprints. This chapter contains information on microbial agents isolated from insect pests and examines their potential for economic pest control. The use of Bacillus thuringiensis Berliner against storage pests has considerable potential and its application is a registered method for the control of lepidopteran storage insects. Several groups of protozoa and nematode are of interest as agents for the natural control of insect pests. The use of naturally occurring viruses for the control of insect pests has long been considered to have great potential, as these viruses are pest-specific and relatively safe to vertebrates. Entomopathogenic fungi are the first microorganisms to be used as microbial insecticides and only regarded as suitable for application in humid tropical climates. Therefore, the priority for the future is the adoption of an integrated pest management (IPM) programme, which includes the use of BT where and when appropriate, and it should be closely supervised by the authorities The use of microbial agents for the control of insect pests of stored products is still in its infancy and further research needs to be undertaken. If candidate materials are to be utilized to their best effects, their ultimately approval must be obtained and careful consideration might be given to the role they will play in pest control strategies and public health.

Biological control of stored grain pests may prove effective, if used in appropriate manner, time and space. The concept of microbial control of insects by use of viruses, bacteria, fungi, nematodes and protozoa have been developed for a broad range of applications, but their use as grain protectants requires further investigation.

Recently, their introduction has attracted greater commercial interest due to developments in technology and closer collaboration between the disciplines of molecular biology, genetics, microbiology, and protein and nucleic acid chemistry. Novel insecticides are subject to the same stringent regulations as other pesticides and their eventual approval must be exercised. It is concluded that although microbial insecticides show considerable potential for the protection of stored products, further research in the scenario is needed.

Now, the molecular tools are available to characterize individual isolates readily and to probe pathogen population structure, and incorporation of such studies into microbial control programmes to facilities pre-and post-release monitoring that is strongly encouraged. Policies are needed to be amended to permit greater inclusion of integrated pest management tactics in the grain inspection and marketing systems.

Organic Sugarcane Production Practices in India-

Sugarcane commercially cultivated in tropically and sub-tropically States of India having diverse agro-climatic conditions. A number of sugarcane verities have been developed which changed the sugarcane varietal scenario of the country. Now in most of the factory zones, area under rejected verities is less than 5-6%. It was because of replacement through newly developed varieties. In few sugar mills area under high sugar early maturing varieties increased to larger extent up to 82% because of high sugar content. During 2015-16, sugar recovery at national level was around 10.65% which was also due to improved varieties and agro techniques adopted. But organically produced sugarcane products like sugar and juice is major concern and time to think on its production which is negligible. Organic sugarcane production in Indian scenario is serious concern because of sugarcane growers are running behind the sugarcane productivity rather than quality sugarcane production. The Land holding for crop cultivation is at marginal level and farmers are also not well aware of organic sugarcane production technology. Besides this, profit from organic sugarcane production is not sure and decided by the government. However, Organic crop production are is increasing day by day which is around 4.68 million hectare in general. For the organic production, a clear production strategy and policy are required to be implemented in increase production and profitability of sugarcane growers.

References-

1. Alaa,A.;Hamdani,A.I.;Merri,M.;Mohammad,K. Effect of bacterial toxin for bacteria, *Bacillus thrigiensis*(Berliner) In some life stages of grain beetle.*Biochemical and Cellular Archives*.2018,18:2293-2297.
2. Chhonkar,P.K., " Organic farming myth and reality," in Proceedings of the FAI Seminar on Fertilizer and Agriculture Meeting the Challenges. New Delhi, India, December 2002.
3. Henry,J.E.(1981).Natural and applied control control of insects by Protozoa. *Annual Review of Entomology*,26:49-73.
4. Inoko, A., "Compost as source of plant nutrients," in Organic Matter and Rice, S. Banta and C.V. Mendoza, Eds.,pp.137-146, IRRI, Los Banos, Philippines, 1984.
5. Siddiqui,Q.H. and M.Sarwar.Pre and post harvest losses in wheat.Pakistan and Gulf Economist.2002,XXI(6):30-32.
6. Wakil,W.;Usman,G.M.;Yasin,M..Natural occurring entomopathogenic fungi infecting stored grain insect species in Punjab,Pakistan. Journal of Insect Sciences,2013,14:182.

Chapter No. 30: Bio-fertilizers in Sugarcane: Present and Opportunities in India

Lalan Sharma, S.K.Shukla, V.P. Jaiswal, Asha Gaur and A.D.Pathak
ICAR-Indian Institute of Sugarcane Research, Lucknow, Uttar Pradesh (India)

Abstract
Bio-fertilizers is live formulations of beneficial microorganism which has potential to solubilize, mobilize and fix plant nutrients for plant growth promotion and enhancing crop yield without effecting our environment. The beneficial microbes are associated with plant parts and root are called plant growth-promoting rhizobacteria (PGPRs). Bio-fertilizers are categorized as nitrogenous Bio-fertilizers (*Rhizobium* spp., *Gluconacetobacter*spp., *Azotobacter*spp., *Azospirillum*spp., Cyanobacteria and Azolla) phosphorus solubilizing bio-fertilizers (*Trichoderma*spp., *Bacillus*spp., *Pseudomonas* spp., *Aspergillus* spp., VAM fungi/Mycorrhiza).Microbial inoculants may be in form of solid, liquid and capsule, etc. Depending on the nature of the microbial inoculants, rate, and mode of bio-fertilizers application in sugarcane is vary. Some precautions should be kept in mind during bio-fertilizers application.

Why should we use Bio-fertilizers?
Agricultural crops require more water and plant nutrients from soil for better growth and development &crop yield. The nutrients requirement is being given through chemical fertilizers. Need based and timely application of fertilizers is very important factor to achieve higher crop yield and quality produce. But, it has been observed that indiscriminate and non-judicious application of chemical fertilizers / agricultural chemicals have polluted not only polluted our crop fields only depleted microbial populations in the soil and caused hazardous to human health. Depleting microbial population either directly or indirectly is affecting our soil quality and fertility. Soil quality and fertility is determined by the presence of microbial diversity & activity, composition, distribution and available organic content. Now days these are depleting in faster rate. Therefore, to minimize detrimental effect of chemical fertilizers / agricultural chemicals, a beneficial microbial intervention is required to be adopted by the farmers to achieve quality crop produce and maximize yield in depleting natural resources.

Soil health Vs. Plant Health
Drastically increasing human population directly or indirectly is affecting the availability of natural resources like fertile land, fresh air & water and congenial environment.In present scenario, intensive crop cultivation and non-judicious application of fertilizers/agrochemicals have been used to fulfill food requirements. Besides this, number of agronomic practices has also been adopted to increase crop production and productivity. They have affected our soil health and fertility, and reduced microbial biodiversity. As we know that the beneficial microbes have close association with plant from its beginning. The plant growth promoting beneficial microbes can mineralize soil by nutrient solubilisation, mobilization, biological nutrient fixation, toxic chemicals detoxification and antagonistic potential. A good soil health can produce more crop yields and improve human economic status if it is rich with microbial diversity (Fig., 1).

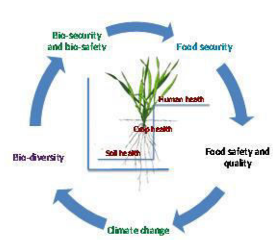


Fig., 1 Cycle of soil health, crop health and human health

Beneficial Microbes

There is globally demand of sustainable, ecologically compatible agricultural practices and techniques for providing quality and quantity food for increased human population without any further risk on soil fertility and environmental conditions. The microbes have close associations, relationships and interactions with plants. Some microbes are beneficial for the plants and others are not. Beneficial microbes are found associated with plant roots, called plant growth promoting rhizobacteria (PGPRs), nodule farming bacteria, yield increasing bacteria and nitrogen fixing bacteria. In spite of less in number and genetic diversity, are performing many functions for better growth and development of plants like production of phyto-hormone, activation plant defense compounds, production of antibiotics and hydrolytic enzymes. Besides this, they are also potential to chelate soil nutrients and oxidation of 1-aminocyclopropane-1-carboxylate (ACC) compounds which is immediate precursor of ethylene. A number of microbial bio-formulations have been developed for the crops like rice, maize, wheat, tomato, chickpea, pea and many more.

What is Bio-fertilizers

Bio-fertilizers are ready to use live formulations of beneficial microorganism which on application to seed, root or soil mobilize the availability of nutrients by their biological activity and help building up the micro flora and thus soil health.Modern agriculture is dependent upon the supply of chemical fertilizers, which are becoming scarcer and more costly. These are major agents for water and air pollution also. This situation has lead to identifying harmless inputs like biofertilizers in crop cultivation, which not only helps in saving chemical fertilizers but also safeguards soil health and quality of crop products.

Fig. 2 Nodule formation in legume crop   Fig. 3 Culture of *Rhizobium* spp.,

Benefits from using Bio-fertilizers

- Increases crop yield by 10-30%
- Replaces chemical fertilizers (inorganic fertilizers) up to 25%
- Stimulates plant growth and defense system
- Activates soil biologically active phenomenon
- Restore natural soil fertility and microbial population
- Provide protection against biotic and abiotic stresses
- Application friendly and environmentally safe

Types of Bio-fertilizers available

1. **Nitrogenous Bio-fertilizers**
   Rhizobium
   Gluconacetobacter
   Azotobacter
   Azospirillum

Cyanobacteria (Blue Green Algae)
Azolla, etc.

2. **Phosphorus Solubilizing Bio-fertilizers**
   Trichoderma
   Bacillus
   Pseudomonas
   Aspergillus
   VAM fungi/Mycorrhiza, etc.

Characteristics of quality Bio-fertilizers

- Increased shelf life/viability
- Better rhizosphere competence
- Ease for mass multiplication
- Broad spectrum of action
- Tolerate desiccation, heat, oxidizing agents and UV radiations
- Safe to environment

Example of some sugarcane Bio-fertilizers

1. ***Gluconacetobacter*Bio-fertilizers**
   - A product with superior strain of *Gluconacetobacterdiazotrophicus*
   - An endophytic bacteria i.e. associates and colonizes within all parts of sugarcane (root, cane stem and leaves)
   - Fixes atmospheric nitrogen and enhances the availability of Nitrogen to sugarcane and also produces growth hormone like Indole Acetic Acid (IAA)
   - Results visible after 5-6 weeks of its application
   - Increases size and length of internodes,
   - Enhances plant growth and development
   - Improves cane yield (5-15 t/ha) and sugar content (5-15%)

2. ***Azotobacter* Bio-fertilizers**
   - A product with potential strain of *Azotobacterchrococcum*
   - A free living bacteria
   - Enhances availability of nitrogen and produces plant growth regulators. Thus stimulates rooting
   - Excretes antibiotics/ bacteriocins, which protect root plant pathogens
   - Stimulates early seedling vigor and improves yield up to 25%

3. ***Azospirillum* Bio-fertilizers**
   - A product with strains of *Azospirillumbrasilense* or *Azospirillumlipoferum*
   - An associative type of bacteria, living in proximity of root zone
   - Fixes atmospheric nitrogen and provides 30-50% of Nitrogen requirement and also produces plant growth hormones like auxins and cytokinins
   - Enhances germination efficiency, early seedling vigor, plant immunity and cane yields up to 20 %

4. **Phosphate Solublizing Microbes (PSM)**
   - A product with single or consortium of *Trichoderma*spp., *Bacillus* spp., *Pseudomonas* sppand*Aspergillusawamor*etc.,
   - Multiply rapidly around the root zone, acts on inorganic bound soil phosphate and makes phosphorous available to the plant
   - Improves plant vigor and yield up to 15%

Rate and mode of bio-fertilizers application in Sugarcane

Rate: 5 kg/acre or 12-15 kg/ha

Mode of application:

- **Sett Treatment**- Suspend and mix thoroughly 5 kg bio-fertilizer (for one acre) in 100 litre of water. Treat sugarcane setts by dipping in this suspension before planting.
- **Soil Treatment**- Suspend 5 kg of bio-fertilizer in 10 litre of water and mix thoroughly with 80-100 kg of Farm Yard Manure. The mixed bio-fertilizer in FYM is sprinkled over cane setts in the rows at the time of planting. Immediately rows should be covered with soil.

Precautions for using Bio-fertilizers

- Bio-fertilizer packets should be stored in cool and dry place or keep away from direct sunlight and heat.
- Do not mix bio-fertilizer simultaneously with inorganic fertilizers/pesticides/agrochemicals.
- Bio-fertilizer packet should have name of the product, crop for which intended, date of manufacture and expiry, batch number, instructions for use, name and address of the manufacturer, to be taken.
- Bio-fertilizer packet should be used before its expiry date in described method and doze.
- For better results, biofertilizers should be used in combination with inorganic fertilizers (maintain application time gap).

Probable reasons for getting poor response of Bio-fertilizers

- Ineffective microbial strain in microbial bio-formulations.
- Insufficient microbial populations to survive and effect.
- High levels of contaminants with other harmful or saprophytic microbes.
- May have been exposed to high temperature or sunlight during storage and application.
- Not followed recommended method and dosage of microbial inoculants.
- Used along with inorganic fertilizers/pesticides/agrochemicals.
- Prevailing high soil temperature or low soil moisture or organic content.
- Applied in high acidity or alkalinity containing crop field.
- High population phages and other factors limit the survival of them.

Steps for Microbial Formulation Production -

1. Clean and maintain hygiene in working area.
2. Glassware, equipments, materials cleaning and sterilization.
3. Culture media preparation (solid, liquid, semi-solid) and sterilization.
4. Sample collection and storage at desired conditions.
5. Media pouring in Petri plate and kept for solidification.
6. Soil sample preparation for analyzing and microbial population isolation & enumeration.
7. Inoculation by Serial Dilution and Spread plate/Pour plate method
8. Incubation at desired temperature.
9. Isolation by Streak plate technique, storage and maintenance.
10. Inspection (Visual and Microscopic examination).
11. Identification (Morphological and Molecular basis).
12. Characterization (Cultural, morphological, biochemical, physiological, molecular)
13. Plant Growth Promoting Activity characterization (Bio-fertilizers & Bio-control Activity).
14. *In-vitro* screening for plant growth promotion attributes.
15. Green house trails for plant growth promotion or disease management.
16. Field trials for plant growth promotion or disease management.
17. Multi-location trials for plant growth promotion or disease management.
18. Quality Control testing of designated strain.
19. Microbial Bio-formulation Development at large scale.

General Aseptic Techniques

1. Before beginning practical work, hands should be washed with soap and warm water, and all should be washed again after the activities are finished.
2. Don't eat in Lab or working area.
3. Don't talk during working time.
4. Clean bench area with sterilizing material.
5. Cultures should be viewed in the unopened containers in which they were grown.
6. All cultures must be heated to kill micro-organisms before disposal.
7. Proper level must be done during microbiological work and reagents preparation.

Conclusion

Good soil health provides better crop growth and ultimately better crop yield. It is urgent need to increase and maintain diversity of beneficial microbes in the soil. Bio-fertilizers are the best options for soil nutrients management.

Chapter No. 31: Natural and biodynamic farming for sustaining sugarcane production system-Concept, practices and strategies

S. K. Shukla
Principal Scientist
ICAR-Central Institute for Subtropical Horticulture, Lucknow

Today's Concerns

- Low use of organic manure leads to diminition of Soil Organic Carbon (SOC).
- Chemicals and salts applied turn soil sterile; soil organisms perish, earthworms disappear and soil becomes dead.
- Biological degradation of soil health due to soil erosion, extreme acidity, alkalinity, addition of toxic substances.
- Soil fertility is contained in the upper layer of top soil, poor soil fertility and low inbalanced nutrition leads to deficiency of macro, micro and trace elements.
- It is eye opening that currently N use efficiency is 20- 50%, depending upon soil health and local conditions.
- Use efficiency of other nutrients is alarming i.e., 15-20 % (P), 60-70 % (K), 8-10% (S) and 1-5% micronutrients.
- There is gap of almost 10 million metric tones of nutrient in a year, even after so much efforts.
- Annual loss of nutrition through soil erosion is almost equal to fertilizers produced by industries in a year in country.
- Management of fertilizers has become expansive, central govt. enhanced subsidy to the tune of 1.40 lakh corore in the currennt year.
- Even with lot of central and respective state government efforts, pathetic situation of farmers standing in long que was a common sceen at number of centres in the recent months.

Natures' gestures to mediate cosmic energy for plant nutrition

- Soil microbial consortia, many soil dwellers including earthworms have capacity to mediate cosmic energy.
- Specific bacteria solublizers for all elements utilized by plants.
- Large number of plants are biological N-fixtures (BNF) including leguminous have specific bacteria capable of mediating free N available in the biosphere.
- Millions of lips beneath foliage are busy in inhaling carbon dioxide and exhaling oxygen essential for survival of human being and other living one.
- Chlorophyll in foliage mediates solar energy in process of photosynthesis, the basic step in preparation of food needed for survival of everyone.
- Without plants we cannot breathe, nor drink and not eat.
- Cow with hump which is pyramid shape, belly is mini replica of cosmos and horns have capacity to mediate cosmic energy.
- Belly of indigenous cow, udder and teats are rich in beneficial microbial consortia, hence the dung, urine and milk obtained from these cows are immense use in agriculture & human health.

What is Natural Farming?

Natural farming is defined as a **"**Chemical- free livestock based farming". Soundly grounded in agro-ecology, it is a diversified farming system that integrates crops, trees and livestock, allowing the optimum use of functional biodiversity. It holds the promise of enhancing farmers' income while delivering many other benefits, such as restoration of soil fertility and environmental health, and mitigating and/or reducing greenhouse gas emissions. This farming approach was introduced by

Masanobu Fukuoka, a Japanese farmer and philosopher, in his 1975 book The One-Straw Revolution. Internationally, Natural Farming is considered a form of regenerative agriculture which is a prominent strategy to save the planet.

Significance of Natural Farming :

Minimized Cost of Production: It is **considered as a cost- effective farming practice** with scope for raising employment and rural development.

Ensures Better Health: As Natural Farming does not use any synthetic chemicals, **health risks and hazards are eliminated.** The food has higher nutrition density and therefore offers better health benefits.

Employment Generation: It generates employment on account of natural farming input enterprises, value addition, marketing in local areas, etc. The surplus from natural farming is invested in the village itself. As it has the potential to generate employment, thereby stemming the migration of rural youth.

Environment Conservation: It ensures better soil biology, improved agrobiodiversity and a more judicious usage of water with much smaller carbon and nitrogen footprints.

Livestock Sustainability: The integration of livestock in the farming system plays an important role in Natural farming and helps in restoring the ecosystem. Eco Friendly bio-inputs, such as Jivamrit and Beejamrit, are prepared from cow dung and urine, and other natural products.

Resilience: The changes in soil structure with the help of organic carbon, no/low tillage and plant diversity are supporting plant growth even under extreme situations like severe **droughts and withstanding severe flood** and wind damage during **cyclones.**NF impacts many farmers positively by imparting resilience to the crops against weather extremities.

Issues and concerns in Natural Farming:

Decline in Yields:Sikkim (India's first organic state), has seen some decline in yields following conversion to organic farming.Many farmers have reverted to conventional farming after seeing their ZBNF (Zero-Budget Natural Farming) returns drop after a few years.

Unable to Boost Productivity and Income: While ZBNF has definitely helped preserve soil fertility, its role in boosting productivity and farmers' income isn't conclusive yet.

Lack of Availability of Natural Inputs: An often-cited barrier by farmers in transitioning to chemical-free agriculture is the lack of readily available natural inputs. Not every farmer has the time, patience, or labour to develop their own inputs.

Nutrient Deficiencies:A study in Nature Sustainability states that while the nutrient value of the natural inputs is similar to the chemical ones used in low-input farms (farms using lower quantities of fertilisers and pesticides), it is less in high-input farms.When such nutrient deficiencies are aggregated at a large scale, it might hamper the yield over the years, potentially leading to food security concerns.

M.Fukuoka in Japan started NF and obtained crop yields comparable with chemical farming without any soil erosion.Basic principle is to reduce use of external inputs to the farm land which degenerates soil nature.He prepared natural insecticide from chrysanthemum roots called pyrethrum and used against cabbage worms and moths. Soil is supplemented with the microbial inoculums like *Beejamrit, Jeevamrit*to accelerate the propagation of soil microflora, helpful to soil enrichment.

Principles

- No till farming-Tilling could destroy crucial physical characteristics of soil such as water suction, its ability to send moisture upwards, even during dry spells. Tilling over pumps oxygen to local soil residents, bacterial and fungi.

- As a result, soil chemistry changes and there is loss of organic matter due increased biological decomposition and increased microbiota at the cost of organic matter.
- No weeding by tillage or herbicides
- No chemical fertilizers

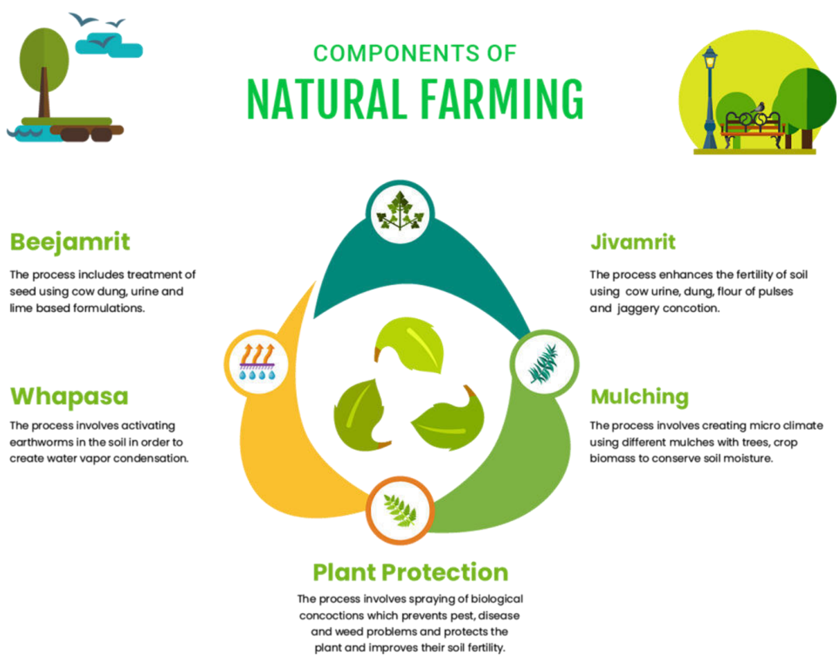
No dependence on chemical pesticides

Practices

- No tillage
- Mulching
- Jeevamrit, GhanJeevamrit
- Beejamrit
- Maintenance of proper balance of air and water in soil's pore spaces (WAFSA)
- N fixing and PSB help in improving the soil fertility and plant growth

Advantages

- Physical work and labour can be highly minimized
- Yields may be less initially but in comparable over the period with chemical farming
- Increase in soil fertility over the years
- Water requirement reduces significant**ly**
- **Has no side effects :Is it realistic**? Yes, because it is based on regeneration of earth's habitats and resources. No, system of production can be sustainable if it constantly takes more resources from the earth Industrial scale farming is absolutely, unquestionably unrealistic.



Habitat management is key to success of NF

- Role of plants in capturing cosmic & solar energy (micro & macro flora) is enormous.
- Both micro & macro flora captures cosmic & solar energy.
- CO_2 in wood & roots is fixed permanently(Ecology).

- Plants have only organic diet i.e. in oxidized ,chelate and ionic form which is accomplished by microbes;
- Plants restrict soil erosion, aerate soil & dead rootlets provide organic matter to soil organisms.
- Primary source of biomass.
- Soil beneath the canopy of few trees is rich in beneficial microbial consortia.
- Few plant parts have pesticide properties utilized for pest management
- Farming System, multi crops, rotation, mixed crops.
- Green manures, cover crops, inter crops, pump crops and mulching have many implications.
- Trees such as casuarinas, tamarind, neem, madhuca help in maintenance of soil biology and environmental ecology.
- Growing fodder and fuel plants on field bunds and in vacant area.
- Species grown in association should have different growth habits and different needs for light.
- Auro greens which can add large amount of organic matter quickly.
- Plants require 30+ nutrients for satisfactory performance.
- Plants get 98 to 98.5 % nutrients from, air, water and solar energy and need hardly 1.5-2% from soil.
- Atmosphere is being polluted by most human activities.
- The NPK, Fe, S and Ca are available in the soil but not in available form. They need to be transformed through action of microbes (Bacteria, microbes and local earthworms) already present in soil but excessive use of chemicals has destroyed them.
- In zero budget farming (ZBF) nothing has to be purchased from outside.

Organic and Natural Farming – A Comparison

Aspects	Organic Farming	Natural Farming
Cost	Organic farming is more expensive than NF because it requires using large amounts of organic manures/fertilizers on the land brought from those who sell them.	Cost of farming gets reduced as it encourages decomposition of organic matter through biological processes after mulching
Effort	Requires activities like mixing of manures/compost, ploughing and tilling	Decomposition of organic matter by microbes and earthworms is encouraged right on the soil surface itself, which gradually releases nutrients into the soil.
Environmental impact	Has an effect on the surrounding environment	It conforms to local biodiversity
Composting	OF wants permitted chemicals and composting of organic waste and FYM for application to the soil for soil nutrition	NF doesn't want any chemicals or organic compost inputs like vermiculture. It promotes a natural catalyst of biological activity in the soil and natural protection form diseases.

Biodynamic farming-Concept and Scope in NF

Biodynamics is a holistic, ecological, and ethical approach to farming, gardening, food, and nutrition. Biodynamic agriculture originated when Dr Rudolf Steiner gave eight lectures about a new method of agriculture to farmers in Germany, in 1924. Rudolf Steiner was an Austrian philosopher and scientist whose thought was very much influenced by oriental philosophy, especially Buddhism, Hinduism, and the Vedic scriptures. Out of this influence and his own studies was born Anthroposophy, or the wisdom (knowledge) of the human being:

At the heart of Anthroposophy is the recognition that the human being (Manushya) is a spiritual being (Purusha). Biodynamic agriculture was Steiner's answer to the farmers' call for help during the beginning of chemical farming in Europe when they noticed the rapid degeneration of the soil, of the quality of the produce, and of seed viability. They had been noticing a general decrease in vitality. Steiner then presented a different way of looking at cultivation and the Earth in general, showing the inter-relationship and connections between all living things.He explained how modern science and therefore chemical agriculture was based on the study of dead things in laboratories, rather than on the observation of living nature and the complex relationships constantly changing therein. Among this web of life he also included the cosmos with its moving planets and stars, and he spoke of how in the past, farmers instinctively knew about the effects of this movement on the life of plants and also animals and human beings. As modern human beings, we must find this connection once more to understand how to work best with nature, but this time in a very conscious, measurable way.

Today there are many people around the globe who concentrate on understanding and recording the effects of the cosmos on our planet Earth, including Maria Thun in Germany who publishes a planting calendar for gardeners and farmers to use. Rudolf Steiner introduced a few preparations based on homeopathic medicine to enhance the beneficial cosmic influences on plants and the soil, and encouraged people to experiment and find new ones as well.

Life is a study of energy from the coarse to the fine, and Biodynamics is primarily concerned with the higher forces, the finer energies and how they influence plants, animals, and human beings. This knowledge and work with the life forces brings balance and healing to the soil, and therefore to anything that grows in that soil and every being that eats those plants.

Principles and Advantages

In order to establish a system that brings into balance all factors which maintain life, the areas, viz. Substance and energy, Soil, Organic matter, Humus, Cow manure, Cosmic forces, Biodynamic preparations, Crop rotation, Peppering, The farm organism, Weeds, Pests and Diseases are taken into consideration while preparing strategy.

Practical applications

- Walk around your land each day, become familiar with all its aspects: minerals, rocks present, type of soil, wild plants growing, types of weeds, insect life, animals present day or night, electric wires crossing over the land, underground streams, presence of water, weather patterns, people living on or using the land.
- Establish environmental control: plant hedges and trees for wind protection, ensure good drainage, be aware of the water quality, use and collection.
- Introduce soil-protecting crop rotations and cover crops.
- Improve soil cultivation practices.
- Introduce green manuring, carefully plowed or dug under.
- Use mulching wherever possible; the Earth likes to be covered and will do it by itself with weeds!
- Build compost heaps and treat them with the preparations: do not waste any organic leftovers-collect everything. First compost manure and all other organic material, and apply only when completely broken down! It can be sieved to re-compost any under-com posted bits. Compost branches larger than your wrist separately as this will take much longer to break down.
- Use the BD preparations 500 and 501 as necessary, at the appropriate times, on the land and growing plants.
- Use other preparations such as the Cowpat Pit Preparation, Panchagavya, or natural liquid fertilizers (equisetum tea, fermented nettle manure) as needed.

Advantages

- Production of top quality fruits and vegetables, with strong flavours and high levels of nutrients (protein and vitamin content)
- Yields always above the average level, higher on average than those produced by organic farming, and consistently high throughout the years as opposed to the falling yields obtained by chemical farming as the soil is mineralised and pest populations become unbalanced and become a problem
- Little trouble with livestock and plant diseases
- No spreading of insect pests, and no great economic damage due to their presence: the question of insect pests is one of balance and control which can be restored by proper management such as planting shrubs and trees which will house natural predators

Few Biodynamic preparations:

BD 500 (Cow horn manure)

It is basically fermented cow dung. It is the basis for soil fertility and the renewal of degraded soils. It is buried in Sept./Nov and lifted in Feb/March. This is the period when the earth is breathing in and comic earth forces are most active (winter).

Preparation process

- Feed cattle with high quality food for two days prior to collecting dung for BD 500 (good green fodder and less protein artificial feed).
- Prepare burial pit: 18 inches deep. Pit area should not be subject to flooding, vigorous root systems or earthworms. BD 500 takes the character of the soil it is buried in, so good quality earth in the burial pit is essential.
- Collect cow horns – remove any paint.
- Collect fresh dung – reasonably firm.
- Fill cow horns with cow dung in October/November (rather than September due to India's warmer climate).
- Place horns in burial pit, 1 inch apart with base downwards, surround with 50% compost and soil.
- Cover with soil and bury for 4 to 6 months. If the soil is not rich enough, add compost to an extent of 50% to enhance soil quality.
- Keep burial pit soil moist and shaded, at temp of approx. 20oC and free from weeds and earthworms.
- After 4 months check for dung fermentation. Dig up one horn. If the green cow dung has turned into a dark, smooth earthy smelling humus (BD 500) they are ready to be lifted. Remove the BD 500, use and store. If not, leave them longer.

How to apply

Apply when the dew is falling (the earth breathes in) i.e. late afternoon or evening – descending Moon.

- 25 grams BD 500/acre in 15 litres rain/pure warm water (approx. 15-20 °C)
- Check water for high calcium, iron or other minerals
- Stir for 1 hour alternately clockwise and anti-clockwise forming a vortex
- Spray in the late afternoon or evening (just before sunset), when Moon is descending
- Spray 4 times a year – during the beginning and after rains, i.e. Feb-May-Nov-Dec.

Storage

- Place in glazed earthenware pots with loose fitting lids.
- Bury in a box surrounded with coir pith, which is kept moist and can be closed.
- Keep in dark and at temp of not more than 25 °C.
- Use within 1 year.

Advantages

- Promotes root activity
- Stimulates/increases soil micro-life
- Regulates lime and nitrogen
- Helps to release trace elements
- Increases germination

BD 501 (Cow horn silica)

This is finely ground quartz crystals specially prepared. The crystal should be of good quality, shape and clear. It is buried in a similar manner to preparation 500 but this time it is buried during the summer time (buried in April/May and lifted in September). This is the period when the earth is breathing out and the cosmic light energy is most active (summer).

Preparation process

- Crush silica quartz using a pounding rod, a mortar and pestle, or hammer
- Grind to a fine powder between 2 plate glasses

First glass - 12" square and 9 mm thick with a wooden frame.
Second glass - 4" square glass plate mounted in a wooden block (handle).

- Ensure that the quartz dust is not inhaled as it could lead to silicosis. It is advisable that masks are provided while making the preparation.
- Moisten with water to make a stiff paste
- Fill horns with the silica paste
- Bury horns in soil pit, 1 inch apart with base downwards, surround with 50% compost and soil from March/April (spring equinox) to September (autumn equinox)

Application process

Apply 501 only after one or two applications of BD 500. Apply when the dew is rising (the earth breathes out) i.e. early morning 6-8 a.m. at sunrise during ascending Moon or Moon opposition Saturn.

- 1 gm silica (enough to cover the small finger nail) in 15 litres of warm quality water
- Dissolve silica in water, stirring for 1 hour before sunrise, alternatively clockwise and anti-clockwise forming a vortex
- Spray the plants using a low-pressure sprayer (Knapsack 80-100 psi). Spray into the air to fall as a gentle mist over the plants
- As a general rule, spray twice during the planting cycle; at the beginning and again just before harvest

Storage

Store in a glass jar with a loose fitting lid, placed in an open area exposed to sunlight up to 3 years.

Effect/result

- Enhances light metabolism, photosynthesis and chlorophyll
- Helps to improve color, aroma, flavor and keeping quality of plants

Cow Pat Pit

Fermented cow dung (60 kg) mixed with 250 g each of crushed egg shell and bentonite/basalt powder. Black soil may be used in place of bentonite/basalt. After mixing the mixture is placed in in a pit of size 3 feetX 2 feet X 1.5 feet. Two biodynamic sets (BD 502-507) are also applied to this mixture, making holes before covering it with wet gunny bag in pit. It is allowed to ferment for 75-90 days. The manure is ready and used for soil application, composting, foliar application, seed and seedling treatment.

Package of practices for natural farming of sugarcane and tree based diversification of sugar cane production systems:

Padam Shri SubhashPalekar (Zero Budget Natural Farming) and Aacharya Devvrat (KamLagatPrakritik Krishi) have given complete package of practices for natural farming of sugarcane in their books available on line which needs attention of the farmers as well as researchers. There is need to generate scientific data on these lines to substantiate the claims as made in natural farming. Poplar cultivation coupled with sugarcane planting in the interspaces in Haryana and Punjab proved more remunerative when compared with sole/mono cropping (Mandal et al., 2013; Chahal et al., 2012). Several intercrops have already been standardized for sugarcane production system.

Conclusions

Enrich the soil with organic input, nutrients and microbial population to make soil healthy and suitable for higher production. Recycling of crop residue, mulching with locally available biomass, frequent use of GhanJeevamrit in place of FYM/Compost, use of Jeevamrit during field preparation & irrigation and 4-6 times foliar spray of CPP/ Biosol/ Panchagavya/Vermi wash,use of BD-500 and BD-501 as per convenience, without using a gram of agrochemicals higher production can be obtained in all crops in all situations. Building up of right microbial culture is much more important than to count N, P, and K in the organic menu. Feeding N, P, and K through chemical route, will not sustain agriculture for long what is being experienced.

Suggested readings:

1. Pathak, R.K., 2019. web: www.cosmicfarmingindia.com
2. Pathak, R.K. and R.A. Ram, 2019. A concept paper on Cosmic Nutrient Management in horticultural crops, Progressive Hort., 51(2): 111-115.
3. Devvrat, A. (2019) KamLagatPrakritikKrishi.IV Edition, PushpakPreshPvt Ltd, New Delhi
4. (https://atarikanpur.icar.gov.in/devrat.pdf)
5. https://archive.org/.../spnfnaturalfarminghimachal/page/n1
6. Chahal, D, Ahmad, A and Bhatia, J.N (2012) Assessment of agroforestry based two ier cropping system in Ambala district of Haryana. Agriculture Update, 73&4):210-213
7. Mandal, B.S., Mandal, N., Singh, Y.P., Kaushik, J.C. and Ajit (2013) Involvement of farmers for adopting of agroforestry system is the today's need. Progressive Research, 8(Special):183-185
8. https://agritech.tnau.ac.in/agriculture/org_farm.html

Chapter No. 32: Role of Conservation agriculture in sustaining soil fertility and crop yields

J.S. Mishra
Director
ICAR-Directorate of Weed Research, Jabalpur (M.P.)

Over exploitation of natural resources has lead to widespread degradation of land, soil nutrient mining and soil carbon loss, and resulted in to serious implications for food security and ecological integrity. Conservation Agriculture (CA) is an approach to managing agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment (FAO, 2014). CA based on three key elements of ***minimizing soil disturbance*** (no-tillage/minimum tillage), ***maintaining soil cover*** (organic soil mulch cover by crop residues and cover crops), and ***crop rotation*** (diversification of crop species in sequence or associations) (**Fig. 1**), enhances biodiversity and natural biological processes above and below the ground surface, which contribute to improved soil health and sustained crop production through increased water and nutrient use efficiency. Although most of the research findings advocate CA as a major technology to sustain the crop productivity, improve the farm profitability and help in mitigating the adverse effect of climate change, there are challenges as well (**Fig. 2**), especially in country like India where most of the farmers are small and marginal with less access to resources and modern tools and techniques. The emerging issues of insect-pests, diseases, weeds and other biotic stresses, if any, due to long-term use of CA technologies need to be addressed properly to harness the full benefit of the technology. The overall goal of conservation agriculture is to make better use of agricultural resources through the integrated management of soil, water and biological resources.

The Conservation Agriculture has been widely advocated worldwide in present day agriculture. The CA system has been adopted on over 180 million hectares globally (Table 1) (Kassam *et al*. 2018). In India, this system has been partially practiced in form of conservation tillage (zero tillage/minimum or reduced tillage). The U.S. Soil Conservation Service defines conservation tillage as any tillage system that leaves at least 30% of the surface covered by plant residues for control of soil erosion. Conservation tillage is a tillage system that conserves soil, water and energy resources through the reduction of tillage intensity and retention of crop residue. It involves the planting, growing and harvesting of crops with limited disturbance to the soil surface.

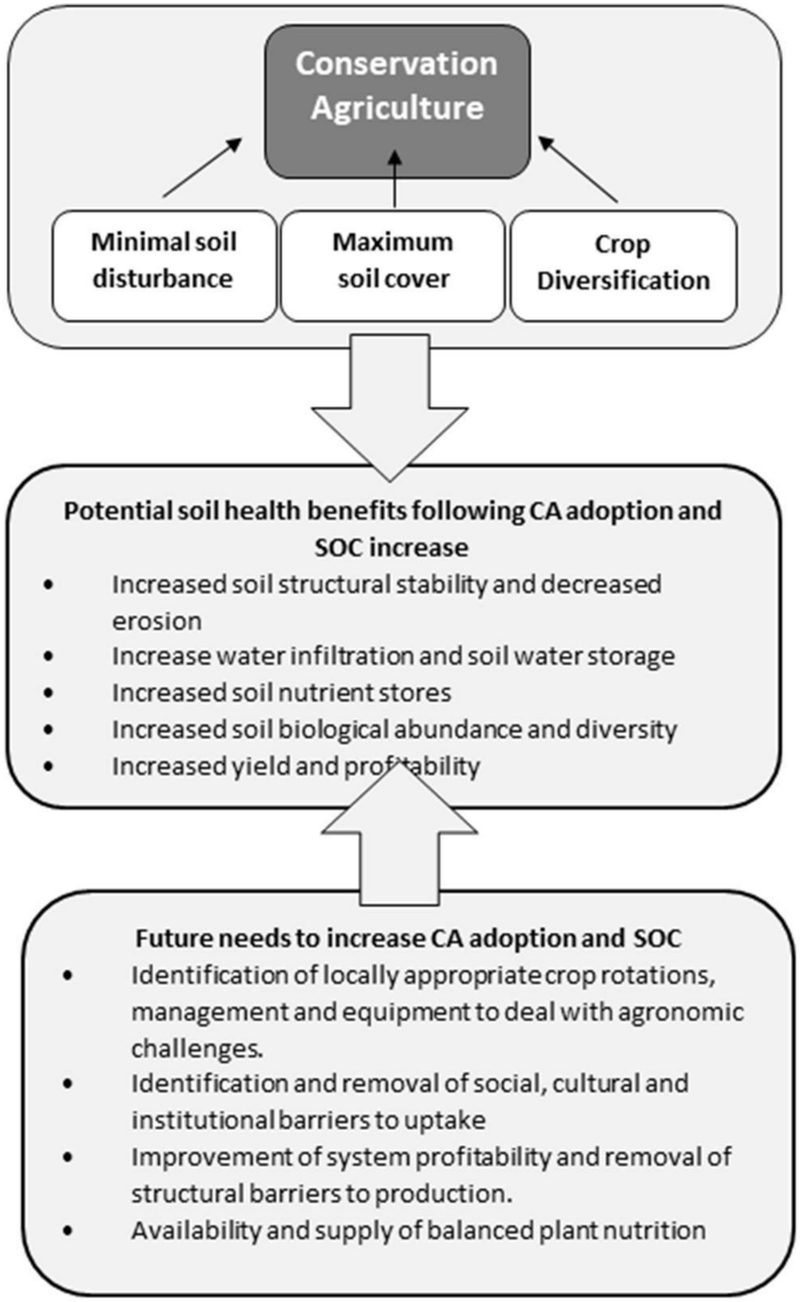


Fig 1. Benefits of increased soil organic carbon (SOC) under conservation agriculture (CA) and the future needs to increase adoption (Page *et al*., 2020).

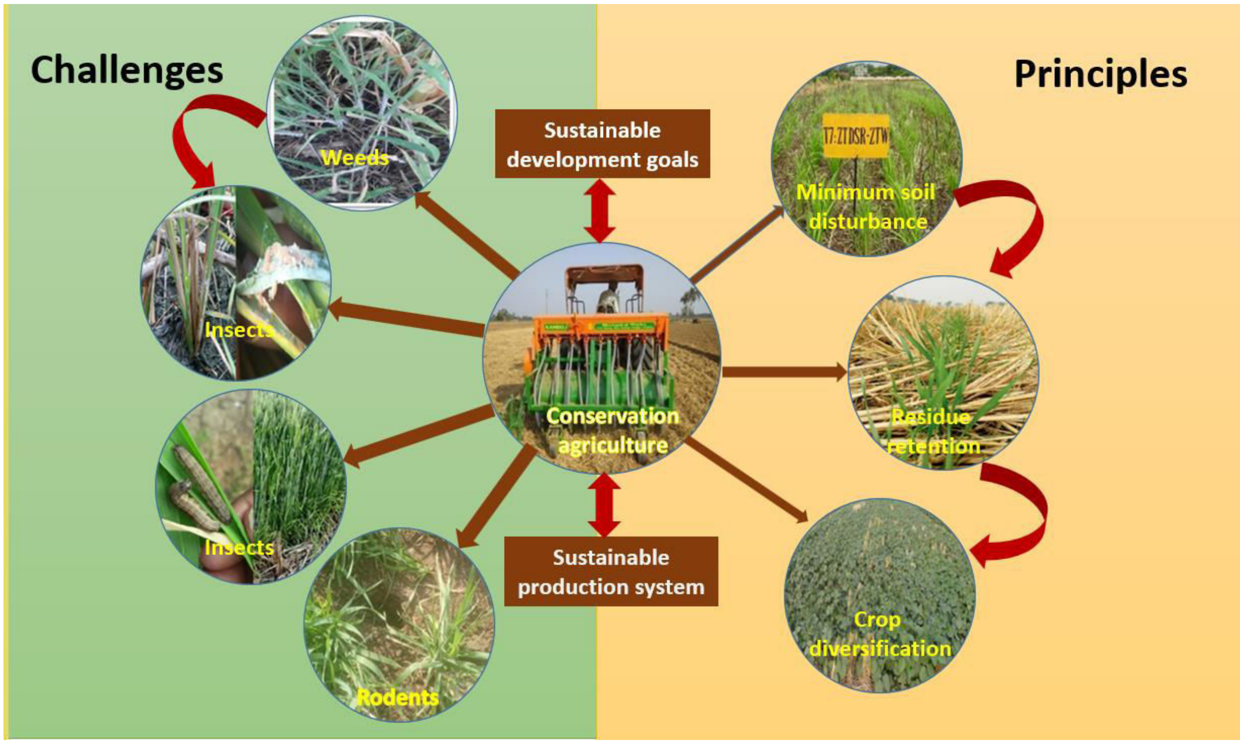


Fig 2. Schematic diagram of conservation agriculture (CA) production system with positivity and emerging issues in rice-based cropping systems of the middle Indo-Gangetic Plain (Kumar *et al*., 2022)

Table 1. Extent of adoption of CA worldwide.

S. No.	Country	CA area '000ha (2015/16)
1	USA	40,204
2	Brazil	32,000
3	Argentina	31,028
4	Australia	22,299
5	Canada	19,936
6	China	9,000
7	Russia	5,000
8	Paraguay	3,000
9	Kazakhstan	2,500
10	India	1,500
11	Uruguay	1,260
12	Others	9,712
13	Total	**1,80,439**

Effect of CA on soil physical properties

Excessive tillage practices for better crop establishment often results in soil degradation and depletion of soil carbon status. Continuous tillage at the same depth results in to development of a sub-surface compact layer, which reduces the root growth and nutrient and water use efficiencies. Adoption of CA practices has a synergistic effect on soil health. It has been reported that CA improves the soil physico-chemical properties and biological processes, reduces soil erosion, compaction, crusting, conserves soil moisture and moderates soil temperature (Somasundaram *et al*., 2020). It improves water infiltration and storage, soil aeration, soil organic carbon, soil structure and porosity, amount of stable macro-aggregates (Mondal *et al.* 2019). Rao *et al*. (2021) also reported that increase in cultivation intensity leads to loss of C-rich macro-aggregates in the soil. The earthworms' activity has been increased in CA (Kumar *et al*., 2021). Number of authors have reported beneficial role of earthworms for macro-aggregates formation during their feeding and casting activities. Earthworm casts have higher amount of organic carbon and water stability in comparison to surrounding soil (Arai *et al.* 2017), and therefore add to the soil quality. CA were reported to decrease soil bulk density and penetration resistance, and increase in soil moisture content, mean weight diameter and water-stable aggregates (Somasundaram *et al*., 2019; Mondal *et al*., 2021). Reduction in tillage operations and addition of crop residue as surface mulch enhances chemical, microbial and enzymatic activities in soil as compared to conventional tillage. In rice-fallow ecosystem of eastern India, CA practice showed higher soil aggregation, increased soil dehydrogenase activity (46.2%), urease activity (29.8%), soil microbial biomass carbon (65.4), and fluorescein diacetate activity (9.0%) in the crop root zone with 3.3-and 4.47-times higher earthworm population and earthworm biomass, respectively (Kumar *et al*., 2021).

Effect of CA on soil chemical properties

Soil chemical properties such as soil pH, cation exchange capacity, and plant nutrients are largely influenced by CA system. Improvement in soil organic carbon (SOC) content at the surface of soil profile due to CA system is linked with higher soil acidity compared to conventionally tilled systems (Sithole and Magwaza, 2019). Under CA system, most of the root system lies in the surface of soil profile, and contributes to higher rates of acidification due to greate root exudation (Limousin and Tessier, 2007). Crop diversification with greater inclusion of legumes and mineral N fertilization also reduces soil pH (Vieira *et al*., 2009).

Changes in SOC and soil pH also influence the cation exchange capacity (CEC) (McBride, 1994). Decrease in pH may leads to lower CEC (Sithole and Magwaza, 2019). Increase in SOC in CA system significantly improves plant nutrient availability. Increased residue addition in soil and inclusion of legumes in cropping system lead to higher nutrient stores and availability in response to increased organic matter. Residue decomposition releases nutrients to the soil and increasing amounts of surface residues are expected to improve soil nutrient content in the long term. However, in some cases, for example N, the total N concentration in soil may be higher in CA, but the amount of N availability may decrease during initial years of CA due to higher C:N. Addition of N may be required to improve the crop yields under such conditions. This is mainly due to lower N mineralization and higher rates of immobilization due to presence of crop residues with higher C-N ratio. Zero-till condition in CA system leads to the stratification of immobile nutrients at the surface soil due to absence of mixing of crop residues in soil (Dang *et al*., 2015). Retention of crop residues on soil surface is expected to improve the availability of phosphorus in topsoil through mineralization (Feng *et al*., 2014). However, Singh and Jones (1976) demonstrated that residues with P concentration less than 0.22% resulted in net P immobilization. Decrease in soil pH due to surface residues have a strong effect on soil P availability (Sato and Comerford, 2005). Crop residues are rich in K content. Surface crop residues resulted in increased exchangeable soil K content compared to bare soil (Ranaivoson *et al*., 2017). Higher infiltration rate in CA system may lead to leaching and movement of nutrients beyond root zone (Radford *et al*., 1995).

Effect of CA on crop productivity

Diversification of the conventional system through the CA based system intensification provides an excellent option of increasing crop productivity and profitability while addressing the issues of declining soil health, input-use efficiency and global climate change. In IGPs, rice is conventionally grown under puddled condition with intensive tillage and shifting to DSR from traditional puddling requires a shift in management practices, especially weeds and crop residue management. Therefore, zero-tillage yield declines in initial years in humid climatic condition and matches conventional tillage practices after 2-3 years. In rice-wheat greengram system, Mishra *et al*. (2021) observed that system productivity was lower by 12-15% in the initial two years. Later in third-year, system yield started to increase and was at par for the fourth year. Similarly, Jat *et al*. (2014) found that in rice-wheat rotation no-till with residue retention showed lower yield than conventional tillage and after 4-5 years yield were equivalent in conservation as well as conventional tillage. The reason for a lower yield in initial years is ascribed to soil stabilization time in benefit return in terms of yield through enhanced soil aggregation, soil organic carbon, available soil moisture etc. (Pittelkow et al., 2015).

Profitability

At the system level, we can draw comfort from the fact that productivity of CA based system may not improve every year, but net profits stayed higher than conventional methods. Long term prospects are also higher for improving water productivity and energy use. That is where the cost has come down. An amount of INR 19610-60400 ha^{-1} $year^{-1}$ could be saved by adopting CA-based system over conventional rice-wheat-greengram system (Mishra et al., 2021). Similar results were obtained in a long-term (10 years) study on reducing tillage practices in rice-maize system that gave a profit of 699-215481 US$/ha/year over conventional system (Jat et al., 2014). The cost reduction was principally due to a decrease in 4-5 tillage operation as reported elsewhere (Jat et al., 2019a). Other researchers also reported higher net returns from zero tillage (Erenstein, 2002). Most important point to focus on is due to the intensification of the system net return of rice-wheat-greengram system as a whole has increased almost double to US$ 4767 $ha^{-1}yr^{-1}$ compared to only rice-wheat system under Conservation Agriculture (US$ 2300 ha^{-1} yr^{-1}) as reported by Jat et al. (2014) in his studies based on 2013 dollar values or 2900 $ha^{-1}yr^{-1}$ (Gathala et al., 2015).

Energy efficiency

More efficient system is that which consumes less energy and gives a higher output (Yadav et al., 2017). Inclusion of legumes especially summer greengram is more efficient in terms of EUE (Soni et al., 2018). In the case of puddled transplanted rice and conventional wheat, the total energy input was higher; in which PTR took maximum labour (transplanting, weeding, harvesting, threshing) as well as a high amount of diesel used mainly for puddling which adds to the input energy (Mitra et al., 2018). Reduced energy requirement in rice and wheat under zero-tillage was mainly due to less input in terms of labour, diesel used for tillage and water pumping (Babu et al., 2020; Mitra et al., 2018). Energy use efficiency of the system varied from 6.09-8.02 being the lowest in SRI-based production system and the highest in CA-based production system. Similar results by Pratibha et al. (2015) showed higher energy efficiency in zero-tillage followed by reduced and conventional tillage in pigeonpea-castor system. As energy use efficiency is the ratio of output energy to input energy, it can be derived that CA-based production system had lesser input energy and produced at par output energy compared to conventional system which enhanced its overall energy use efficiency (Jat et al., 2019c). From all these energy related parameters, it is clear that CA-based production system with low input use and higher or at par output energy makes it more energy efficient system. Moreover, energy efficient CA-based system provides possibilities to intensify the rice-wheat system with the inclusion of legume crop as greengram which makes system more productive and efficient in terms of energy (Becerril and Rios, 2016).

Global warming potential

The global warming potential (GWP) of different rice treatments showed that ZTDSR had the lowest GWP. With a change in rice tillage practices from puddle transplanted rice, ZTDSR has 56.2% less methane emission. Under puddled soil methane is emitted under anaerobic condition in submerged soil by the methanogenesis process (Le Mer and Roger, 2001). As compared ZTDSR field were only kept moist which released less methane from soil (Jain et al., 2014). Gupta et al. (2016) reported that PTR treatments had 82-87% higher emission compared to DSR. In case of nitrous oxide, emission was 28% higher in ZTDSR compared to PTR (Mishra et al., 2021) which was because of alternate wetting and drying favouring nitrification and denitrification process (Jain et al., 2014). Higher N_2O emission from ZT may be due to higher compaction with higher bulk density and soil moisture which reduces oxygen diffusion rate favouring anaerobic condition under which more nitrous oxide is emitted (Gupta et al., 2016). Zero tillage combined with crop residue retention reduce GHG emission (Wassmann et al., 2009), increase carbon sequestration in uppermost soil layer (Li et al., 2020; Modak et al., 2019), reduce emission of methane (Metay et al., 2007) and CO_2 (Reeves et al., 2001); and save irrigation water and diesel. Similar results were obtained by Gupta et al. (2016) where DSR-ZTW in IGPs showed a 44-47% reduction in GWP in rice-wheat system.

References

Arai M, Miura T, Tsuzura H, Minamiya Y and Kaneko N. 2017. Two-year responses of earth-worm abundance, soil aggregates, and soil carbon to no-tillage and fertilization. *Geoderma*, **332**: 135-141.

Babu, S., Mohapatra, K.P., Das, A., Yadav, G.S., Tahasildar, M., Singh, R., Panwar, A.S., Yadav, V. Chandra, P., 2020. Designing energy-efficient, economically sustainable and environmentally safe cropping system for the rainfed maize–fallow land of the Eastern Himalayas. Sci. Total Environ., 137874.

Becerril, H., De los Rios, I., 2016. Energy efficiency strategies for ecological greenhouses: experiences from Murcia (Spain). Energies 9, 866.

Bhatia, A., Sasmal, S., Jain, N., Pathak, H., Kumar, R., Singh, A., 2010. Mitigating nitrous oxide emission from soil under conventional and no-tillage in wheat using nitrification inhibitors. Agr. Ecosyst. Environ. 136, 247-253.

Dang, Y. P., Seymour, N. P., Walker, S. R., Bell, M. J., and Freebairn, D. M. 2015. Strategic tillage in no-till farming systems in Australia's northern grains growing regions: I. Drivers and implementation. *Soil and Tillage Research* 152, 104–114. doi: 10.1016/j.still.2015.03.009

Erenstein, O., 2002. Crop residue mulching in tropical and semi-tropical countries: An evaluation of residue availability and other technological implications. Soil Till. Res. 67, 115-133.

FAO 2014. What is Conservation Agriculture? FAO CA website (http://www.fao.org/ag/ca/1a.html).

Feng Y., Liu Q., Tan C. et al. 2014. Water and nutrient conservation effects of different tillage treatments in sloping fields. *Arid Land Res Manag* 28: 14-24.

Gathala, M.K., Ladha, J.K., Saharawat, Y.S., Kumar, V., Kumar, V., Sharma, P.K., 2011b. Effect of tillage and crop establishment methods on physical properties of a medium-textured soil under a seven-year rice–wheat rotation. Soil Sci. Soc. Am. J. 75, 1851.

Gathala, M.K., Timsina, J., Islam, M.S., Rahman, M.M., Hossain, M.I., Harun-Ar-Rashid, M., Ghosh, A.K., Krupnik, T.J., Tiwari, T.P., McDonald, A., 2015. Conservation agriculture based tillage and crop establishment options can maintain farmers' yields and increase profits in South Asia's rice–maize systems: Evidence from Bangladesh. Field Crops Res. 172, 85-98.

Gupta, D.K.., Bhatia, A., Kumar, A., Das, T.K., Jain, N., Tomer, R., Malyan, S.K., Fagodiya, R. K., Dubey, R., Pathak, H., 2016. Mitigation of greenhouse gas emission from rice–wheat system of the Indo-Gangetic plains: Through tillage, irrigation and fertilizer management. Agr. Ecosyst. Environ. 230, 1-9.

Jain, N., Dubey, R., Dubey, D.S., Singh, J., Khanna, M., Pathak, H., Bhatia, A., 2014. Mitigation of greenhouse gas emission with system of rice intensification in the Indo-Gangetic Plains. Paddy Water Environ. 12, 355-363.

Jat, R.K., Sapkota, T.B., Singh, R.G., Jat, M.L., Kumar, M., Gupta, R.K., 2014. Seven years of conservation agriculture in a rice–wheat rotation of Eastern Gangetic Plains of South Asia: yield trends and economic profitability. Field Crop Res. 164, 199-210.

Jat, H.S., Kumar, P., Sutaliya, J.M., Kumar, S., Choudhary, M., Singh, Y., Jat, M.L., 2019a. Conservation agriculture based sustainable intensification of basmati rice-wheat system in North-West India. Arch. Agron. Soil Sci. 65, 1370-1386.

Jat, S.L., Parihar, C.M., Singh, A.K., Kumar, B., Choudhary, M., Nayak, H.S., Nayak, M.D. Parihar, N. Parihar, Meena, B.R., 2019c. Energy auditing and carbon footprint under long-term conservation agriculture-based intensive maize systems with diverse inorganic nitrogen management options. Sci. Total Environ. 664, 659-668.

Kassam A, Friedrich T and Derpsch R. 2018. Global spread of conservation agriculture. International *Journal of Environmental Studies*: http://doi.org/10.1080/00207233.2018.1494927.

Kumar Rakesh, **Mishra JS**, Mali SS, Mondal S., Meena RS, Lal Rattan., Jha BK, Naik SK, Biswas AK, Hans H, Sundaram PK, Choudhary AK, Monobrullah Md, Kumar Sanjeev, Kumar Santosh, Raman RK, Bhatt BP and Kumar U. 2021. Comprehensive environmental impact assessment for designing carbon-cum-energy efficient, cleaner and eco-friendly production system for rice-fallow agro-ecosystems of South Asia. *Journal of Cleaner Production*, 331, 129973, https://doi.org/10.1016/j.jclepro.2021.129973.

Kumar Rakesh, **Mishra JS**, Naik SK, Mondal S., Meena RS, Kumar Saurabh, Dubey AK, Makarana G, Jha BK, Mali SS, Choudhary AK, Hans H, Dubey R., Kumar, Santosh, Sundaram PK, Raman RK, Monobrulah, M., Kumar Sanjeev, Kumar Ujjawal and Bhatt, BP. 2022. Impact of crop establishment and residue management on soil properties and productivity in rice-fallow ecosystems in India. *Land Degradation and Development*, 1-15, https://doi.org/10.1002/ldr.4204.

Le Mer, J., Roger, P., 2001. Production, oxidation, emission and consumption of methane by soils: a review. Eur. J. Soil Biol. 37, 25-50.

Li, Y., Li, Z., Chang, S.X., Cui, S., Jagadamma, S., Zhang, Q., Cai, Y., 2020. Residue retention promotes soil carbon accumulation in minimum tillage systems: Implications for conservation agriculture. Sci. Total Environ. 140147.

Limousin, G., and Tessier, D. 2007. Effects of no-tillage on chemical gradients and topsoil acidification. *Soil and Tillage Research* 92, 167–174. doi: 10.1016/j.still.2006.02.003

McBride, M. B. 1994. *Environmental Chemistry of Soils*. New York, NY: Oxford University Press.

Metay, A., Oliver, R., Scopel, E., Douzet, J.M., Moreira, J.A.A., Maraux, F., Feigl, B.J., Feller, C., 2007. N_2O and CH_4 emissions from soils under conventional and no-till management practices in Goiânia (Cerrados, Brazil). *Geoderma*. 141, 78-88.

Mishra JS., Poonia SP, Kumar Rakesh, Dubey Rachana, Kumar Virender, Mondal Surajit, Dwivedi S.K., Rao K.K. , Kumar Rahul, Tamta Manisha, Verma Mausam, Saurabh Kirti, Kumar Santosh, Bhatt B.P., Malik R.K., Andrew McDonald, and Bhaskar S. 2021. An impact of agronomic practices of sustainable rice-wheat crop intensification on food security, economic adaptability, and environmental mitigation across eastern Indo-Gangetic Plains. *Field Crops Research,*267, 108164, https://doi.org/10.1016/j.fcr.2021.108164.

Mitra, B., Patra, K., Bhattacharya, P.M., Chowdhury, A.K., 2018. Unpuddled transplanting: A productive, profitable and energy efficient establishment technique in rice under Eastern sub-Himalayan plains. Oryza. 55, 459-466.

Modak, K., Ghosh, A., Bhattacharyya, R., Biswas, D.R., Das, T.K., Das, S., Singh, G., 2019. Response of oxidative stability of aggregate-associated soil organic carbon and deep soil carbon sequestration to zero-tillage in subtropical India. Soil Till. Res. 195, 104370.

Mondal S, **Mishra JS**, Poonia SP, Kumar Rakesh, Dubey R, Kumar Santosh, Verma M, Rao KK, Ahmed A. 2021. Can yield, soil C and aggregation be improved under long-term conservation agriculture in the eastern Indo-Gangetic Plain of India? *European Journal of Soil Science*, doi: 10.1111/ejss.13092

Mondal, S, Das, TK, Thomas P, Mishra AK, Bandyopadhyay KK, Aggarwal P and Chakraborty D. 2019. Effect of conservation agriculture on soil hydro-physical properties, total and particulate organic carbon and root morphology in wheat under rice-wheat system. *Indian Journal of Agricultural Sciences*, 89 (1): 46-55.

Page K.L., Dang Y.P. and Dalal R.C. 2020. The ability of conservation agriculture to conserve soil organic carbon, and the subsequent impact on soil physical, chemical and biological properties and yield. *Frontiers in Sustainable Food Systems*, doi: 10.3389/fsufs.2020.00031

Pittelkow, C.M., Linquist, B.A., Lundy, M.E., Liang, X., van Groenigen, K.J., Lee, J., van Gestel, N., Six, J., Venterea, R.T., van Kessel, C., 2015. When does no-till yield more? A global meta-analysis. *Field Crop Res*., 183, 156-168.

Pratibha, G., Srinivas, I., Rao, K.V., Raju, B.M.K., Thyagaraj, C.R., Korwar, G.R., Venkateswarlu, B., Shanker, A.K., Choudhary, D.K., Rao, K.S., Srinivasarao, C., 2015. Impact of conservation agriculture practices on energy use efficiency and global warming potential in rainfed pigeonpea–castor systems. *Eur. J. Agron*. 66, 30-40.

Radford, B. J., Key, A. J., Robertson, L. N., and Thomas, G. A. 1995. Conservation tillage increases soil water storage, soil animal populations, grain yield, and response to fertiliser in the semi-arid subtropics. *Australian Journal of Experimental Agriculture* 35, 223–232. doi: 10.1071/EA9950223

Ranaivoson L., Naudin K., Ripoche A., Affholder F., Rabeharisoa L. and Corbeels M. 2017. Agroecological functions of crop residues under conservation agriculture: A review. *Agronomy for Suatainable Development*, 37:26.

Rao KK, Samal, SK, Poonia, SP, Kumar Rakesh, **Mishra JS**, Bhatt, BP, Dwivedi, SK, Mondal, S., Choubey, AK, Kumar Santosh, Kumar Manoj, Malik RK, and Dalal RC. 2021. Conservation agriculture improves soil physical properties and crop productivity: a long-term study in middle Indo-Gangetic Plains of India. *Soil Research*, doi: 10.1071/SR20329.

Reeves, T., Pigali, P.L., Rajaram, S., Cassaday, K., 2001. Crop and natural resource management strategies to foster sustainable wheat production in developing countries. Pp. 32-36. In: Bedo, Z., Lang, L., (Eds.), Proceedings of the 6th International Wheat Conference, 5-9 June, 2000, Budapest, Hungary, Kluwer Academic Press, Dordretch.

Sato S. and Comerford, N.B. 2005. Influence of soil pH on inorganic phosphorus sorption and desorption in a humid Brazilian Ultisol. *Rev Bras Cienc do Solo*, 29:685-694.

Singh B.B. and Jones J. 1976. Phosphorus sorption and desorption characteristics of soil as affected by organic residues. *Soil Science Society of America Journal* 40:389-394.

Sithole N. J. and Magwaza, L. S. 2019. Long-term changes of soil chemical characteristics and maize yield in no-till conservation agriculture in a semi-arid environment of South Africa. *Soil and Tillage Research*. 194:104317. doi: 10.1016/j.still.2019.104317

Somasundaram, J., Salikram M., Sinha, N.K., Mohanty, M., Chaudhary RS, Dalal, R.C., Mitra, NG, Blaise D, Coumar, MV, Hatti K.M, Thakur JNeenu S., Biswas, AK., Patra, AK and Chaudhari, S.K., 2019. Conservation agriculture effects on soil properties and crop productivity in a semi-arid region of India. *Soil Research* 57: 187-199.

Somasundaram, J., Sinha, N.K., Dalal, R.C., Lal, R., Mohanty, M., Naorem, A.K., ..., and Chaudhari, S.K., 2020. No-till farming and conservation agriculture in South Asia–issues, challenges, prospects and benefits. Crit. Rev. Plant Sci. 39, 236-279.

Soni, P., Sinha, R., Perret, S.R., 2018. Energy use and efficiency in selected rice-based cropping systems of the Middle-Indo Gangetic Plains in India. *Energy Report* 4, 554-564.

Vieira, F. C. B., Bayer, C., Zanatta, J., and Ernani, P. R. 2009. Organic matter kept Al toxicity low in a subtropical no-tillage soil under long-term (21-year) legume-based crop systems and N fertilisation. *Australian Journal of Soil Research* 47, 707–714. doi: 10.1071/SR08273

Wassmann, R., Jagadish, S.V.K., Sumfleth, K., Pathak, H., Howell, G., Ismail, A., Serraj, R., Redona, E., Singh, R.K., Heuer, S., 2009. Regional vulnerability of climate change impacts on Asian rice production and scope for adaptation. Adv. Agron. 102, 91-133.

Yadav, G.S., Lal, R., Meena, R.S., Datta, M., Babu, S., Das, A., Layek, J., Saha, P., 2017. Energy budgeting for designing sustainable and environmentally clean/safer cropping systems for rainfed rice fallow lands in India. J. Clean Prod. 158, 29-37.

Chapter No. 33: Organic sugarcane and jaggery production & certification: scope and opportunities

T.K. Srivastava
Principal Scientist (Agronomy), Division of Crop Production
Indian Institute of Sugarcane Research, Lucknow

Sugarcane is one of the most important agro-industrial as well as cash crops of India. It is pivotal for socio-economic security of Indian peasants on one hand and supports the massive sugar industry by satiating its raw material requirements on the other. During the year 2021 - 22 sugarcane occupied an area of 5.45 m ha with total production of 431 million tonnes and productivity of 81 t/ha. A retrospection of achievements indicates that we reached the present level of production from 59 m tonnes in 1951-52 with a rate of 3.02 per cent growth per annum out of which, area increased at a rate of 1.72% and productivity by 1.30% for the country as a whole. Contribution of area towards increased production is, therefore, greater than that of the productivity, despite significant increase in the use of market purchased inputs such as high analysis chemical fertilizers, pesticides, growth regulators, fungicides, herbicides, etc. as evident from their ever increasing consumption in Indian Agriculture. The scenario, hence, reveals a palpable decline in total factor productivity of the chemical based sugarcane production system, owing to irreparable loss of native soil organic carbon. Moreover, reports about secondary and micro-nutrient deficiencies are frequenting the headlines which make it imperative to adopt a cultivation system which is based on natural resources and maintains harmony with the ecological principles.

In such a backdrop an important option left with us is the adoption of organic farming practices for sugarcane cultivation. This is not entirely a new phenomenon for India, which has been following the organic agriculture since the time immemorial till 50 years back. In 1949 the use of organic manures in India was 99.86 per cent of the total nutrient use which is feared to have decreased to the level of below 20% at present (Subba Rao & Srivastava, 1998). Sugarcane being a widely spaced, long duration, high input requiring crop fits well in the organic farming system. As a common understanding organic farming is a production system which avoids or largely excludes the use of chemical fertilizers, pesticides and growth regulators. To the maximum extent feasible organic farming system relies upon crop rotations with leguminous crops, addition of crop residues, animal manures, green manuring, bio-fertilizers and bio-pesticides. Organic farming both in philosophy and practice is based on internalizing the externalities considering the farm as a living organism that needs to be maintained in a healthy state to ensure the long term sustainability of food production, environment and economic profitability. Several experts and followers of organic farming have defined the term organic farming in their own ways, however the convergent view is that organic farming is not merely based on the use of a particular type of inputs but it is a system that stresses upon the maintenance of soil health and ecological balance on one hand and sustainable farm production on the other. The International Federation of Organic Agricultural Movements (IFOAM, 1998) has narrated the following definitions/ principles of organic farming:

1. To produce food of high quality in sufficient quantity.
2. To interact in a constructive and life enhancing way with natural systems and cycles.
3. To consider the wider social and ecological impact of the organic production and processing system.
4. To encourage and enhance biological cycles within the farming system, involving micro-organisms, soil flora and fauna, plants and animals.
5. To maintain and increase the long -term fertility of the soils.
6. To maintain the genetic diversity of the production system and its surroundings including the protection of wildlife habitats.
7. To promote the healthy use and proper care of water, water resources and all life therein.
8. To use, as far as possible, renewable resources in locally organized production systems.

9. To create harmonious balance between crop production and animal husbandry.
10. To progress towards an entire production, processing and distribution chain which is both socially just and ecologically responsible.

Stockdale et al. (2001) has opined that “the term organic is not directly related to the type of input used, but refers to the concept of the farm as an organism, in which all the component parts-the soil minerals , organic matter, micro-organisms, insects, plants, animals and humans interact to create a coherent whole”.

It is noteworthy to mention here that except a few farmers in tropical India specially in Maharashtra and Karnataka, who cultivate sugarcane following only organic practices, a research based complete package of organic sugarcane cultivation is yet to be developed. Research work done on the organic cultivation of sugarcane in India is presented below under various heads.

1. Integrated Nutrient Management (INM):

INM in sugarcane has been found to play a major role in improving the productivity of soil and quality of produce. A sugarcane crop to yield 100 t/ha removes 208, 53, 280, 3.4, 1.2, 0.6 and 0.2 kg/ha of N, P, K, Fe, Mn, Zn and Cu, respectively from soil (Yadav & Dey, 1998). To replenish the soil with these nutrients it has been found that various components of INM viz., inorganic fertilizers, legume intercropping, organic manures, residue incorporation, use of sugar factory by- products/effluents and bio fertilizers not only reduce the cost but also maintain the soil health. In two field experiments conducted at IISR, Lucknow on five successive sugarcane crops including four ratoons, the decline in yield over the period was associated with the drop in organic carbon content of the soil. However, the combined application of FYM and urea increased the organic carbon content of the soil by 0.023% and minimized the reduction in cane yield. Incorporation of farm waste materials such as cane trash, rice straw and legume husk also brought about significant increase in organic carbon content of the soil (Yadav and Prasad, 1992).

Superiority of organic manures viz., FYM and ground-nut cake over the chemical fertilizer (ammonium sulphate) gets established by a critical assessment of the seven long term experiments on manures and fertilizers in sugarcane conducted during 1935 to 1984 at Anakapalle (AP), Padegaon (Maharashtra), Mandya (Karnataka), Pusa (Bihar) and Muzaffarnagar and Shahjahanpur (UP). Results revealed that relative efficiency of FYM & groundnut cake was higher to that of ammonium sulphate under the conditions where either soil texture or imbalanced nutrient availability was a limiting factor (Singh and Yadav, 1994). Continuous use of FYM as basal application resulted in buildup of organic carbon in Anakapalle soil (from 0.39% initial to 0.69%). It was also noticed that organic carbon decreased markedly when sugarcane in different cropping system was not manured. However, a balanced application of NPK alone or with FYM, and FYM addition either maintained or improved the organic carbon content in soils.

Sugarcane occupies 2.8 per cent of the net cultivated area of the country and consumes approximately 2.1 per cent of the total fertilizers used in India annually. Obviously the scenario is not that balanced when we consider the fertilizer consumption by the crop in major sugarcane growing states. Being a high input-requiring crop it takes lion’s share of fertilizer consumption leaving other crops on inadequate nutrient supply. Hence, substitution of chemical fertilizers with organic inputs in sugarcane not only helps in maintaining the sugarcane ecosystem but also ensures better nutrient supply to other crops of the system followed in a particular region. As observed by Swamy et al (1999) available N and P improved due to integrated use of fertilizers and manures at 100 and 50% N status respectively but depleted in the absence of such schedules. Green manures have been used from time immemorial by Indian farmers as a source of supplementing manures. The principal leguminous crops used for green manuring included san hemp, dhaincha, guar etc. The green manuring of legume crops may give a benefit of 27 to 43 per cent increase in the yield of spring sugarcane over monsoon fallow (Mishra, 1971). On equal N basis, green manuring was found as effective as fertilizers and more than twice as effective as FYM in increasing the cane yield. The practice of preceding green manuring in sugarcane based cropping system is now out of vogue due to loss of one cropping season. This led to growing of green manure crop in the inter-row spaces of sugarcane as intercrops. Singh et al (1993) observed 13% increase in the cane yield of first ratoon due to the residual effects of intercropped green manure without adversely affecting the plant cane. The practice of green leaf manuring is more common in tropical region. Addition of green manure from out side has the similar effect as in situ green manuring. Glyricidia, leucaena, etc. are commonly used for green leaf manuring. Growing of dual purpose legumes as intercrop between sugarcane rows resulted in the addition of N to the extent of 51.8 kg/ha with green gram, 71.6 kg/ha with cowpea and 72.7 kg/ha with dhaincha taken as intercrop. Additional yield of cowpea and green gram significantly enhanced the net return over that of sole sugarcane.

Compilation and analysis of data from several experiments carried for evaluation of INM in sugarcane clearly reveal that neither the organics nor in- organics when used alone could perform at par with the INM system, however, total substitution of inorganic fertilizers with organic sources of nutrients could sustain the soil fertility and crop productivity equally well.

2. Residue recycling:

Experimental evidences have amply revealed that recycling of crop debris in the soils is an important renewable source of plant nutrients which can supplement to the crop need besides maintaining the soil fertility. The incorporation of cane trash, stubble, root; legume residues; cereal straw/husk and utilizable foliage of other crops in sugarcane based cropping systems increases cane yield, improves juice quality and enhances sugar productivity. Sugarcane trash has been reported to contribute to the available N pool of the soil (Yadav and Prasad 1986) apart from controlling weeds and conserving soil moisture. Thus a saving of 50 kg N/ha may be effected in sugarcane by trash mulching. Continuous trash mulching for three years improved the soil organic carbon by 0.13%, available N by 37 kg/ha and available P by 10 kg/ha, thereby increasing the yield of third ratoon over the first one (Yadav et al., 1994). It is estimated that in rice-wheat-sugarcane- ratoon system about 146.4 mt of crop residues are produced with total NPK potential of 2.20 mt.

The straw and husk of the cereals/legumes are very good source of renewable input to augment the nutrient demand and improve the soil health. Wheat/paddy straw and paddy/legume husk could be used in sugarcane based cropping system. At IISR, Lucknow increase in organic carbon content and NPK status was observed by incubation of soil with paddy straw and legume husk. Paddy husk was found effective in increasing the yield of sugarcane under tropical conditions also. An improvement in the yield and quality of ratoon cane by the application of paddy straw in non-saline sodic soils has been observed. Potato foliage that contains nearly 2.60% N contributes 31 kg N/ha when used as a green manure.

3. Sugar factory by- products:

A number of by products containing plant nutrients are produced in the process of sugar manufacturing. Prominent among them are sulphitation press mud cake (SPMC) and spent wash. India produces more than 3.0 mt of presmud annually which is normally used as source of organic matter and soil ameliorating agent. Press mud is a rich source of organic phosphorus and contains most of the essential plant nutrients especially S. Sapkal (1974) reported an improvement in hydraulic conductivity, maximum water holding capacity, bulk density, porosity and status of organic carbon due to incorporation of press mud cake. Integrated use of press mud with fertilizer N increases its recovery. The N recovery from 30 t/ha sulphitation press mud was almost equal to that of 100 kg N/ha applied to sugarcane. On an average, each tonne of SPM contains 17 kg N, 36 kg P, 64 kg K and 23 kg S. Press mud cake gave 96% as much cane yield as that obtained with ammonium sulphate. SPM when applied on the basis of its S content produced 19.9 tonnes more cane/ha than control plot and proved better than other S sources.

Distillery effluent, spent wash, is another important organic waste which contains appreciable amount of plant nutrients. In view of its awful smell, disposal and pollution problems, attempts have been made to apply it to the soil after lagooning treatment. Spent wash is a rich source of K and application of vinnase @ 100 m3/ha had no adverse effect on sprouting of sugarcane.

4. Biofertilizers:

Cultivation of legumes with non-legumes in the cropping system is an age old agronomic practice. Recently it has been established that there is role of N fixing bacteria in supplementing the N needs of sugarcane. Azotobacter chrococum, A. vinelandii, Clostridium, Azospirillum, Acetobacter and Bacillus have been isolated from sugarcane rhizosphere at Lucknow, Pusa and Shahjahanpur. Experiments have shown that use of biofertilizer either by screening of setts or root dipping or by root band method have a promise for N economy in sugarcane culture. Trials in Tamilnadu indicated 25% saving of N due to biofertilizers, Azotobacter or Azospirillum. Phosphates solubilizing bacteria also offer promise for their greater exploitation as experiences in Karnataka with Bacillus polymixa indicated saving of NPK to the extent of 25 per cent.

5. Integrated pest and disease management:

Sugarcane crop gets afflicted with several diseases and insect-pests owing to its year round presence in the field and its lush green canopy. Damages caused by insects-pests and diseases put together reach to the level of 20% of the crop yield. As for as control measures are concerned, the dense growth of sugarcane crop and presence of hard rind in the stalk prove to be great impediment in the way of the use of chemicals. Hence, the crop becomes a natural choice for adoption of integrated pest management or bio-intensive pest management practices.

Use of natural enemies of sugarcane insect-pests for their control started with the large scale breeding and release of an indigenous egg parasite Trichogramma evanescens minutum Riley (Trichogramma chilonis) against the shoot borer, Chilo infuscatellus in 1935 at Mandya (Karnataka). Because of the ease with which the parasitoid, Trichogramma sp. can be mass multiplied, the major thrust of last four decades happened to be the use of this egg parasite against the tissue borers in different sugarcane growing tracts of India. Innovative release of T. chilonis attempted in Tamilnadu since August 1982, had covered 5000 ha area till 1987, involved release of 12 million of parasitoid adults per acre in 6 split doses. This effectively checked the internode borer infestation. In sub-tropical India also releases of T. chilonis @ 50,000 adults/ha at 10 days internal from July to October reduced Tarai borer infestation in Punjab, Bihar, Gurdaspur borer in Punjab, root borer in Haryana and internode borer in Uttar Pradesh.

Larval parasitoid Sturmiopsis inferense has been successfully distributed and established in several factory areas in Tamilnadu. Parasitisation of shoot borer by S. inferens was only 25% in Coimbatore. However, release of this parasitoid in coastal region has been found very effective. Several other parasitoids against borers of sugarcane have been identified, however their rearing and multiplication techniques are underway.

Pyrilla, a major sucking insect-pest of sugarcane crop can effectively be controlled by the field release of Epiricania melanoleuca @ 4000-5000 cocoons and 4-5 lakh eggs/ha without any chemical use. Fungi, Beauveria bassiana, sprayed @ 107 spores/ml and release of Cavalerius sweetie @ 5000 adults/ha seeded with fungus induced sizeable mortality in black bug, a major insect- pests of sugarcane ratoon.

As far as disease management in sugarcane through natural means is concerned, it has been noticed that bioagents viz., Trichoderma harzianum and Chaetomium globosum when inoculated 24 hours prior to red rot pathogen C. falcatum effectively checked the infection by changing the reactions of the cultivars towards resistance.

Conclusion:

It is, therefore evident that organic cultivation of sugarcane is possible as information on natural ways of managing nutrient supply, cropping systems, crop rotations, insect-pest & disease management etc. are available in plenty with a good record of field level success. Presently efforts are required to be made towards standardization of these techniques and their compilation into a package for successful cultivation of organic sugarcane.

References:

Mishra, G.N. (1971). Response of sugarcane to green manuring under north Indian Conditions. Indian Sugar 20 (11):789-793.

Sapkal, S.V. (1974). M.Sc.(Agric.) Thesis, MPKV, Rahuri.

Singh, G.B. And Yadav, D.V. (1994). Creitical analysis of the long term manurial experiments on sugarcane in India. Fertilizer News. 39(10): 25-34.

Singh, G.B. Yadav, D.V. and Yaduvanshi, N.P.S. (1993). Indian J. Sugarcane Technology. 8(1): 5-19.

Subba Rao, A. and Sanjay Srivastava (1998). Role of plant nutrients in increasing crop productivity. Fertilizer News 43 (4): 65-75.

Swamy, Ramalinga K., D.V.N. Raju, T.K.V.V. Mallikarjuna Rao and Padma Raju (1999). Effect of integrated use of fertilizers and organic manures on soil and crop productivity under sugarcane (S. officinarum) based cropping system. Indian J. Agric. Sciences. 69 (8): 547-550.

Yadav, D.V. and Dey. P. (1998). Integrated nutrient management based on systems approach. Sugar Crops Newsletter. 8 (1): 2-3.

Yadav, R.L. and Prasad, S.R. (1986). Indian Journal of Sugarcane Technology. 3: 24-28.

Yadav, R.L. and Prasad, S.R. (1992) Conserving the organic matter content of the soil to sustain sugarcane yield. Experimental Agriculture. 28: 57-62.

Yadav, R.L., Prasad, S.R., Singh Ramphal and Srivastava, V.K. (1994). Bio resources Technology. 49: 231-235.

Chapter No. 34: Carbon sequestration in sugarcane based system for sustaining soil health and crop productivity

Sudhir Kr. Shukla
Principal Scientist
ICAR-Indian Institute of Sugarcane Research, P.O. Dilkusha, Lucknow

The rice-wheat rotation is the principal cropping system in south Asian countries and occupies about 13.5 million hectares area in the Indo-Gangetic Plains (IGP), of which 10.5 million hectares is in India (Gangwar, 2010), 2.2 million ha in Pakistan, 0.8 m ha in Bangladesh and 0.5 m ha in Nepal. This system covers about 33% of the total rice area and 42% of the total wheat acreage in four countries as stated above. Sugarcane is an important commercial crop of India and occupies around 4.95 millionha of land with an annual cane production of around 352.16 million tonnes (GOI, 2016).

Residue recycling provides ample scope to sustain soil fertility and improve crop productivity in irrigated agro ecosystem.Since, simple incorporation of rice residue causes nutrient immobilization and yield reduction in wheat. Residue/stubble decomposition can be enhanced by inoculation of some cellulolytic fungi such as *Trichoderma (*Yadav*et al.,* 2009).Residue mulching has been reported to promote the storage of soil carbon. *Trichoderma* sp. increased the nutrients uptake and concentration of a variety of nutrients (copper, phosphorus, iron, manganese and sodium) in roots in hydroponic culture and even under anoxic conditions (Yedidia*et al.,* 2001). *Trichoderma* has shown to have significant decomposing activity of combined harvested paddy straw when incorporated with silica solubilizing bacteria and *Pleurotus* at 14 days after transplantation (DAT) and showed higher yield in succeeding rice (Hemlatha*et al.,* 2007).

Rhizosphere is the region of soil where roots influenced the microbial activity. The physico-chemical properties of the region create different growing conditions for microorganisms in comparison to root free soil. Land used activities particularly related to residue management practices can have considerable impact on the size and activity of soil microbial community and biological health of soil. A 10-26% increase in microbial biomass under soil organic management has been reported (Fraser *etal.,* 1994). Some researchers have shown that incorporation of organic amendments increased soil microbial activity and densities of bacteria (VanBruggen and Semenov, 2000). The majority of research has shown increased microbial diversity in soils from organic farming systems compared to conventional farming systems (Shannon*et al.,*2002). Organic matter decomposition serves two functions providing energy for growth and supplying carbon for the formation of new cells.

Soil respiration is a measure of carbon dioxide (CO_2) released from the soil from decomposition of soil organic matter (SOM) by soil microbes and respiration from plant roots and soil fauna. The amount of soil respiration is an indicator of nutrients contained in organic matter being converted in available forms to crops (e.g., phosphate as PO_4, nitrate-nitrogen as NO_3, and sulfate as SO_4). Inherent soil respiration rates depend on amount and quality of SOM, temperature, moisture, salinity, pH, and aeration. Soil health and long term soil respiration improved with increased SOM. Leaving crop residues on the soil surface, notillage, cover crops or other practices that add organic matter in the soil increases soil respiration. High residue producing crops coupled with added N (from any source) increase decomposition and accrual of SOM. *Trichoderma* inoculation increased soil basal respiration and presence of higher amount of available nutrients in the soil during initial phase of crop growth (Yadav *et al.,* 2009).

In order to elucidate the intricate interrelationships and controlling mechanisms of the input/output fluxes of nutrients and energy in the soil ecosystem, a reliable quantification of the microbial biomass is required. The global storage of soil microbial biomass C estimated to be 16.7 Pg C in the 0-30 cm soil profiles and 23.2 Pg C in the 0- 100 cm soil profiles (Xu*et al.,* 2013). About half the microbial biomass carbon is available in the surface 10 cm of a soil profile and most of the nutrients are releasedin this horizon. The microbial biomass carbon accounts for only 1-3% of soil organic C but it is the eye of the needle through which all material that enters the soil must pass (Jenkinson, 1977), where microorganisms convert the materials to produce energy and also produces new cellular metabolites to support their maintenance and growth. In the C-limited soil system, available C in organic materials entering the soil is the driving force behind these processes but other essential nutrient elements (particularly N, P and K) are also involved. The extent of this turnover is controlled by the size and activity of the microbial biomass under suitable environmental conditions.

Soil enzymes are a group of enzymes whose usual inhabitants are the soil and are continuously playing an important role in maintaining soil ecology, physical and chemical properties, fertility, and soil health. These enzymes may include amylase, arylsulphatases, b-glucosidase, cellulose, chitinase, dehydrogenase, phosphatase, protease, and urease released from plants (Miwa*et al.,*1937), animals (Kanfer*et al.*1974), organic compounds, and microorganisms (James*et al.,*1991) and soils (Ganeshamurthy*et al.* 1995). They are important to maintain soil health and sustainability of production. Soil enzyme activities have potential to provide a unique integrative biological assessment of soils because of their relationship to soil biology, easy of measurement, and rapid response to changes in soil management.

Various Researchers shown that soil microbial biomass and activity responds to crop and soil management practices such as organic manure and inorganic fertilizers application (Livia*et al.,* 2005), crop rotation (Yusuf*et al.,* 2009), tillage and fallow (Wang*et al.,* 2008) and land-use change (Wang*et al.*2009). Soil enzymes are essential components involved in the dynamics of soil nutrient transformations (Masto*et al.,* 2006). Enzyme activity in the soil environment is considered to be the major contributor of overall soil microbial activity (Frankenberger and Dick, 1983) and soil quality. In sugarcane crop, root volume and density was greater than the rice or wheat crop and rooting depth was higher than the rice or wheat crop. In the rhizospheric condition, the microbial population was higher in sugarcane crop but in case of rice crop, top 0-7 cm was an anaerobic condition due to submergence that's why microbial population was lower than sugarcane crop root vicinity. Under different residue management practices, application of*Trichoderma viride*recorded the highest SMBC, SMBN and soil respiration. On an average, at all the stages of crop growth, *Trichoderma* inoculation increases soil basal respiration. Presence of higher level of available nutrients in the soil during the initial phase of crop growth influenced higher soil respiration rate (Yadav*et al.,* 2009).

Liu*et al.,* (2010) studied long term effects of chemical fertilizers, straw and manure on soil chemical and biological properties and reported that the soil microbial biomass carbon (SMBC) and soil microbial biomass nitrogen (SMBN) contents increased with the application of nitrogen and phosphorus inorganic fertilizers. However, there was greater increase of these parameters when organic manure was applied along with inorganic fertilizers. Organic manure application also increased soil dehydrogenase, alkaline phosphatases, β-glucosidase and urease activity significantly. Their results indicated that long-term additions of organic manure had the most beneficial effects on grain yield and soil quality among the investigated types of fertilization. Tirol Padre*et al.,*2007 studied the impacts of continuous applications of an organic manure (farmyard manure [FYM], green manure [GM], and wheat straw [WS]) combined with inorganic fertilizers (N, P, and K) on soil parameters and productivity of rice (*Oryza sativa* L.)–wheat (*Triticum aestivum*L.) system and they investigated two long-term experiments under conventional tillage in Ludhiana, India, and Bhairahawa, Nepal. They concluded that the current practice of inorganic fertilization alone cannot maintain the soil quality needed to sustain crop productivity and organic amendment restored the soil quality parameters like SOC, SMBN, SMBC and enhanced soil enzyme activity like urease activity in soils of Ludhiana in the long term study for a period of 20 years.

Trichoderma application with residue incorporation recorded the maximum enzymatic activity (Frankenberger and Dick, 1983; Tirole Padre*et al.,* 2007).Boopathy*et al.,* 2001 have demonstrated the decomposition of sugarcane residues in the field with increase in soil microbial population and cellulase activity and decrease in total cellulose content of the residue.The enzymes viz., invertase, urease and alkaline phosphatase are related to soil C, N, and P transformations (Dick, 1994). Moreover, Acosta-Martinez and Harmel(2006) reported that the soil microbial biomass was positively correlated with soil enzymatic activities. These findings are in conformity with the results reported by Ge*et al.*(2010), indicating that these treatments can strengthen the soil nutrient (e.g., C, N, and P) cycling. Among biological indicators, enzyme activities are important dynamic indicators of soil quality because of their quick response to management practices (Ding *et al*., 2011). Enzyme activities originate from the cells of soil organisms and plant roots, which form the basis of soil metabolism (Kapralek, 1986). The dehydrogenase activity (DHA) is considered as an indicator of the oxidative metabolism in soils and thus of the microbiological activity (Quilchano and Maranon, 2002). Phosphatases catalyse the hydrolysis of both organic phosphate esters and anhydrides of phosphoric acid into inorganic P. Phosphates activity may originate from the plant roots (associated mycorrhiza and other fungi) or bacteria (Tarafdar and Marschner, 1994).

Sugarcane and cane equivalent yields

Crop yield is the combined effect of its genetic makeup and environment/management (Andrew *et al.,* 2010). Crop residue recycling alongwith *Trichoderma* improved soil quality parameters (Chaudhary, 2016). Thus nutrients availability to crop plants improved. Role of nitrogen in chlorophyll formation, tillering, protein formation and improving crop vigour is well known (Rajshekar*et al.,* 2017). Increased tillering during early phase improved the number of millable canes besides improving individual cane length, diameter and weight. Positive effect of application of crop residues was also observed on soil quality parameters and yield attributes of rice and wheat in rice-wheat cropping system. Crop residue management also improved soil moisture availability for longer period to crop which created congenial rhizosphere for soil microbial growth (Carter, 1995).*Trichoderma i*s cellulose decomposer and could improve residue decomposition process.Thus besides improving soil quality parameters, crop yields could also be improved by residue recycling along with *Trichoderma*. Higher yields of sugarcane (plant crop/ main crop) and ratoon increased cane equivalent yields as well.

Conclusions

Thushigher activities of soil respiration, microbial biomass carbon, microbial biomass nitrogen and enzymescould be obtained in sugarcane-ratoon-wheat system than the Rice-Wheat-Rice-Wheat cropping system. Residue application with *Trichoderma* recorded the highest soil respiration, microbial biomass carbon, nitrogen and soil enzymes.Residue incorporation either full with *Trichoderma* application also recorded higher soil enzymes activity.Thus residue management along with *Trichoderma*in both the cropping systems improved crop yields besides improving soil quality.

Further readings/References

1. Shukla, S.K.,SwahaShee, Maity, S K., Solomon, S., Awasthi, S.K. Asha Gaur, A. D. Pathak, V. P. Jaiswal. (2017). Soil carbon sequestration and crop yields in Rice–Wheat and Sugarcane Ratoon–Wheat cropping systems through crop residue management and inoculation of *Trichoderma viride* in subtropical India. Sugar Tech. 19(4): 347-358.
2. Shukla, S.K., Solomon, S., Sharma, L., Jaiswal, V P., Pathak, A D., Singh Priyanka. (2019). Green technologies for improving cane sugar productivity and sustaining soil fertility in sugarcane based cropping system. Sugar Tech. 21(2):186-196.
3. Shukla, S.K., Yadav, R L., Awasthi, SK and Asha Gaur. (2017). Soil microbial biomass nitrogen, *in situ* respiration and crop yield influenced by deep tillage, moisture regimes and N nutrition in sugarcane based system in subtropical India. Sugar Tech. 19(2):125-135.

Chapter No. 35: Weather parameters affecting sugarcane yield and sugar recovery and climate change mitigation strategies

Ram Ratan Verma
Sr. Scientist, Soil Science
Division of Crop Production
ICAR-Indian Institute of Sugarcane Research, Lucknow

Sugarcane is a long duration crop with the multiple ratooning capability passes through the different climatic season of the year. Hence, in the change of agro-meteorological weather parameters affects the sugarcane crop growth and sugar recovery as well. The climate change impacts on rainfall and temperature in sugarcane growing upper Gangetic plains of India has been studied (Verma et al., 2019) and weather variability trends and its influence on sugarcane cropping systems and adaptation strategies were suggested in sub tropical India(Srivastava et al. 2021). Sugarcane planted with it setts in soil which takes about a months to germinate. The soil and air temperature during this period play an important role. The crop faces the extreme weather conditions during its growing period. It faces the extreme cold during the winter and extreme hot during the summer season. In both side of extreme temperature, either hot or cold are not favourable for its proper germination. Hence, the sugarcane planting time is specific to weather condition of the location of the sugarcane growing area. Crop of the of the sugarcane passes through the different growth phases like germination phase, tillering phase, grand growth phase, maturity and ripening phase. The each growth of the sugarcane needs specific weather conditions for growth and sucrose accumulation (Shrivastava et al. 2015). The adverse weather condition at different sugarcane growth phases affects cane yield contributing parameters and result on cane yield and sugar recovery. The role of weather parameters has been discussed below in details with different sugarcane growth phases and various mitigation/ adaptation strategies have been also suggested.

Germination phase

Considering the weather condition in sub-tropical India, the planting of sugarcane has been recommended in October to November during the autumn season and February to March during the spring season. Early planting during the autumn season may be hampered by the sporadic late monsoon rainfall and delay planting germination may affect due to the low soil and air temperature. Similarly, early planting during the spring may delay the germination and lade planting of sugarcane may be affected by the high germination which may result to poor germination and low tillering and reduced plant population result to low cane yield. In sugarcane, germination is activation and subsequent sprouting of the bud which commences from 7 to 10 days and usually lasts for about 30-35 days. Optimum temperature for sugarcane germination is 32 to 38 °C. We observe slow or even no germination when temperatures fall below 21 °C. The germination of bud is influenced by the external (soil moisture, soil temperature and aeration) as well as internal factors (bud health, sett moisture, reducing sugar and nutrient status). A warm and moist soil ensures rapid germination. High temperatures negatively affect sprouting of buds as well as and emergence of shoot. Poor emergence of shoots results in low plant population. Higher temperatures of above 32 °C leads to higher number of shorter internodes, high fibre and lower sucrose contents. With an increase in afternoon humidity, cane yields increased. In north-east Andhra, it was observed that temperatures (maximum and minimum both) and relative humidity during the first three months at the formative phase profoundly influenced cane yield.

Tillering phase

Tillering is a process of underground branching from very short joints on the stem by which number of shoots are produced in family Poaceae ultimately contribute for the number of millable canes in sugarcane. It starts from around 45 days after planting and lasts up to 120 days. It is influenced by variety, fertilizer application, irrigation (to alter soil moisture), light intensity and ambient temperatures. For tillering, adequate light must reach the base of the sugarcane plant. A temperature around 30 ^{o}C is optimum for tillering but below 20 ^{o}C retards it. The base temperature for shoot emergence to be 12 ^{o}C, however, had reported a higher value of 16 ^{o}C as based temperature for shoot emergence. Early formed tillers form relatively thicker and heavier millable canes but the late formed ones are either destined to die or remain short or immature and do not contribute to the millable harvest. Tillering and grand growth phases, where most of the biomass is produced, are critical for water deficit. Distribution of rainfall is important but its excess hampers the rate of sugarcane growth and more so, when drainage is impeded. The exposure of the sugarcane plants to wind at this stage increases root development as compared to plants kept under a shelter.

Grand growth phase

Sugarcane crop grand growth phase is characterized by increase in stem size, weight and high leaf production. It starts typically 4 months after planting and lasts until the 7th month, a total period of about 120 days. During the early part of this phase, tiller mortality occurs. Only 35-50% of the total tillers produced survive to make millable canes. Under favourable conditions, only 4-5 internodes are produced per month. Mean evaporation at this stage shows a significantly positive correlation with final sugarcane yield. At grand growth phase, rate of evapo-transpiration is very high which indicates that some of assimilates produced are used in growth processes for building up of new tissues. Moisture stress reduces inter-nodal length. Temperatures around 30 ^{o}C, and relative humidity of around 80 % is conducive to growth. During the grand growth phase, rainfall is conducive to rapid cane growth, its elongation as well as internodes formation. Leaf area index increases rapidly during 3 to 5 months with peak values attained during early grand growth phase in tropical India and somewhat before the end of grand growth phase in subtropical India. Some of the physiological processes like photosynthesis, partitioning of assimilates, stomatal conductance and respiration decrease with decrease in water availability. Temperatures below 25 ^{o}C or above 35 ^{o}C retard sugarcane growth but the growth may cease below 10 ^{o}C or above 38 ^{o}C. During sprouting and growth period, the plant needs to absorb high amounts of water, consuming from 69 to 168 liters to yield 1 kilogram of sugarcane. For ripening, a temperature below 20 °C slows down growth rates but promotes sucrose accumulation in millable canes. Air temperature increase during this phase may adversely affect the sucrose accumulation process.

Maturity Phase

Maturity phase is also called sucrose build-up stage. The subtropical climate of Northern India, the crop undergoes forced maturity at the onset of winter. In a twelve-months crop, it lasts for about three months starting from 270 and lasting up to 360 days (or more). This phase is characterised by a reduced vegetative growth, rapid sugar synthesis and its accumulation. In the maturation stage, the plant needs a dry and cold climate to accumulate the sugar/sucrose in the stalks. Ample sunshine, clear skies, cool nights and more diurnal variation in temperature (warm days) and dry weather are highly conducive for ripening. Most of the climatic variables correlate positively with growth and yield, but the correlation coefficients were non-significant. In an irrigated crop of sugarcane, advent of low temperatures, promote natural ripening. An inverse relationship was noted between air temperatures (average of 120-150 days before harvest) and maturity.

Ripening Phase

Meteorological variables influence the productivity and quality of sugarcane. Lower temperatures associated with moderate water deficits and nitrogen deficiency is conducive to ripening. During ripening, sucrose levels in stalks gradually increase but the percentage of glucose and fructose decrease. In most of the humid tropical and subtropical regions, with approach of harvest, the dry season as well as low temperatures slow down the sugarcane growth and convert reducing sugars into sucrose. Poor natural ripening conditions like low as well as high temperatures and excess rainfall/soil moisture exist in most of the sugarcane growing areas of the world, and about 85-90 of the world's sugarcane is harvested under these conditions. Under such conditions, agronomic and genetic means of improving sugarcane quality continue to be limiting. Management techniques like withholding irrigation, application of certain growth regulating compounds (ripeners) and inter-generic hybridization have been utilized to ameliorate ripening behaviour and to improve cane quality.

Mitigation and adaptation strategies of sugarcane to climate change

The mitigation of climate change impacts on sugarcane are the interventions to reduce the pace of climate change as well as to overcome its detrimental effects, either by developing climate resilient sugarcane varieties or certain technological interventions for drought and flood, high CO_2 concentration responsive, high water and nutrient use efficient, aiding carbon sequestration through high biomass, rhizo-deposition, resistance to pests and diseases, *etc*. Success in this direction may also be achieved through use of biotechnology. Avoiding pre-harvest burning and using trash as a mulch will overcome gaseous pollution, conserves water by using mobile app for irrigation scheduling (Srivastava et al. 2022), organic matter, nutrients and to some extent checks soil erosion. GHGs emissions could be achieved by residue recycling, green cane harvesting, mulching, soil and water conservation, improving the fertilizer use efficiency, *etc*. Among these, organic manuring, application of bio-agents, and crop residue incorporation are time-tested ones. A shift from pre-harvest burning to green harvest may increase sugarcane residues and improve soil health and sustain its fertility. Minimizing soil tillage may help to reduce mineralization of soil organic matter and aids soil carbon sequestration. As the land preparation operation in sugarcane use large quantity of fossil fuel, adopting minimum tillage operation may mitigate climate change to some extent. The agronomic management of sugarcane under changing climate holds the key to stave off negative influences and harness the positive effects (Srivastava and Verma 2017). Sugarcane-based co-generation and second generation alcohol production may mitigate climate change to some extent by partially fulfilling the fuel demands. The climate change impacts mitigation is possible by adoption climate smart sugarcane varieties and with adoption of technologies for healthy soil and environment for sustainable sugarcane yield and recovery.

References :

1. Verma RR, Srivastava TK, and Singh P. 2019. Climate change impacts on rainfall and temperature in sugarcane growing upper Gangetic plains of India. *Theoretical and Applied Climatology* 135(1-2): 279-292. DOI: 10.1007/s00704-018-2378-8
2. Srivastava TK, Singh P and Verma RR. 2022. Weather variability trends in Gangetic plains of Uttar Pradesh, India: influence on cropping systems and adaptation strategies. *Environment, Development and Sustainability*, 24(3):3588-3618. https://doi.org/10.1007/s10668-021-01578-8
3. Shrivastava AK, Singh VK, Srivastava TK, Kumar V and Mishra V. 2015. Impact of Climate Change on Sugarcane and its Mitigation. *Agricultural Engineering Today* 39 (4): 31-40.
4. Srivastava TK, Hasan SS and Verma RR**.** 2022. Mobile 'app' for precise irrigation scheduling in sugarcane cultivation under Indian subtropics. *Sugar Tech,* 24: 822–831. https://doi.org/10.1007/s12355-021-01100-4
5. Srivastava, TK and Verma RR. 2017. Climate change and sugarcane. *Agriculture World* 3(10): 22-29.

Chapter No. 36: Sugarcane intercropping systems as a potential tool for effective utilization of land and improving farmers' income

S. N. Singh, C. Gupta, V. K. Singh, M. K. Tripathi and A. P. Dwivedi
Principal Sceintist, Division of Crop Production
ICAR-Indian Institute of Sugarcane Research, Lucknow

Scientific and economic importance

Intercropping refers to growing two or more crops simultaneously on the same piece of land with definite row-planting patterns to obtain higher productivity per unit area and time. Rapidly increasing population, increased demand for food, limited scope for extension of cultivation to new areas, diversified needs of small farmers for food and cash, *etc.* have necessitated the adoption of intercropping systems. In the case of sugarcane, much of the space between two rows of sugarcane remains un-utilized for an initial period, due to slow crop growth. Intercropping offers an opportunity for profitable utilization of available space. Sugarcane growers take advantage of this and grow various short duration crops like cereals, pulses, oilseeds, vegetables, spices, flowers, and medicinal plants etc. as intercrops to obtain interim return. Small sugarcane growers need not to wait until the harvest of the sole crop to obtain financial returns. Intercropping of economically important short duration crops with sugarcane through utilization of the present limited land resources would help to sustain sugarcane cultivation and provide interim return to marginal and small farmers, besides meeting the ever-increasing demand for vegetables and pulses.

Scope for intercropping in sugarcane

In long duration crops like sugarcane, intercropping holds much promise as a great potential for enhancing productivity and profitability as well. Due to slow establishment of sugarcane from germination to the start of tillering phase, the greatest scope for complementary effect lies in the addition of annual intercrops to the temporal system to improve resource use efficiency in the early crop growth period. Legume intercrops in cropping systems enhance soil fertility through the excretion of amino acids into the rhizosphere. The nitrogen fixed by the legume intercrops may be available to the associated sugarcane in the current season itself, as sugarcane remains in the field for over nine months after the harvest of the legumes. A further possibility of soil fertility improvement is through addition of crop residues, which on decomposition adds to the fertility of the soil. Since considerable addition of nutrient occurs through intercrop, there is a possibility of reducing N application through chemical fertilizer.

In general, the optimum row spacing recommended for sugarcane is 90 cm which is widely followed in sub-tropical India. With the introduction of very high tillering and high yielding varieties of sugarcane, there is a possibility to adopt wider row spacing which undoubtedly paves the way for higher cane productivity besides introducing mechanization in sugarcane agriculture. Such wide row spacing permits intercropping without adversely affecting the cane yield and thus increases the overall productivity and profitability of the system. The present problem of man-power shortage may create a great problem to cane growers and sugar industry as well. Wide row spacing becomes an important agronomic consideration for mechanization point of view in future in developing countries. For example, 120-150 cm row spacing was successfully attempted in some sugarcane growing areas in India, which recorded higher yield than 90 cm row spacing. High tillering and low tiller mortality in wide row spacing helped achieve such high yields in spite of the lower seed cane used with reduced cost of cultivation.

Intercropping in subtropical region

In the subtropical region, sugarcane is normally planted in autumn (September- October), *i.e.* before the onset of winter or during the spring season (February-March), *i.e.* after the cessation of winter. The cane planted in the autumn season germinates before the onset of winter and remains in the field without much growth until the spring sets in. During this period, the cane does not make much demand for the growth resources. This facilitates raising of location specific *rabi* crop as an intercrop with autumn planted sugarcane. Several studies demonstrated that the total productivity of crops in sugarcane + *rabi* crop intercropping system is substantially higher than the total productivity of sole *rabi* crop in winter followed by sole sugarcane planted in spring season. Similarly, sugarcane planted in spring season completes its germination in about five weeks from planting and attains the stage of canopy closure by about 15 weeks after planting. Dwarf type crops with compact canopy including legumes, oilseeds and vegetables are suitable as intercrops in spring planted sugarcane too. Several short duration crops have been attempted as intercrops in the subtropical region. Maize and wheat, especially with autumn planted sugarcane, have been extensively tested as an intercrop in autumn planted sugarcane and reported to be overall advantageous compared to sole cropping of cane, though cane yield reductions were recorded as compared to sole crop of cane.

Several studies have been conducted to evaluate the performance of mustard as an intercrop in autumn planted sugarcane in subtropical India. Though there was reduction in cane yield on account of intercropping due to smothering effect of mustard to cane plants, but the overall system's yield was found to be more remunerative as compared to sequential cropping of mustard spring cane. It has been reported about the beneficial results of intercropping Japanese mint with spring planted cane near Pantnagar in Uttar Pradesh. Cowpea was reported to be suitable as an intercrop in spring planted sugarcane in western part of Uttar Pradesh. Potato has been reported to be a promising intercrop in autumn planted sugarcane in subtropical India. The results of the experiments carried out on the effect of intercropping of potato in sugarcane were reviewed by various workers. There have been several studies on intercropping of potato in sugarcane in Uttar Pradesh and reported to be a successful intercrop in sugarcane. Onion as a spice and vegetable was evaluated as intercrop by some workers in Uttar Pradesh. The yield of onion could be increased under paired row system of cane plantation by accommodating higher intercrop population compared to conventional row system. The yield of onion under paired row systems was 4.4 t/ha while it was 2.25 t/ha under conventional row system. Intercropping onion with paired row cane showed the highest potential for increasing the net returns per unit area under intercropping systems. Compared to other crops, onion exerted least detrimental effect on the emergence, tillers, millable canes and yield of sugarcane. Higher yield of cane due to intercropping with onion was reported and found to be a remunerative intercrop in several studies. Therefore, cultivation of short duration spices and vegetables like onion, garlic and coriander as intercrops in sugarcane can be a successful package as it provides the needed income during the early stages and increases the total productivity without affecting the cane yield in the system.

Improved use of farm resources gives a significant yield advantage in most of the cases, increases the uptake of other nutrients such as P, K, and micronutrients, and provides better rooting ability and better ground cover as well as higher water use efficiency. Thus, selection of crops that differ in competitive ability in time or space is essential for an efficient intercropping system as well as decisions on when to plant, at what density, and in what arrangement. Although in this way, crop management decisions specify the design of intercropping systems and intercrop performance that governs largely by the availability of land and the competition for the environmental resources. Research has shown that intercrops are most productive when component crops differ greatly both in their growth habits and duration. It must be noted here that Land Equivalent Ratio shows the efficiency of intercropping for using the environmental resources compared with mono-cropping with the value of unit to be the critical one. When the Land Equivalent Ratio is greater than one (unit) the intercropping favours the growth and yield of the species, whereas the Land Equivalent Ratio is lower than one the intercropping negatively affects the growth and yield of the plants grown in mixtures. Higher yield advantage of the system can be realized in intercropping system when growth patterns in terms of time (growth rapidity and maturity period) and space (plant architecture) of component crops is optimum. Complementarities would occur when growth pattern of component crops in intercropping system differ in critical period of high demand for resources. Great potentials exist in India for increasing crop production and productivity through wider use of multiple cropping systems with sugarcane. It can be best achieved by growing a short duration crop in between the rows of sugarcane crop. Due to slow establishment of sugarcane from cane buds germination to the start of tillering phase, the greatest scope for complementary effect lies with temporal system in which annual crops are added between the cane rows to improve the resources use in the early part of the growing period, very effectively and efficiently. Intercropping has been shown to produce higher and more stable yields in a wide range of crop combinations, while the system is characterized by minimal use of inputs such as fertilizers and pesticides, emphasizing the production of healthy, safe, and high quality food in the context of environmentally sound production system.

Intercropping in autumn planted sugarcane

As already stated that in the sub-tropical region, sugarcane is normally planted in autumn (September- October), *i.e.* before the onset of winter. This planting of sugarcane invariably yields 15-20% higher sugarcane as also 0.5 percent units more sugar recovery than that of spring planted sugarcane. The cane planted in the autumn season germinates before the onset of winter and remains in the field without much growth until the spring sets in. During this period, the cane does not make much demand for the growth resources. This facilitates rising of some *rabi* crops as intercrops with autumn planted sugarcane. Several studies demonstrated that the total productivity of crops in sugarcane + *rabi* crops intercropping system is substantially higher than the total productivity of sole *rabi* crop in winter followed by sole sugarcane planted in spring season. Dwarf type crops with compact canopy including legumes, oilseeds, cereals, spices and vegetables are suitable as intercrops in autumn planted sugarcane. Potato has been reported to be a promising intercrop in autumn planted sugarcane in sub-tropical India. Therefore, cultivation of short duration spices and vegetables as intercrops in sugarcane can be a successful package as it provides the needed income during the early stages and increases the total productivity without affecting the cane yield in the system. There is a higher demand for vegetables in the market now-a-days since the consumption of vegetables is increasing at a faster rate in modern time as these are supplementary items in human diet.

It is well known that the government of India has stressed the need for enhancing farmers' income, and is taking various steps to achieve this objective accordingly. The Govt. has thus desired that the sugarcane farmers should be encouraged to adopt intercropping to boost their income. To boost income of cane farmers, the Govt. has called upon the farmers to go for intercropping and grow pulses, oilseeds or vegetables along with sugarcane. Moreover, progressive farmers in certain areas of Punjab have improved their earning three times what they did earlier after they started inter-cropping their cane with garlic, potato and turmeric. In inter-cropping, cane rows are sown three to four feet apart and this space is used for the other crops. Alongwith vegetables and spices , the under mentioned *rabi* crops can be grown successfully as intercrop with autumn planted sugarcane in Indian sub-tropics for enhanced yields and net returns (Table 1).

Table 1: Crops suited for intercropping with autumn planted sugarcane

Cereals	Wheat
Legumes	Pea, French Bean, Chickpea, Lentil
Oilseeds	Mustard, *Toria*, Linseed, Sunflower, Sesame
Flowers	Gladiolus, marigold
Medicinal and aromatics	Mentha, Ginger
Spices	Chillies, Onion, Garlic, Coriander, Fennel, Cumin, Fenugreek, Nigella, Turmeric
Vegetables	Potato, Tomato, Carrot, Turnip, Cauliflower, Cabbage, Knoll Kohl, Lettuce, Radish , Lady's Finger, Cucurbits

Package of practices for vegetables intercropping with autumn planted sugarcane

Vegetable crops *viz*., cauliflower, cabbage, knol-khol, turnip, carrot, radish and potato are suitable for intercropping with autumn planted sugarcane (Fig 1 to Fig 6). Agronomic practices adopted for raising different intercrops are given in Table 2. Sugarcane is planted in furrows 90 cm apart keeping one-three bud setts @ 30 cm row length in the first fortnight of October. Sugarcane is fertilized with 150 kg N/ha (1/3 at planting as basal dressing + 2/3 in two equal split doses as top dressing after harvesting of intercrops at proper moisture) while, intercrops are given half of the total N + full doses of P_2O_5 and K_2O at their respective sowing times and remaining half of N is top dressed after 30 days of sowing as per Table 2.

Table 2: Details of variety, row arrangement, date of sowing / harvesting, seed rate and fertilizer application for different intercrops

Intercropped vegetables	**Variety**	**No. of intercrop rows in between two cane rows**	**Date of sowing**	**Date of harvesting**	**Plant to plant distance (cm)**	**Seed rate (kg/ha)**	**Application of fertlizers (kg/ha)**		
							N	P	K
Cauliflower (*Brassica oleracea var.botrytis L.*)	PSB-16	Two	First Fortnight of November	First Fortnight of November	45	0.350 (for nursery)	80	40	40
Cabbage (*Brassica oleracea var.Capitata F.alba)*	Pride of India	Two	First Fortnight of November	First Fortnight of November	45	0.400 (for nursery)	80	40	40
Knol-khol (*Brassica oleracea var.Caulorapa O.C. Linn.)*	King of North	Three	First Fortnight of November	First Fortnight of November.	20	0.450 (for nursery)	60	30	30
Turnip (*Brassica rapa* L.)	PTWG	Three	First Fortnight of November	First Fortnight of November	20	0.800	40	20	20
Carrot (*Daucus Carota L.)*	Pusa Keshar	Three	First Fortnight of November	First Fortnight of November.	10	3.50	60	30	30
Radish (*Raphanus sativus L.*)	Jaunupuri	Three	First Fortnight of November	First Fortnight of November.	10	7.00	40	20	20
Potato (*Solanum tuberosum* L.)	C-3797	Two	First Fortnight of November	Second Fortnight of February	20	2200	160	80	80

Fig 1: Sugarcane + Potato

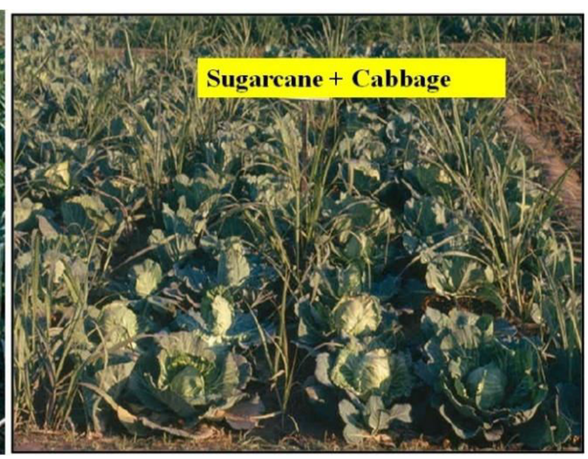


Fig 2: Sugarcane + Cabbage

Fig 3: Sugarcane + Knol khol

Fig 4: Sugarcane + Radish

Fig 5: Sugarcane + Cauliflower

Fig 6: Sugarcane + Turnip

Intercropping with spring planted sugarcane

Maximum acreage of sugarcane is taken for plating in spring season (February-March) in Uttar Pradesh. Growth of sugarcane in this planting is less in first two-three months. Resultantly, the space in between two sugarcane rows is left un-utilized. Many weeds start growing in these vacant spaces, which restricts the initial growth of sugarcane drastically. Farmers have to incur expenses on doing intercultural operations for the management of these weeds. Experimental results have clearly indicated that short duration legumes crops as per Fig 7 to Fig 9 (green gram, black gram, cowpea *etc.*) and vegetables (ladies finger, french bean *etc.*) can successfully be grown in between two rows of spring planted sugarcane. Although the sugarcane farmers are very much reluctant to grow these legumes and vegetables with spring planted sugarcane, but these intercropping systems not only provide additional income in mid season to the farmers, but also manage the incidence of weeds and enhancing the fertility of soil upon decomposition of left over residues after their harvesting. There is no adverse effect on the growth of sugarcane plants since these short duration intercrops attain their growth well before the growth of sugarcane. The package of practices of these intercrops is given in Table 3.

Table 3: Package of practices of growing some major intercrops with spring planted sugarcane

Sr. No.	Package of practices	Sugarcane	Green gram	Black gram	Cowpea	French bean	Ladies finger
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	Suitable varieties	As per recommendations for the region	Pant moong 2, Malviya Jagrati, Samrat, Malviya Jyoti	Pant Urd 19, 30, T-9, Azad, Urd 1, Shekhar-2	Pusa do phasli, Pusa komal, Pusa phalguni	Pant anupama, Pusa parvati	Pusa sawani, Parbhani kranti
2	Sowing/ planting time	February-March	After sugarcane planting (15 Feb-15March)	After sugarcane planting (March)	Immediately after sugarcane planting	After sugarcane planting (2nd fort night of Feb)	After sugarcane planting (2nd fort night of Feb)
3	Seed quantity (per ha)	60-70 quintals	15-20 kg	15-20 kg	15-20 kg	35-40 kg	8-10 kg
4	Row to row spacing	90 cm	Two rows at 30 cm apart in between two rows of sugarcane	Two rows at 30 cm apart in between two rows of sugarcane	Two rows at 30 cm apart in between two rows of sugarcane	Two rows at 30 cm apart in between two rows of sugarcane	Two rows at 30 cm apart in between two rows of sugarcane
5	Fertilizers (per ha)	150, 60, 60 kg : NPK	N: 8-10 kg P_2O_5: 20-25 kg	N: 8-10 kg P_2O_5: 20-25 kg	N: 8-10 kg P_2O_5: 20-25 kg	N: 30 kg	N: 40 kg
6	Irrigation	5-6	First : After 30-35 days	First : After 30-35 days	First irrigation after germination of sugarcane	First : After 30-35 days	First irrigation after germination of sugarcane
7	Weeds management	Atrazine 50% WP @ 2 kg *a.i.*/ ha after sugarcane planting	One intercultural operation after 20-25 days	One intercultural operation after 20-25 days	One intercultural operation after 20-25 days	One intercultural operation after 20-25 days	One intercultural operation after 20-25 days
8	Plant protection	As per necessicity	Spraying Dimethoate 30 % EC @ 1 lit + 600-800 lit of water/ha on the appearance of insects on plants	Spraying Dimethoate 30 % EC @ 1 lit + 600-800 lit of water/ha on the appearance of insects on plants	Spraying Dimethoate 30 % EC @ 1 lit + 600-800 lit of water/ha on the appearance of insects on plants	Spraying Dimethoate 30 % EC @ 1 lit + 600-800 lit of water/ha on the appearance of insects on plants	Spraying Dimethoate 30 % EC @ 1 lit + 600-800 lit of water/ha on the appearance of insects on plants
9	Harvesting	Feb-March	Left over crop residues after pods picking may be incorporated in between cane rows	Left over crop residues after pods picking may be incorporated in between cane rows	Left over crop residues after pods picking may be incorporated in between cane rows	Left over crop residues after pods picking may be incorporated in between cane rows	Left over crop residues after pods picking may be incorporated in between cane rows
10	Yield (per ha)	700-800 q	7-8 q	6-7 q	40-50 q (pods)	30-40 q (pods)	25-30 q

Fig 7: Sugarcane + Black gram **Fig 8:** Sugarcane + Urd bean

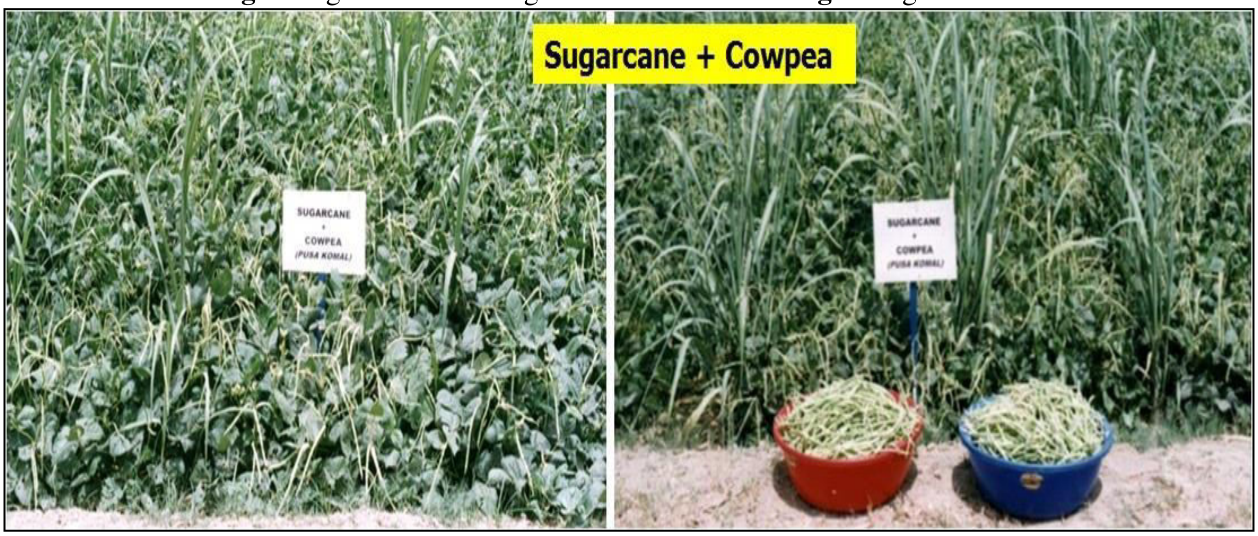


Fig 9: Sugarcane + Cowpea

Relay intercropping of autumn sugarcane with skipped row transplanted rice

In rice-sugarcane growing areas of eastern Uttar Pradesh, sugarcane planting in autumn season (October) is not practically feasible due to delayed harvesting of low land rice (specially scented varieties) and fields remaining wet. In such agro-ecosystems, autumn planting of sugarcane as a relay intercrop with rice in September-end can conveniently be adopted to improve the overall productivity and profitability of the cropping system. The system may be worth adopting by sugarcane farmers as it saves not only time and energy on pre-planting tillage operations but also ensures higher productivity and better economic returns.

Chapter No. 37: Strengthening of forage resources in sugarcane based system for enhancing productivity and farm income

Sunil Kumar Tiwari
Head, Crop Production Division
ICAR-Indian Grassland and Fodder Research Institute, Jhansi-284003
Email: sktiwari98@gmail.com

India sustains about 15 percent of the world's livestock population (536 m heads as per Census 2019) but their productivity is quite far from world average. Animal husbandry is still continuing as one of the major avocations in India contributing nearly 4.9% to the national GDP and 28.4% of the agricultural GDP (BAHS, 2019). The major constraint in the productivity of Indian livestock is non-availability of adequate quantity and quality of forage. With current change in dietary pattern and food habits and migration of people from one region to another region, demand for livestock products has increased. To keep pace with the demands, the livestock sector has to tune itself by increasing the productivity of livestock. In India out of 55 micro-regions as much as 43 micro- regions are deficient in fodder availability. There are regional and seasonal disparity in fodder production and availability. Due to lack of sufficient post harvest and storage facility, surplus fodder is not properly utilized. At present, the country faces a net deficit of 30.65% green fodder, 11.85% dry crop residues and 44% feeds. To meet the current level of livestock production and its annual growth in population, the deficit in all components of fodder, dry crop residues and feed has to be met from either increasing productivity, utilizing untapped feed resources, increasing land area (not possible due to human pressure for food crops) or through imports. This situation indicates that green forage supply has to grow at 3.2%, to meet the deficit. Due to more emphasis on food production at the national level, the actual potential of quality fodder for animal feed has not been fully utilized.

India has about 4.9% of the total cropped area under cultivated forages, which is almost static since last few decades. The inability of producers to feed animals adequately throughout the year remains the major technical constraint in meeting future demands for meat and milk. There is a need for exploring the option of integrating forage resources in the existing cropping systems in different regions of the country. One of the potential areas could be strengthening the fodder resources in sugarcane based system. This may be possible through diversification of forages in rotation, intercropping and having forage based system after 3-4 years of main crop & ratoon. Other alternative or non-conventional fodder resources may be like fodder sugarcane, moringa, azolla, sugar beet, cactus and hydroponics based fodder production. Although azolla and hydroponics could be ideal sources of fodder and occupy lesser land area, they are labour intensive activities. These could be the better options when house-hold labour is involved in augmenting the fodder resources and those livestock keepers, who have lesser number of animals. However, these can be supplementary in nature and cannot substitute natural fodder production. There is also need to have policy intervention on crop residues, utilization of sugarcane tops & its silage, bagasse for fodder bank and allowing only non-edible crop residues for packaging and other industrial use.

Sugarcane and its potential as fodder

About 282 lakh tonnes per annum sugarcane is produced in India. Green tops are used as cattle feed during the harvesting period (Nov. to April).Without any suitable utilisation major part are left as such or burnt in field. It has been also a practice of grazing / feeding of whole sugarcane in areas of Maharashtra, Karnataka in the pre- summer /summer months in the event of drought or scarcity of fodder or sometimes uneconomical harvesting for sugar industry. However, seasonal harvesting of high accumulated sugarcane tops waste increase rapidly environmental pollution and greenhouse gas emissions. In recent years, utilisation of agriculture by products as an alternative feed ingredient has extensively promoted to reduce requirement of traditional feed material. Therefore, strategies needed to foster and impede these pollutants could contribute toward a cleaner, greener and sustainable livestock production. Preservation practice has considerable potential, preserved sugarcane tops silage can be provided as green fodder for livestock during lean period.

Sugarcane may be a potential feed source for beef cattle in subtropical and tropical areas. Its advantages as a forage crop include: i) adaptation to the tropical and subtropical environments, ii) less sensitivity than other crops to poor soil fertility, the hot-humid climate, and insect and disease problems, iii) existing technology for its production, iv) a high yield capability, and v) the unique ability to maintain consistent quality as a standing crop in the field. Sugarcane grown for forage should be treated the same as cane for sugar production with regard to agronomic practices such as cultivation, fertilization, and pest control. Thus, recommendations already developed for an area should be used.

The most important decision when growing sugarcane for animal feeding is variety selection. Sugarcane has numerous varieties with widely varying characteristics. The three important items to consider are crop yield (plant and ratoon crops), nutritive quality (i.e., sugar and fiber contents) and ease of harvesting. In terms of nutritive quality, sugarcane varieties grown for sugar production are probably best for feeding purposes, because sucrose, the important part, is a highly digestible nutrient. However, in sugar production, less emphasis is placed on the quantity of fibre contained in a variety which could adversely and materially affect nutritive value to livestock. For example, a high-fibre, high-sucrose yielding variety may be acceptable for sugar production but could be less desirable as an animal feed because sugarcane fibre is poorly digestible. The fibre content is negatively related to *in vitro* digestibility. As the percentage of sugarcane in the diet increases, rate of gain, feed utilization, and carcass quality decreases. Increasing levels of sugarcane in the diet also resulted in less DM intake which would limit rate of gain.

Fodder sugarcane – as non-conventional fodder resource

Fodder sugarcane is material or type selected for its fodder value having more sprouting and succulence as compared to normal sugarcane grown for sugar purpose. Botanically it's a perennial grass (as tussocks stays healthy up to 7-8 years) with erect, almost cylindrical, solid, yellowish green stem showing presence of white coloured pith inside. Depending upon the growth and management practices, its stem attains 9-10 ft height and 2.5 to 4.5 cm stem diameter. Fodder sugarcane is a tropical plant however; it can be grown in sub-tropical climate too as in northern India. Under warm humid conditions, it can continue its growth and development. Temperature above 50^0C and below 15^0C slows down its vegetative growth and development. During extreme winters its growth remains stunted and it regain growth after rising of temperature above 15^0C. Low temperature reduces its tillering and regeneration capacity. The best quality of green fodder can be produced in areas where annual precipitation occurs in range of 75 to 125 cm per annum. Fodder sugarcane grass is an indigenous collection obtained from genetic material used for sugarcane breeding material. It is different from sugarcane varieties in terms of leafiness, thin juicy stem, regeneration capacity and protein content. This grass is most suited for growing as perennial green fodder crop.

Sugarcane silage

Sugarcane tops can be ensiled like other forage crops, but its nutritive value is significantly reduced. Silage making process is dependent on many factors, such as the natural microbial population, sugar content of the forage and harvesting conditions. Sugarcane tops has very less amount of soluble sugar due to which its fermentation is very difficult for silage making, so additives act as a boon for it. Sugarcane tops are deficient in true protein and various minerals and also have low energy value and can fulfilled the maintenance requirements of cattle. Silage of sugarcane tops treated with various additives showed some good results in feeding of dairy buffaloes. Additives increase the nutritive quality of the silage, as the result increase animal production and give the farmer a return greater than the cost of the additive.

Exploring the integration of forages in sugarcane based system

In long duration crops like sugarcane, intercropping holds much promise. Due to slow establishment of sugarcane during the first 90-120 days, the greatest scope for complementary effect lies in the addition of annual intercrops to the temporal system to improve resource use efficiency in the early crop growth period. Legume intercrops in cropping systems enhance soil fertility through the excretion of amino acids into the rhizosphere. The nitrogen fixed by the legume intercrop may be available to the associated sugarcane in the current season itself, as sugarcane remains in the field for over nine months after the harvest of the legumes. A further possibility of soil fertility improvement is through addition of crop residues, which on decomposition adds to the fertility of the soil. Since considerable addition of nutrient occurs through intercrop, there is a possibility of reducing N application through fertilizer. Since the underutilized growth resource prevails only for a short time, the intercrops and cultivar selected should be of dwarf type with compact canopy and short duration. Short duration legumes, forage legumes, oilseeds and vegetables are the most suitable intercrops in main season planted sugarcane

Intercropping of forages in sugarcane based systems

(i) Tropical region

In tropical India, maize is grown as an intercrop, especially in north Karnataka and Maharashtra basically for fodder purpose. All the results showed a negative effect on the growth parameters and cane yield. Under such situations intercropping of maize + cowpea/horsegram is advocated for faovorable effect to main crop of sugarcane. When nitrogen fertilizer is limited, biological nitrogen fixation is the major source of nitrogen in legume-cereal mixed cropping systems Use of leguminous intercrops leads to natural increase in the available soil nitrogen thereby reducing the use of inorganic fertilisers.

(ii) Subtropical region

In the subtropical region, sugarcane is normally planted in autumn (September- October) or during the spring season (February-April). The cane planted in the autumn season germinates before the onset of winter and remains in the field without much growth until the spring sets in. During this period, the cane does not make much demand for the growth resources. This facilitates raising of any *rabi* crop as intercrop with autumn planted sugarcane. Several studies demonstrated that the total productivity of crops in sugarcane + *rabi* crop intercropping system is substantially higher than the total productivity of sole *rabi* crop in winter followed by sole sugarcane planted in spring season.

a. Inter cropping in autumn planted cane

About 15% of sugarcane area comes under autumn (October) planting in subtropical India. In autumn, sugarcane, in subtropical India, tillering is almost ceased during the winter season (November–January), and it favors the growth of any other component crop/ intercrop. Adopting early maturing sugarcane varieties also plays a significant role in improving sugar recovery. If planted in spring, early maturing varieties may be harvested in the coming December. However, if these varieties are grown under autumn cultivated conditions, it may improve sugar recovery with tonnage if harvested in Nov–Dec. producing more fodder of good quality. Intercropping of high-density early-bulking forage crops (Egyptian clover/Indian clover, shaftal, fenugreek, lucerne) enhances bud sprouting in winter initiated ratoon by regulating rhizospheric thermal regime and serving as live mulch to protect sprouts from frost/cold damage during severe winter. Egyptian clover-berseem after cuttings left the highest amount of available N in the soil (243.5 kg/ha in 0–15 cm and 233.6 kg/ha in 15–30 cm soil layer) besides improving the physical conditions of the soil .

b. Cereals- legume mixtures in spring planted cane

Cereals like maize /sorghum/pearl millet as intercrops generally have adverse effects on the tillering of the base crop of sugarcane during the tiller development stage. It is reported reduction of 9.1 and 27.0% in cane yield when sorghum was grown for fodder with and without fertilizer, respectively. Cowpea was reported to be suitable as an intercrop in spring planted sugarcane in Haryana

c. Intercropping with spring-planted sugarcane

About one million hectares additional area can be brought under pulses by intercropping short duration pulse crops,viz., green gram and black gram in spring-planted sugarcane, especially in Uttar Pradesh, north Bihar, Punjab, and Haryana. After picking green pods for vegetables and/or mature pods for grains, the legume plants with longer leaf area duration were incorporated in the soil between the inter-row spaces of sugarcane as green manure. These systems affect nitrogen economy in sugarcane to the extent of 35–40 kg/ha besides producing a bonus yield of pulses. The compatibility of intercrops varies with the row arrangements and genotypes selected as intercrops in the system. Sugarcane growth and yield were also not affected adversely. Subsequent ratoon raised from mung bean (green gram) intercropped plant crop yielded higher than that raised from sole sugarcane. The benefits were to the tune of 18–20 t/ha of sugarcane. Intercropping of lucerne and berseem (leguminous fodder crops) with sugarcane did not raise the fiber content of cane rather decreased it marginally. Reduction in cane yield to the extent of 15.2 and 14.6%, respectively, was observed due to intercropping of Lucerne and berseem at Dapoli. The economic evaluation of different crop sequences revealed berseem/mung bean/wheat cropping systems meet the multiple needs of the farmers under subtropical condition and were found suitable.

d. Intercropping in ratoon crop

Sprouting of winter initiated ratoon is the major constraint in ratooning under subtropical conditions. Earlier in subtropical India, early maturing high sugar varieties were considered poor ratooner. Introducing early-bulking high-density intercrops (Egyptianclover, Persian clover, and Indian clover) can mitigate the problems associated with winter-initiated ratoon. Moreover, intercropped forage legumes serve as live much, regulate the rhizospheric thermal regime through root respiration, protect stubble buds from frost damage and encourage the sprouting of subterranean buds during the winter season. Intercropping of berseem in winter-initiated sugarcane ratoon significantly increased the number of millable canes (117.8 thousand/ha), cane yield (72.4 t/ha), cane-equivalent yield (90.81 t/ha) and commercial cane sugar (8.81 t/ha) compared with sole cropping (7.66 t/ha). The cane yield, cane-equivalent yield and sugar yield increased significantly with increase in N level in sugarcane + berseem and sugarcane + *senji* intercropping systems. Early-maturing, high-sugar variety 'CoS 687' sugarcane yielded higher (63.1 t/ha) under berseem intercropping system than sole cropping (54.7 t/ha).

Intercropping and juice quality

As regards sucrose content in cane juice, the different intercrops had no significant effect on juice quality parameters, especially sucrose content in cane juice which varied from 15.93 to 19.0% in other systems. However, intercropping of winter pulses with autumn sugarcane optimizes higher net return with improved resource use efficiency. No adverse effect of sugarcane main crop/ratoon crop on the quality of intercrop (component crop) has been reported.

Important forage crops & varieties for sugarcane based systems

Wide range of forage species are grown under varying management situations in different agro-ecological regions of the country. Due to their flexibility in growth and duration, forages offer ample scope in different cropping systems as a short duration, catch/intercrop or alley crop under different resource use situations. Production and productivity of cultivated fodder crops is low, as these crops are getting least attention in allocation of resources, and by growing in poor and marginal lands. Major forage crops during *kharif* are guinea grass, napier bajra hybrid, setaria, dinanath (grasses), sorghum, pearl millet, maize, teosinte (cereals) cowpea, rice bean and guar (legumes); and during *rabi* season crops like oat (cereal), berseem, lucerne are grown under cultivated condition as a sole or as component crop in cropping systems. In sugarcane based system choice is limited to few cultivated cereal & legume forages like maize, sorghum, teosinte, pearlmillet & cowpea, horsegram, ricebean in spring planted sugarcane; and rabi forage legumes like berseem, lucerne, fenugreek, shaftal in autumn planted and ratoon crop.

(i) Selection of crop and varieties

Forage crops are adopted well in different agro-climatic situations and can be grown in *kharif*, *rabi* and summer seasons. A forage crop may include several species within genus and several varieties within a species or may be a single species. In choosing a suitable crop, species or variety of crop to be grown, the following characteristics should be considered: i) growth cycle ii) growing season iii) adaptation to soil and climate iv) uses of the crops v) yield and quality of the harvest product vi) resistance to insects, disease, and nematodes and vii) market acceptability of the variety. It is important to choose a variety of crop plant that is well adapted to local conditions of soil, water, climate and disease resistance. Based on soil type and water availability forage crops and varieties are selected for different regions of the country. In view of stiff competition with food & other commercial crops, forage varieties with tolerance in drought/water scarcity situations holds promise and can fit well in existing farming systems. These varieties can be very well adopted and promoted in suitable agroclimatic zones of the states. Zone wise suitable crops and their varieties are given as under;

(ii) Suitable crops and their varieties for sugarcane based systems

Fodder crops	Varieties
Sorghum	UP Chari-1, 2, Pusa Chari -1, MP Chari, PC-6, 9, Raj Chari-1, 2, Sudex, Hara sona
Maize	African Tall, J-1006, Vijai, Moti , Jawahar Composite
Cowpea	UPC-5286, GFC-1, -3, -4, BL-1,-2, UPC-622
Berseem	Wardan, BB-2, BB-3, JSB-1 (single cut), BL-1, BL-10, BL-2, BC-180
Lucerne	Anand-2, Anand-3, RL 88, CO-1, T-9
Shaftal	

(iii) Forage based crop intensification (Round the year forage productions) in long rotations of sugarcane based systems

Sugarcane based systems consists of main crop and ratoons maintained in the same piece of land for 2-3 years. These are highly exhaustive cropping systems, which needs a break for restoration and improving the soil fertility status. So inclusion of some seasonal/ perennial based fodder sequences (1-2 years rotation) in these existing sugarcane based cropping patterns provides an opportunity for soil restoration & support fodder to livestock. Such classical arrangements of farm holding in rotation may pave way for addressing the fodder shortage in these regions. Intensive forage production systems are tailored with an objective of achieving high yield of green nutritious forage and maintaining soil fertility. Overlapping cropping system that comprises of raising berseem, inter-planted with Bajra Napier Hybrid/Guinea grass in spring and intercropping the inter-row spaces of the B N Hybrid/Guinea grass with cowpea during summer after the final harvest of berseem can supply green fodder round-the year. Under assured irrigation multiple cropping sequences sorghum + cowpea - berseem + gobhi sarson - maize + cowpea and sorghum (multi-cut) + cowpea-berseem + gobhi sarson are promising for providing green fodder round the year. The fodder can also be knitted in existing food grain/ commercial production systems as these are equally or more remunerative. The detailed list of fodder based crop sequences for different agro-climatic zones of the state is given as under;

Crop diversification and promising intercropping system under irrigated condition in long rotations of sugarcane based systems

Zone	Cropping system	Green Fodder yield (t/ha)	Area required to sustain 1 ACU* (ha)
Subtropical	Maize + cowpea – Toria - oats	150-175	0.04
	Sorghum/Maize + cowpea - berseem	150-170	0.04
	Maize + cowpea – Toria - Shaftal	150-160	0.04
Tropical	Sorghum + cowpea/horsegram – Lucerne	130-140	0.05
	Lucerne annual (sole)		

*6.5 tones green fodder is required to sustain 1 ACU (350 kg body weight) in a year.

Conclusion

Sugarcane is a long duration crop and takes about 90-120 days for canopy development, which allows for growing intercrops during the early stage. Taking advantage of this, sugarcane cultivators grow various short duration crops like pulses, vegetables, etc. as intercrops to get interim return since small sugarcane growers cannot wait for a long time to get financial return from sole sugarcane crop. Livestock keepers have an advantage of integration of forages in sugarcane based system for nutritious forage legumes for their livestock**.** Additionally, sugarcane offers several unique advantages over other field crops as forage for cattle in the tropical and subtropical areas. It is adapted to environmental conditions and a technology for its production exists in tropical and subtropical regions. Fodder sugarcane is emerging as new opportunity to sugarcane growers. Sugarcane maintains a consistent quality for long periods as a standing crop in the field. However, sugarcane silage can be effectively used as a roughage source in cattle fattening diets and as a winter supplement for producing brood cows. Chopped sugarcane should be fed to grazing cattle only when the availability of forage is very limited. Sugarcane, itself, should be grazed only in emergency situations, and then only once annually and in a manner to completely clean the grazing area within one-week. Current economics indicate that it is economically feasible to feed diets containing large quantities of chopped sugarcane to growing cattle in developing countries in the tropics.

Future prospects

- Diversification of sugarcane through winter forage legumes is a potential area, which needs to be explored with selection of suitable cane & fodder varieties for managing soil health, cane yield and supplementation of fodder to livestock.
- Integration of forage crops in sequence or in intercropping in sugarcane based systems is very critical to solve the fodder crisis in many regions.
- Making all efforts to utilize the cane tops, bagasse or silage through additives would be great efforts towards sustainable management of underutilized fodder resource to large chunk of livestock of sugarcane growing areas.
- Fodder sugarcane is emerging opportunity to the farmers for round the year green fodder in tropical and sub tropical areas, in addition to cultivated grasses viz., BN hybrid, Guinea grass, TSH.
- Like maize and sorghum, it is also suitable for silage making, would be a substitute to maize and sorghum in areas where farmers are not growing these crops.

References

BAHS, 2019. Basic Animal Husbandry Statistics 2019. Govt. of India. Ministry of Animal Husbandry, Dairying and Fisheries. Department of Animal Husbandry and Dairying. Krishi Bhawan, New Delhi.

F.M. Pate, J. Alvarez, J.D. Phillips, and B.R. Eiland, 2002. Sugarcane as cattle feed: Production and Utilization, Bulletin 844, Department of Animal Sciences, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, USA, pp.21.

Kumar, S., Agrawal, R.K., Dixit, A.K., Rai, A.K., Singh, J.B. and Rai, S.K. 2012. Forage Production Technology for Arable Lands. Indian Grassland and Fodder Research Institute, Jhansi. pp 48.

P. Geetha, K. Sivaraman, A.S. Tayade and R. Dhanapal, 2015. Sugarcane based intercropping system and its effect on cane yield, *Journal of Sugarcane Research* (2015) 5 (2) : 1 - 10

Shukla S. K., Lalan Sharma,V. P. Jaiswal, A. P. Dwivedi, S. K. Yadav and A. D. Pathak, 2022. Diversification options in sugarcane-based cropping systems for doubling farmers' income in subtropical India, *Sugar Tech*, 24(4):1212–1229 https://doi.org/10.1007/s12355-022-01127-1.

Singh A.K., Lal Menhi, Prasad S.R., Srivastava T.K, 2006 Productivity and profitability of winter-initiated sugarcane (*Saccharum* spp. hybrid complex) ratoon through intercropping of forage legumes and nitrogen nutrition, Indian Journal of Agronomy, 51 (4): 31-33.

Chapter No. 38: Rejuvenation of Indian sugar industry through national biofuel policy and adoption of sustainable sugarcane production technologies

R.B.Doule
Chief Sugarcane Adviser
National Federation of Cooperative Sugar Factories Ltd. New Delhi

Introduction:
The Indian Sugar Industry is a key driver of rural development, supporting India's economic growth. The industry is inherently inclusive, supporting over 500 lakhs farmers and their families, along with workers and entrepreneurs of over 500 mills, apart from a host of wholesalers and distributors spread across the country. The industry is at a crossroads today, where it can leverage opportunities created by global shifts in sugar trade as well as the emergence of sugarcane as a source of renewable energy, through ethanol and cogeneration. The domestic sugar production in 2021-22 is 359.55 Lakhs tones which is a highest Indian record. The country has not only become self-sufficient in sugar but a sizable portion is also earmarked for export, earning precious foreign exchequer.

India is the largest consumer and the second largest producer of sugar in the world. Brazil has historically led the world in sugar production. However, of late, Brazil has been diverting a large proportion of its sugarcane to the production of ethanol, and soon India will take over the position as the world's leading sugar producer. India's average annual production of sugarcane is 35.5 crore tonnes, with sugar production of around 3 crore tons.

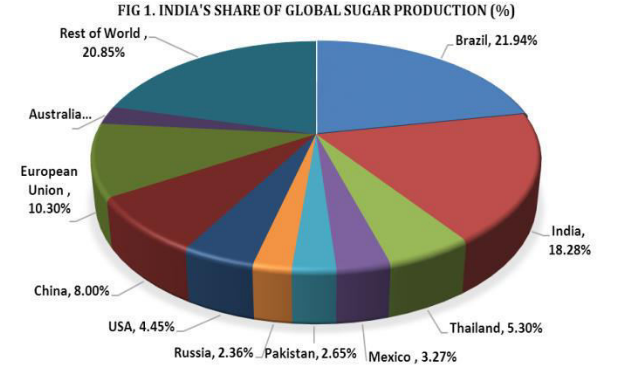
Being the largest consumer of sugar, the domestic consumption of India is estimated to be around 2.6 crore tones. However, the per-capita consumption of India is lower than in Europe, at 20 kg as opposed to the latter's average of 50–65 kg. In India, 35% of sugar is used in household consumption and 65% goes for industrial uses, including beverages and food manufacturing.

The contribution of sugarcane to the national GDP is 1.1% which is significant considering that the crop is grown only on 2.57% of the gross cropped area (Vision SBI, 2030). Adoption of effective management practices holds great promises for remunerative sugarcane yield in the country.

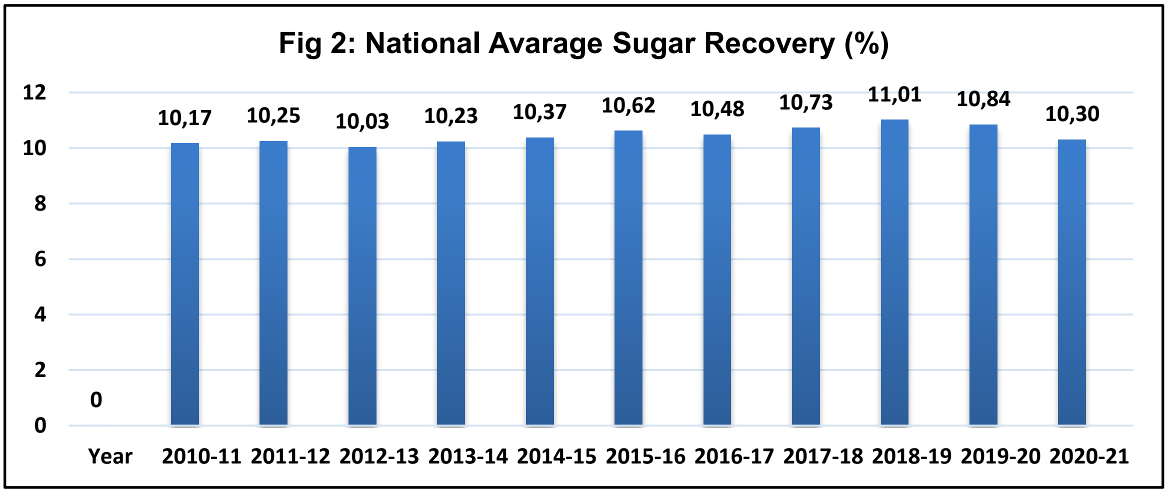
Emerging businesses like fuel ethanol and structural reforms worldwide including the removal of EU subsidies have provided new horizons for the sector. The sector today has transformational opportunities that would enable it not only to continue to service the domestic markets but also emerge as a significant carbon credit and power producer and support an ethanol blending program of E10 and beyond.

India's share in the world sugar production increased @18.28 % as against of 14.75 % (Fig 1). In recent years, many sugar mills have shown interest in diversifying their processing facilities to promote green energy production viz., Cogen, Bio-CNG, Bio-ethanol, etc. Bio-fuel in India is of strategic importance as it is planned well with the ongoing initiatives of the government such as offering a great opportunity to integrate with the ambitious target of doubling farmer's income, import reduction, employment generation, waste to wealth creation, etc.

FIG 1. INDIA'S SHARE OF GLOBAL SUGAR PRODUCTION (%)

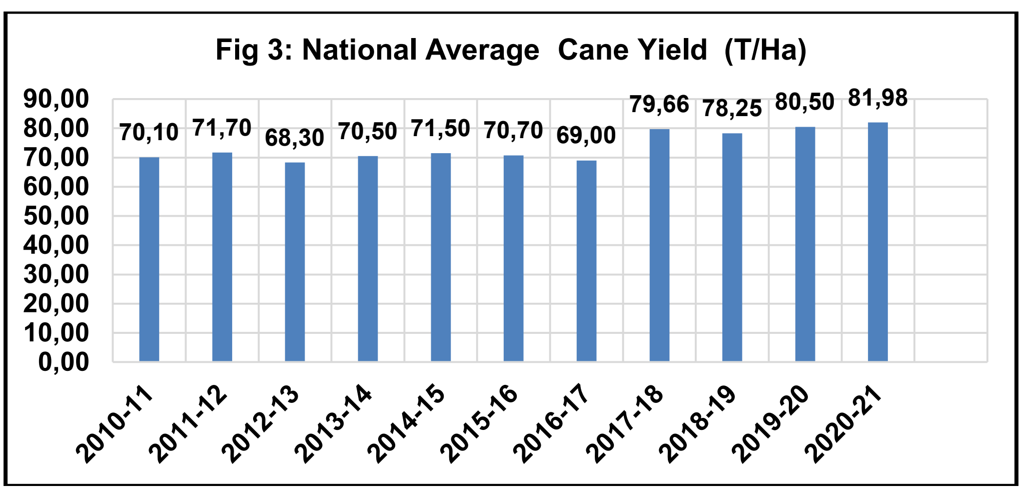


Both sugarcane and sugar are essential commodities and thus subject to control through various provisions of the Essential Commodities Act, 1955. This means that the industry is strictly regulated in terms of land demarcation for cultivation, sugarcane price, sugarcane procurement, sugar production and sale of sugar by mills in domestic and international markets. The average sugarcane productivity and sugar recovery has been recorded around 81.98 t/ha during 2020-21 sugar season (Fig 3) and 11.01% respectively in the country during 2018-19 (Fig. 2). Sugarcane is grown as a major cash crop after cotton in India.



Adoption of effective management practices holds great promise for remunerative sugarcane yield in the country. The cultivation of improved and early maturing varieties has recorded significant increase in sugar recovery in sub-tropical regions of the country. The sugarcane crop in the three main sugarcane growing states viz., Uttar Pradesh, Maharashtra and Karnataka which contributes around 80% of the total sugar production of the country.

The cost of cultivation is the function of the costs of inputs, land, labour and energy involved in cultivation practices and time. The technological interventions and experiences of peasantry gained over the years have devised several ways and means of lowering the cost of production by evolving more efficient techniques without compromising yield of the sugarcane crop and adopting more rationalized approaches with respect to location specific issues.



Account of major states in India with sugar production (Last 3 years):
Average sugarcane yield in India during 2018-19 was 78.25 t/ha and it has increased to 81.98 t/ha during 2020-21, showing an increasing trend (Table 1). While in Maharashtra, cane yield during 2018-19 was 79.50 t /ha and it was increased to 85 t/ha during 2020-21. Tamil Nadu has made a significant progress in obtaining a higher cane yield of 100 t/ha during 2020-21 whereas sugar recovery had shown a slightly decreasing trend which recorded 08.93 % (2018-19) as it was 09.05 % (2016-17). During the crushing season 2016-17 India's average sugar recovery was 10.48 % and it was increased to 11.01 % in 2018-19. Maharashtra State had shown a slight decrease of sugar recovery of 11.27% (2018-19) as it was 11.34 % (2016-17). Uttar Pradesh, with almost half the sugar cane area in the country has made significant progress in sugar recovery and cane yield (t/ha). The state has recorded productivity of 81.31 t/ha and sugar recovery of 11.45% in 2018-19 crushing season due to Co 0238 and congenial weather conditions. In Andhra Pradesh average sugarcane yield was recorded 79.33 t/ha during crushing season 2018-19 and it has decreased to 78.08 t/ha during 2020-21 which recorded less compared to average cane yield (t/ha) of India (81.98t/ha). Andhra Pradesh had shown a slight increase of sugar recovery of 09.40% (2018-19) as it was 09.37 % (2016-17)

Table 1: Status of area under sugarcane, average sugarcane yield, sugarcane and sugar production, and average sugar recovery of different states: Sugar Season 2018-19 to 2020-21

Sr. No.	State	Sugarcane Area			Average sugarcane Yield			Sugarcane Production			Sugar Production			Sugar Recovery		
		2018-19	2019-20	2020-21	2018-19	2019-20	2020-21	2018-19	2019-20	2020-21	2016-17	2017-18	2018-19	2016-17	2017-18	2018-19
1	Andhra Pradesh	1.02	0.86	0.55	79.33	79.19	78.08	80.91	67.24	42.95	3.85	4.74	5.08	9.37	9.50	9.40
2	Assam	0.3	0.30	0.30	37.07	41.01	37.78	11.12	12.18	11.33	--	--	--	--	--	--
3	Bihar	2.26	2.24	2.19	51.70	60.65	68.43	116.61	135.79	150.05	5.26	7.16	8.41	9.21	9.59	10.38
4	Chhattisgarh	0.33	0.35	0.32	44.34	50.00	55.50	14.52	17.59	17.50	0.52	0.95	1.16	10.35	8.81	9.64
5	Gujarat	1.67	1.61	1.83	71.97	71.89	74.53	120.36	115.70	136.21	8.85	10.67	11.23	10.58	10.19	10.82
6	Haryana	0.94	0.96	0.93	80.37	80.27	81.19	75.71	77.30	75.67	6.68	8.44	7.01	10.35	10.39	10.36
7	Jharkhand	0.08	--	--	69.52	--	--	5.46	--	--	--	--	--	--	--	--
8	Karnataka	5.06	4.29	4.28	83.00	89.00	96.00	420.06	381.81	410.88	21.44	36.58	44.28	10.25	10.64	10.73
9	Kerala	0.01	0.01	0.01	13.16	127.19	116.31	0.13	1.21	0.74	-	--	--	--	--	--
10	Madhya Pradesh	1.18	1.25	1.06	58.95	59.47	53.45	69.56	74.34	56.66	3.43	4.69	4.34	9.76	9.82	9.95
11	Maharashtra	11.63	8.22	11.42	79.50	84.28	85.00	924.43	693.12	970.70	42.38	107.05	107.21	11.34	11.25	11.27
12	Odisha	0.06	0.09	0.07	63.06	56.42	56.14	3.81	5.05	3.89	0.38	0.35	0.39	9.40	9.34	9.75
13	Punjab	0.95	0.91	0.95	81.83	80.24	82.60	77.74	73.02	78.55	6.61	8.24	7.86	9.78	9.78	10.14
14	Rajasthan	0.05	0.04	0.05	83.45	73.04	57.08	4.48	3.26	2.84	0.1	0.07	0.10	8.55	9.02	9.18
15	Tamil Nadu	1.65	1.31	1.39	98.24	107.62	100.00	162.08	141.19	139.44	10.62	6.92	9.70	9.05	8.61	8.93
16	Telangana	0.40	0.26	0.20	70.00	77.42	76.82	28	20.13	15.36	1.16	2.69	2.57	10.38	10.84	10.65
17	Uttar Pradesh	22.24	22.08	21.80	80.81	81.31	81.31	1797.15	1795.39	1772.62	87.78	120.46	118.21	10.61	10.84	11.45
18	Uttarakhand	0.91	0.92	0.84	69.55	75.41	82.30	63.29	69.38	69.13	3.45	4.19	3.71	9.85	10.24	11.00
19	West Bengal	0.19	0.19	0.19	88.00	79.66	83.00	16.55	15.28	15.60	0.01	--	--	7.18	5.21	--
20	Others	0.21	0.13	0.13	45.14	48.17	49.31	9.6	6.03	6.44	0.1	0.06	0.07	8.38	7.92	7.58
	All India	**51.14**	**46.03**	**48.51**	**78.25**	**80.50**	**81.98**	**4001.57**	**3705.00**	**3976.57**	**202.62**	**323.26**	**331.33**	**10.48**	**10.73**	**11.01**

Demand and Supply of Sugar:
Trend in Domestic demand for sugar, supply and opening balance at the beginning of each sugar season since 2011-12 is presented in Fig. 4. Domestic use of sugar has increased steadily from 220 lakh metric tons during the year 2011-12 to 270lakh metric tons in the recent years. In the same period production increased from 263lakh metric tons to 360lakh metric tons in year 2021-22. The gap in the total use of sugar and supply has been rising over time resulting in significant increase in opening balance in each year. The opening balance in year 2017-18 was estimated to be more than 50 per cent of production in the same year.

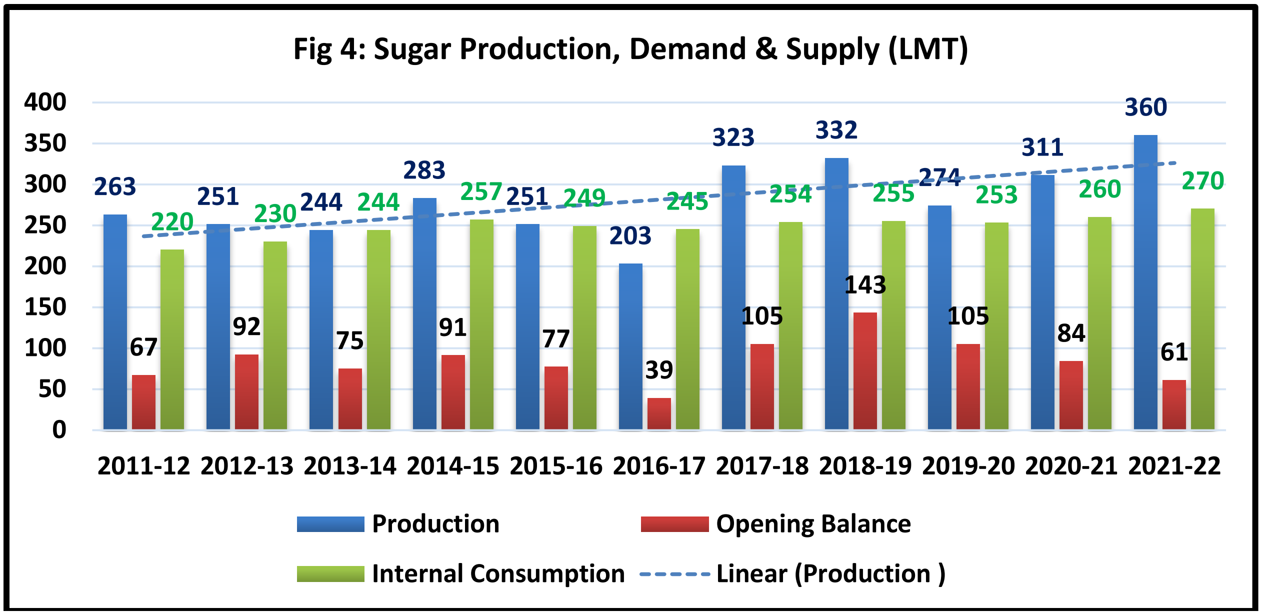


Fig 4: Sugar Production, Demand & Supply (LMT)

The balance sheet of sugar over the last seven seasons (October–September) is given in the Table 2. It can be seen that the opening balance of sugar during 2021-22 has reduced to83.88 lakh tones and production has increased to 359.55 lakh tones compared to 311 lakh tones in the previous year, even as consumption has increased only marginally. This is expected to continue to put pressure on domestic prices in the near term.

Table 2: Fair & Remunerative Price (FRP) of Sugarcane fixed by Govt of India

Year	FRP of Sugarcane (Rs. Per Qtl)	Linked to basic sugar recovery % cane	Premium on every 0.1 % increase in sugar recovery % of cane (Rs. Per Qtl)
2017-18	255	9.5	2.68
2018-19	275	10	2.75
2019-20	275	10	2.75
2020-21	285	10	2.85
2021-22	290	10	2.90
2022-23	305	10.25	3.05

Table 3: Sugar balance sheet for the Last 8 sugar seasons (Lakh Metric Ton)

Particulars	2014–15	2015–16	2016–17	2017–18	2018–19	2019–20	2020-21	2021-22
Carry-over stocks with sugar mills from previous season	75.28	91.20	77.25	39.41	104.71	143.33	104.78	83.88
Sugar Production	283.13	251.25	202.62	323.28	331.62	273.85	311.00	359.55
Sugar Import	12.36	-	4.48	2.24	-	-	-	-
Estimated total availability	370.77	342.45	284.35	364.93	436.33	417.18	415.78	443.43
Internal Consumption	256.55	248.50	244.48	253.90	255.00	253.00	260.00	270.00
Sugar Export	23.02	16.70	0.46	6.32	38.00	59.40	71.90	50.00
Total estimated Consumption&Export	279.57	265.20	244.94	260.22	293.00	312.40	331.90	382.00
Estimated closing stocks with sugar mills at the end of season	91.20	77.25	39.41	104.71	143.33	104.78	83.88	61.43

Regardless of the few shortage years now and then, India structurally has become a sugar-surplus nation. Sugarcane farmers are getting more and more attracted to growing sugarcane with higher assured prices (which has nearly doubled since 2009) as well as assured marketing. Consequently, sugarcane production is on a growth trajectory for the last ten years, ever since the concept of FRP for sugarcane was introduced (Table 3). This in itself has become a major concern, resulting in surplus stocks in warehouses time and again.

Sugar Export:

Exports can be a viable option for disposal of the excess production. However, many a time it becomes difficult for the Indian sugar industry to compete in the international markets because most of the overseas markets are already captured by other sugar-surplus-producing countries. For Indian sugar to be competitive enough, a thorough analysis and understanding on international market is needed. The basic factors in export competitiveness of sugar are the difference between the cost of cane and cost of producing sugar in India *vis a vis* other major sugar-producing countries of the world. The other factor is the quality of sugar being exported from India in comparison to the quality of sugar in the international markets.

As per the details provided by the Indian sugar industry, cane prices on average account for about 70%-75% of the cost of sugar. In Brazil, Thailand and Australia, the cane price per ton was USD 25.11, 27.45 and 24.05, respectively, while in India it was USD 42.30 (in 2017–18 sugar season). This makes nearly a 65% difference in cost price. As a result, the total cost of producing sugar in India turns out to be ₹36 per kilo as compared to ₹18.50 globally. Additionally, as mentioned earlier, the global sugar industry is mostly a captured market. Brazil is the leading exporter to the Americas while China, Thailand and Australia have conquered the markets of Asia and Africa. For India to enter such a competitive market will be a mammoth task considering its high prices.

As a result, the export of sugar to dispose of excess sugar stocks in the country is not a viable solution in the short term. Certain solutions to boost exports as recommended by the industry include provision of Government support in terms of subsidy/assistance and providing mandatory quota for exports. However, the sugar exports of India can only be competitive once the internal problems of the Indian sugar industry are resolved. This is with respect to overall production cost, pricing policy, alternative uses of cane, returns to mills, etc.

Constraints of sugar Industry:

1. Surplus sugar production in the country.
2. Sugar selling price is not increasing at the national and international market.
3. Excess sugar production has led to many related problems such as lower ex-factory price of sugar due to which sugar mills are not in a position to pay cane price to farmers on time.
4. Low crushing capacity of the sugar mills.
5. Short / Long crushing duration.
6. Low sugar recovery.
7. High cost of production of sugar.
8. Glut in sugar production resulting in accumulating highest ever inventory levels.
9. No uniform cane price across the country and no linkage of it with sugar production.
10. No provision for creation of price stabilization funds in the country.

Ethanol Blending Program for Solution of Excess Sugar Production:

With the production of sugarcane and the stock of sugar growing every year, strategies to divert excess cane production have been sought. One prime strategy that is being implemented is of using sugarcane for the production of ethanol and diverting it away from sugar production. Ethanol, which is an agro-based product and an important renewable fuel, is naturally obtained from the fermentation of sugarcane molasses (a byproduct of sugar production). Ethanol being an eco-friendly fuel source can be mixed with gasoline to create different blends of fuel and, when the blend is used to run machines, emits lesser environmental pollution. Harnessing the excess sugarcane for ethanol production will not only help divert excess stocks but also benefit the sugar industry and the economy in several other ways.

In 2003, the Government launched the Ethanol Blended Petrol (EBP) programme primarily to promote environment-friendly fuels (by increasing the usage of ethanol) and reduce energy imports. The programme, in general, was conceptualised with multiple objectives in mind. By increasing the usage of biofuels, it aims to control carbon emissions while also conserving foreign exchange and reducing import dependency. More specifically, the EBP programme injects liquidity into the sugarcane sector by providing a sustained demand for ethanol. Thus, it helps in the reduction of accumulated arrears and permits timely compensation for cane farmers(Ramesh Chand and Yogesh Suri, 2021).

Beginning in 2003 as a pilot project, the EBP programme has now been extended to the entire country (with the exception of the Union Territories of Lakshadweep and Andaman and Nicobar Islands). It is implemented through a network of 186 depots of Oil Marketing Companies (OMCs), drawing ethanol from 179 distilleries with an installed ethanol-producing capacity of 305 crore litres.

National Policy on Biofuels 2018:

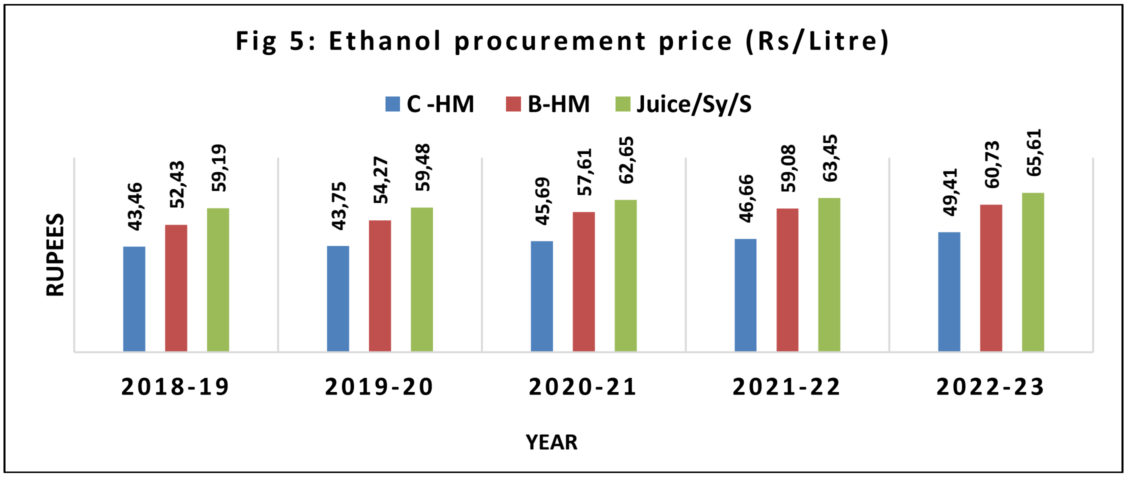
The erstwhile National Policy on Biofuels (2009) permitted the procurement of non-food feedstock like molasses, celluloses and lignocelluloses. Until 2017–18 ethanol for EBP programme came from molasses, allowing utilisation of a byproduct of the sugar industry. The present outputs of molasses allow for the production of approximately 300 crore litres of alcohol/ethanol, which is targeted at 10% blending. The 2018 National Policy on Biofuels broadens the scope for the raw material procurement for ethanol production. The policy targets a 20% blending percentage by 2029–30.Department of Food and Public Distribution (DFPD) is the nodal department for promotion of fuel grade ethanol producing distilleries in the country. Government has allowed ethanol production/ procurement from sugarcane-based raw materials viz. C&B heavy molasses, sugarcane juice/sugar/ sugar syrup, surplus rice with Food Corporation of India (FCI) and Maize. The raw material wise conversion efficiency is tabulated in Table 4 below.

Table 4: Feedstock cost, ethanol yield & price

Sr. No.	Feedstock	Costof Feedstock (Rs./MT	Quantity of Ethanol per MT of Feedstock	Ex.Mill Ethanol Price(Rs./Liter)
1	Sugarcane Juice/Sugar/Sugar syrup	Rs. 3,050*	70 Literper ton of sugarcane	65.61
2	B Heavy Molasses	Rs.13500	300 Liter	60.73
3	C Heavy Molasses	Rs.7123	225 Liter	49.41
4	Damaged Food Grains (Broken Rice)	Rs.16,000	400 Liter	51.55
5	Rice available with FCI	Rs.20,000	450 Liter	56.87
6	Maize#	Rs.15,000	380 Liter	51.55

(#Ratesvaryfromregiontoregionandalsoinaccordancewithdemand/supplyorquality, *Sugar Season-2022-23- Price of sugarcane @10% sugar recovery)

OMCs Ethanol Purchase- Ethanol Procurement Price increased:
A differential pricing mechanism for ethanol based on its source material has been introduced. Public sector OMCs follow an order of priority for ethanol procurement from 100% sugarcane juice, B heavy molasses/ partial sugarcane juice, C heavy molasses, and damaged food grains, in descending order.Unlike grain-based ethanol the Cabinet approves ethanol purchase prices of OMCs when the fuel is produced by sugar mills. Country's ethanol production capacities are required to be enhanced to about 1,700 crore litre to achieve a 20 per cent blending target by 2025. To achieve the blending target, the Government has been raising ethanol prices feed stock wise almost every year(Fig.5). For the ongoing ESY 2022-23, the ethanol rate is Rs.49.41/litre if made out of C-heavy molasses, Rs.60.73/litre for B Heavy molasses and Rs.65.61/litre from sugarcane juice/sugar/sugar syrup route.



(HM-Heavy Molasses, Sy-Sugar syrup & S-Sugar)

By mandating OMCs to procure ethanol under the EBP programme at fixed prices, the Government has effectively been subsidising the sugar industry. This is due to the higher price of domestically produced ethanol vis-a-vis the price in the international market. For blending of 20%, the required quantity of ethanol is about 1000 crore litres.

Various measures and Policies undertaken by Govt of India for increases Ethanol Production:
Various measures have been undertaken by the Government of India to encourage the domestic production of ethanol. These include amendments to the Industries (Development and Regulation) Act, 1951, to legislate exclusive Central control over denatured alcohol, reduction of the Goods and Services Tax (GST) levied on ethanol for EBP to 5%, reintroduction of the administered price mechanism, expansion of the programme and opening up alternate production routes.The government has also adopted different pricing methods to boost the supplies of ethanol for the EBP programme.

Government Initiatives

- The government has reduced the Goods and Services tax (GST) on ethanol targeted for blending from 18 percent to 5 percent in July 2018.
- To ensure the clearance of dues of farmers the government brought out a comprehensive package of about Rs.7000 crore which includes a plan of Rs.4400 crore for increasing the ethanol capacity in the country.
- In September 2018, the Cabinet Committee on Economic Affairs (CCEA) took a decision to provide incentives for the production of ethanol from sugar cane.
- Government has announced three progressive rates for ethanol procurement based on their purity.
- Ethanol produced from 100 per cent sugarcane juice will be priced the highest.

- Ethanol produced from B grade molasses: They are made from partial sugarcane juice and will be priced lower than those produced from 100 per cent sugarcane juice.
- Ethanol produced from C grade molasses: Inferior than B heavy molasses will be priced the least
- Advisory to Oil Market Companies (OMCs): They have been advised to prioritize ethanol procurement based on the purity and give preference to ethanol made from 100 per cent sugarcane juice.
- The Policy expands the scope of raw material for ethanol production by allowing use of Sugarcane Juice, Sugar containing materials like Sugar Beet, Sweet Sorghum, Starch containing materials like Corn, Cassava, Damaged food grains like wheat, broken rice, Rotten Potatoes, unfit for human consumption for ethanol production.

The 2018 National Policy on Biofuels seeks to address these issues. A National Biofuel Coordination Committee has been set up under the policy. It hopes to resolve the lack of raw material availability by expanding the base of raw materials to include B molasses, sugarcane juice and damaged food grains unfit for human consumption. This measure aims to help OMCs achieve higher blending targets (Table 5). Presently, the Ministry of Petroleum and Natural Gas (MoP&NG) has achieveda 10% ethanol blending program in petrol by 2021–22.

Until April 2019, OMCs have allocated 268.6 crore litres of ethanol procurement via EOI/tenders. The allocation of tenders from different feedstocks is as shown below and supplies of given quantities have started for the Ethanol Supply Year 2018–19.There is significant scope to enhance allocation of ethanol produced through 100% sugarcane juice route.

Table 5: Allocation Tenders of Ethanol during 2020-21 (Dec-Nov)

Raw Material for Ethanol Production	**Allocated Quantity (Crore litres)**
Sugarcane juice/sugar /sugar syrup	42.2
B-Heavy molasses	181.97
C-Heavy molasses	59.50
Damaged Food Grains (DFG) / Maize	38.42
Rice available with FCI	3.43
Total	**325.52**

Source: Department of Food and Public Distribution, GOI.

Implementation of Interest Subvention Scheme:

Attempts to incentivize ethanol production have been made via an interest subvention scheme, namely: the scheme for augmenting and enhancing ethanol production capacity. The scheme is jointly monitored by MoP&NG and the Department of Food and Public Distribution (DFPD). In December 2020, CCEA approved a modified scheme for extending interest subvention to expand ethanol production capacity. Under the scheme, the government would bear interest subvention for five years, including one-year moratorium against the loan availed by project proponents from banks, at the rate of 6 per cent per annum or 50 per cent of the rate of interest charged by banks, whichever is lower. Rs.4573 crore additional funds have been provided towards interest subvention for extending loans to project proponents under the ethanol interest subvention scheme, in addition to Rs. 4687 crore already approved by CCEA in its meeting held on 06.06.2018 and 07.03.2019.

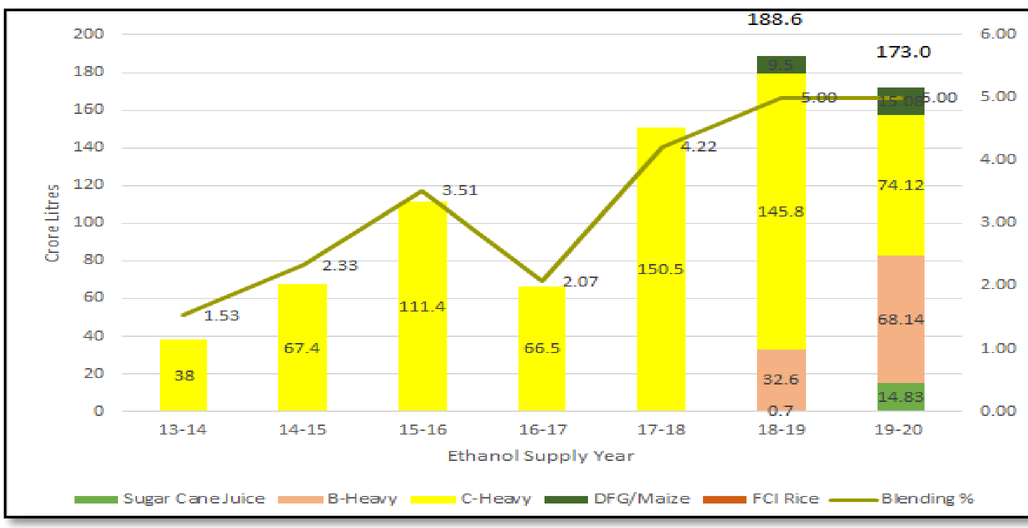
The amendment of the IDR Act also aims to smoothen inter- and intra-state movement of ethanol by giving the Central Government exclusive control over it. The possibility of higher blending, beyond 10%, in ethanol-surplus states of Uttar Pradesh and Maharashtra is also being explored to avoid the movement of ethanol across the country. For this, the Bureau of Indian Standards has already notified E-20 Standards.

Despite the above measures, a major challenge for the successful implementation of the EBP programme remains ensuring the cooperation of its multiple stakeholders. So far, only 11 states have implemented the amendments to the IDR Act. Several important states like Delhi, Uttar Pradesh, Haryana, Rajasthan, and West Bengal, etc., continue to levy excise controls and trade duties that hinder the smooth implementation of the EBP programme. While participation of ethanol suppliers and OMCs is being facilitated, automobile manufacturers have expressed concerns over material compatibility and drivability performance of higher ethanol blends when used in vehicles. Modalities need to be worked out at the earliest between MoP& NG and the different State Governments where the implementation of amendments of IDR Act can begin. It is very important for Uttar Pradesh to be on board as it is a state prominent in sugar and ethanol production. For states such as Uttar Pradesh and Maharashtra that witness excess production, higher blending target can be fixed (Coop. Sugar Press News, Dec., 2019).

Roadmap for Ethanol Blending in India 2025:

The government of India has allowed ethanol production/ procurement from sugarcane-base draw materials viz. C&B heavy molasses, sugarcane juice/ sugar / sugar syrup, surplus rice with Food Corporation of India (FCI) and Maize.The raw material wise conversion efficiency is mentioned in the following graph(Fig 6).

Fig 6: Different feedstock for ethanol production



(Source- NITI Aayog Report, 2020, GOI)

Ethanol Blending Targets:

There is a need to achieve the target of 20% blending expeditiously. Any impediments to this process be looked at seriously by the Government and rectified to make it seamless. Government may also consider preponing the 20% blending target from the different sources.The targets (Table 6) of ethanol blend percentage and estimates of the quantity of ethanol required for blending in petrol is as under:

Table 6: Ethanol Blending Targets

Ethanol Supply Year	Estimated required quantity of ethanol of different sources (Crore liter)		Total quantity of ethanol (Crore liter)	Targeted Ethanol Blend %age
	Molasses	Grain		
2019–20	426	258	684	5
2020–21	450	260	710	8.5
2021–22	511	300	819	10

2022-23	625	350	975	12
2023-24	725	450	1175	15
2024-25	730	700	1430	20
2025-26	760	740	1500	20

Source: Ministry of Petroleum and Natural Gas, GOI.

Current ethanol production capacity:

At present, the country has a total ethanol production capacity of 849 crore litres, which includes 569 crore litres of molasses-based distilleries and 280 crore litres of grain-based distilleries.Government has completed a target of 10% blending of fuel grade ethanol with petrol by 2022.Ethanol production capacities are required to be enhanced to about 1700 crore litres to achieve 20 per cent blending by 2025. Currently, 113 Grain based distilleries (21st March, 2022) and 239 molasses based ethanol projectsis operating in India (Feb 03, 2022).

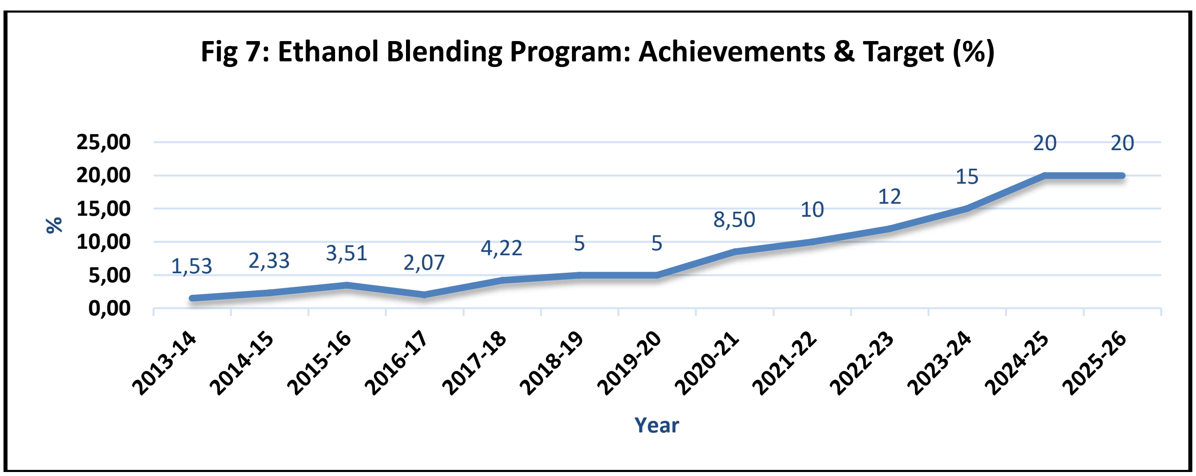
Ethanol Blending Program(EBP) Status in India:

The table below shows the quantities of ethanol supplied and the blending percentages subsequently achieved by OMCs(Table 7, Fig 7). This is largely due to supply-side constraints, which include limited distillation capacity and availability of molasses.

Table 7: India's Ethanol Production Status, Quantity of Ethanol Supplied & Ethanol Blending Program (EBP) - Last 9 Years

Sr. No	Ethanol Production Year	Quantity of Ethanol Supplied (Crore liter)	Remark	EBP (%)
1	2013-14	38.0	Molasses base	1.53
2	2014-15	67.4	Molasses base	2.33
3	2015-16	111.4	Molasses base	3.51
4	2016-17	66.5	Molasses base	2.07
5	2017-18	150.5	Molasses base	4.22
6	2018-19	188.6	Sugar mills & grain based plants	5.00
7	2019-20	173.0	Sugar mills & grain based plants	5.00
8	2020-21	332.0	Sugar mills & grain based plants	8.50
9	2021-22	380.0	Sugar mills & grain based plants	10.00

(Source: Ministry of Food & Public distribution, GOI)



NITI Aayog Report June, 2021)

Benefit of Ethanol Blending Program (EBP) to Sugar Industry:

- The EBP will encourage the production of ethanol and will thus reduce excess sugar in the country.
- It will increase the liquidity with the sugar mills and will help them settle the arrears of the farmers.
- Diversion of surplus sugar into ethanol will improve liquidity and check the fall in sugar price.
- It will incentivize ethanol output and will increase Investment in capacity addition of the sugar mills.
- India will save at least 120 billion through EBP, thus cutting down on its import bill.
- The Ethanol Blending Programme (EBP) helps to reduce pollution, conserve foreign exchange and increase value addition in the sugar industry enabling them to clear cane price arrears of the farmers.
- Achievement of E10 has already resulted in additional revenue of about ₹18,000 crores in revenue of sugar mills which will exceed ₹35000 on achievement of E20 blending with petrol by 2025.
- Achieved capacities to enable conversion of surplus sugar and molasses into ethanol for blending with fuel
- Ethanol blending programme delivering multiple outcomes such as Environmental benefits, Forex savings and Value addition in the economy
- The blending programme intends to decrease India's dependence on crude oil imports and increase farmer income.
- EPB also helps to save precious foreign exchange for the country worth about ₹30,000 crore per annum.
- Blending ensured an alternative market for farmers' produce like rice, maize helping them achieve better returns, more than MSP and also faster payment from sugar mills.
- All these activities are leading to transforming the Indian Farming community from 'Anna Daata' to 'UrjaDaata',"

InnovativeApproaches for Sustainable Sugarcane Production Technologies:

There are about 120-125 lakhs cane growers in India having the average cane farm-size of 0.77 ha. The average holding of cane growers indicates that more than 90% of sugarcane in the country is grown by small and marginal farmers. This small size of holdings of the average cane farm makes it difficult to adopt costly improved sugarcane production technologies. Hence, adoption of low cost technologies in such scenarios has become essential to improve the profitability through adoption of recent approaches for doubling farmer's income in sugarcane based cropping system.

Major Constraints for Increasing Cane Productivity:

1. Tremendous gap between potential yield and yield realization.
2. Unavailability of quality / pure seed material of promising sugarcane varieties for planting.
3. Increases the high cost of sugarcane cultivation.
4. Monoculture of cane cultivation.
5. Depletion of fertility status of the soils.
6. Lack of adequate irrigation.
7. Lack of balance dose of fertilizers.
8. Delayed and untimely operations due to labour problems.
9. Low net returns to cane growers.
10. Poor economic conditions of the cane growers.
11. Low land holdings under cane cultivation.

12. Effect on cane yield & sugar recovery due to natural calamities i.e. increases pests and diseases (invasion of red rot in U.P), erratic rain fall, drought, flood, soil fertility status degrading day by day, etc.
13. Non adoption of scientific ratoon management practices.
14. Untimely payment of cane price in surplus cane production years.

Average Sugar Recovery Stagnant in India?

1. Lack of adequate varietal improvement programme to meet the demand of sugar industry, only two varieties major area under cane cultivation across the country i.e.Co 86032 (Tropical region) and Co 0238 (Sub-Tropical region)
2. Loss of genetic vigour and purity of the existing good cane varieties.
3. Lack of varietal planning and scheduling by the sugar factories.
4. Lack of proper varietal balance i.e. more than 90 % area under only one variety.
5. Lack of a healthy seed programme i.e. most of the mills don't have cane development programs.
6. Occurrence of severe insects, pests and diseases in sugarcane crop i.e. Red rot problem in sub-tropical region of the country
7. Longer crushing season during surplus cane production years and shorter crushing duration in less cane production years which affects the varietal planning.
8. Improper cane harvesting and transport program at mill level.
9. Lack of efficiency in the factory operations due to multi-various problems.
10. Impact of adverse agro-climatic conditions.
11. Cane harvesting is not as per the maturity period of the varieties.
12. Cane payment is not on the basis of sugar content present in sugarcane juice.

Following are the approaches for enhancement of sugar recovery and cane yield and doubling the farmer's income:

Integration of sugarcane production technologies for improvement in farm productivity, diversified sugarcane production system, reduced cost of cultivation along with increased processing plant efficiency and diversification to produce value added products shall ensure smooth and higher payment to the farmers. Development of low-cost technologies to convert "waste to resource" on a smaller scale shall also help the farmers to increase their income further.

Following are the important approaches for enhancement of sugar recovery and cane yield.

- **Selection of an appropriate varieties:**

Selection of an appropriate variety is one of the most important non-monetary inputs deciding the production and productivity of sugarcane. A large numbers of varieties developed by different research stations and SAUs/ICAR Institutes for cultivation in different zones have been recommended (Table 8). Most of the farmers are attracted towards high yielding varieties. However, varietieshavinghighersucrose content are the choice of sugar industry. Besides, sugarcane ratoon crop matures earlierthan plant crop in 10 months and behave like early maturing variety (sugar accumulation).

Table 8. Major sugarcane varieties in cultivation in different States during sugar season 2017-18 / 2018-19

Sr. No.	State	Important varieties
1.	Gujarat*	CoM 0265 (31%*), Co 86032 (12.8%), Co 98517 (10.4%), Co 86002 (8.9%), CoSi 6 (6%), CoN 05071 (5.6%), Co 97009 (5.6%), MS 10001 (3.8%), CoN 07072 (2.5%), CoC 671, CoN 05072.

2.	Karnataka*	Co 86032 (58.8%), Co 91010 (15.2%), CoM 0265 (12.5%), Co 62175 (2.8%), CoVc 14061 (VCF 517), Co 8011.
3.	Tamil Nadu*	Co 86032 (53.4%), CoV 09356 (17.4%), CoV 94101 (3.5%), PI 00-1110 (3.0%), CoC (SC) 24 (3.0%), SI 309, CoV 92102, TNAU (SC) 8, Co 97009, Co 0212, Co 09004, Co 11015.
4.	Punjab	Co 0238 (63.7%), Co 0118 (10.83), CoJ 85 (7.5%), Co 89003, CoJ 88, CoPb 91.
5.	Maharashtra*	Co 86032 (51%), CoM 0265 (36.1%), Co 92005 (5.2%), Co 62175 (1.9%), CoC 671, CoVSI 9805.
6.	MP	Co 86032, Co 8014, CoVSI 3102, Co 0238 , CoM 0265
7.	Haryana	Co 0238 (60.5%), Co 89003 (10.7%), Co 0239 (7.4%), CoJ 85 (7%), CoH 160 (6%), CoH 119 (4%), Co 0118.
8.	A.P.	CoV 09356 (52.7%), CoA, 92081 (21.9%), 98V 95 (3.2%), Co 86032 (2.5%), CoV 94101 (86V96-2.2%), CoV 92102 (83V15-1.6%), 99V30, 2002V48, 93V297, Co 62175, CoV 95101 (91V83).
9.	U.P.	Co 0238 (69%), CoLk 94184 (6.7%), CoSe 01434 (2.5%), Co 0118 (2.48%), Co 98014 (2%), Co 0239, CoS 8436, CoS 767, CoS 97264, CoS 08279, CoS 91269
10.	Bihar*	Co 0238 (45.3%), Co 0233 (12.4%), BO 110 (7.6%), CoP 2061(5.6%), BO 91 (4.2%), CoS 92423, CoP 9301, Co 0232, Co 0118, CoLk 94184.
11.	Uttarakhand	Co 0238 (59.9%), CoJ 88 (8.7%), CoS 767 (7.31%), CoS 88230 (4%), CoS 97264, CoJ 85, CoS 846, Co 98014, Co 0118, CoPant 03220.
12	Odisha*	CoA 89085 (12.6%), CoOr 03151 (10.6%), CoV 94101 (86V96-7.1%), Co 6907 (7.0%), Co 62175 (6.9%), Co 86249 (6.3%), CoOr 04152 (6.2%), Co 86032 (5.8%), CoOr 05346 (5%), Co 8201, Co 99082, CoA 92081, Co 7805.
13	Telangana	Co 86032 (56.8%), 93V297 (21.2 %), CoV 09356 (15.8%), CoA 82081 (4.4%)

Note: * % area during 2017-18 season; others % area during 2018-19 (Dr.Bakshiram, Proc.National Seminar, NFCSF, New Delhi, 15th March, 2019)

- **Adoption of three-tier seed nursery program:**

Due to negligence in use of quality seed material presently there are many states that don't follow proper seed production programs i.e. the seed replacement rate in Maharashtra state is only 6%. Sugarcane seed should be replaced once after every three years, due to which yield increased by 10-15% and sugar recovery by 0.5-1 units. For successful seed replacement there is a need to maintain a three tier seed production plot under factor area. Seed produced by this system should be free from pest and diseases. Different improved techniques of sugarcane seed nursery programme needs to be adopted viz., Bud chip technology for rapid seed multiplication, Use of single eye bud settlings, Use of Tissue culture seedlings in seed production chain and STP method produced seedlings, etc.

- **Sugarcane varieties planting planning and harvesting programme:**

As we know, in sugar factories, there is an over availability and sometimes shortage of good quality sugarcane for crushing; the only reason is lack of planting planning and harvesting program. So, for uniform supply of raw material to sugar factory during crushing period there is a need to be proper planning to grow and harvest the crop/varieties according to their maturity period, which increases the sugar recovery and sugarcane yield.

- **Soil fertility and fertilizer management**

Soil degradation, problem soils is an emerging issue so; there is a need to manage this on a sustainable basis by maintaining the soil organic carbon between 0.75 to 1.00 percent by incorporating organic manure, green manure, bio compost and trash management to achieve targeted yield. Addition of organic matter in to soil improves soil physical, chemical and biological properties of soil and also water holding capacity, which has a positive effect on microbial count and nutrient availability.Foliar fertilization is also useful when crop is under stress. Nutrient/ fertilizer management through drip irrigation (fertigation) not only saves the water but also increases the fertilizer use efficiency and saves 30% of the fertilizer. Silicon @ 400 kg/ha (commercial) can also be applied in sugarcane. or it is applied through 1.5 t bagasse ash with 2.5 lit/ha silicon solubilizing bacteria makes the plant able to tolerate abiotic and biotic stress.

- **Use of Bio fertilizers for increasing sugar recovery and cane yield:**

Bio-fertilizers have a potential role in sustainable agriculture; these can be used along with chemical fertilizers to enhance the soil fertility and crop yield. In India, farmers' especially marginal farmers can get more profit from the same size of land by using biofertilizers viz., Nitrogen fixing bacteria, P solubilizes, etc. instead of application of chemical fertilizers alone (Beneficial microbes have been isolated and characterized, and their microbial formulations have been developedi.e. *Gluconacetobacter* is a nitrogen-fixing bacterium specific to sugarcane and is present inside the plant tissue as an endophyte). However, most farmers are not aware of it; therefore, to popularize this technology training should be provided to the farmers and this can be done through demonstration trial

- **Liquid bio fertilizers - A step forward to bio fertilizer technology:**

The advantages of liquid biofertilizers over powder based are that microorganisms have longer shelf life up to 2 years, generally they circumvent the effect of high temperature than $10^9 ml^{-1}$upto 12 months and better survive on seeds and soil, in addition, liquid biofertilizers are easy to use, handling and storage by farmers, the dosage is ten times less than that of powder form, it can be packed in different volumes and save carrier materials.

- **Drip irrigation:**

Drip irrigation saves 40-50% of water and gives 90-95% of irrigation efficiency, as compared to conventional methods of irrigation besides that it improved the soil health. Fertilizer application is also possible through this system; it saves the fertilizers up to 40% and increases the yield by up to 30%.

- **Agronomic practices:**

Timely implementation of agronomic practices is a key factor of higher cane productivity, including set treatment with fungicide and insecticide that reduces the incidence of pest**s** and diseases at the initial growth stage which offer healthy crop growth.

Light earthing up is carried out at 45-60 days after planting (DAP) when tillering starts, which helps to support the tillers, reduces the incidence of early shoot borer and fertilizer will **b**e mixed with soil.

At the grand growth stage crop needs support otherwise lodging occurs, effects on yield, so for that final earthing up is carried out at 120 DAP which helps to reduce the unnecessary tillers, reduces lodging and helps in soil aeration.

All the tillers cannot become good millable canes. 50 % of tillers converted into trash after final earthing up. Thus there is wastage of Nutrients, Irrigation water. Plant population in cane field should be maintained by removing the extra tillers after final earthing up operation.

- . **Crop Diversification and Intercropping:**

Selection of an appropriate intercrop variety as a component of cropping system acts as non-monetaryinputandnetprofitcouldbeincreasedwithoutinfluencingthecostofproduction The slow initial growth and wider row spacing in sugarcane offer great opportunity forgeneration of mid-season income to farmers by introducing short duration crops as intercrop. Theinclusionofshortduration,high value crops in sugarcane based production system as intercrops viz., potato, onion, coriander,mustard, cabbage, etc., holds great promise in increasing the land utilization efficiency, reducing the production cost, economizing the use of market purchased costly input sand making the system sustainable.

Sugarcane+ Cabbage **Sugarcane+ Potato**

- **Wider row planting:**

Besides increasing cane yield and better sugar recovery, the wider spaced planting of sugarcane also provides enough space to the farmers for taking inter-crop. Under sub-tropical conditions, during autumn season (mid Sept-mid Oct), planting/transplanting of sugarcane at **five feet** inter-row spacing can give better cane yield as well as provide space for various vegetables, cereals and pulses as intercrop during Rabi season. The **four feet** inter row spacing during spring (Feb-March), also gives higher cane yield than the conventional narrow spacing.

- **Plant protection:**

Sugarcane is a hardy crop but recently due to climate change crop have been attacked by several serious pest and diseases like red rot, smut, grassy shoot, pokkahboeng**,** white grub, shoot borer, wooly aphid and recently army worm attacked on large scale.We cannot increase the yield by controlling pest and disease but stop the losses caused by them, so for sustenance of the crop and ecosystem there must be integration of all the pest control measures (Chemical, Biological, physical) to keep the pest population below economic threshold level.

Use of Biological control of sugarcane pests to reduce the application of pesticides which hazardous to climate and water pollution.

- **Management of Drought:**

Under moisture stress the environment, planting method, trash mulching, weed management, organic application, K nutrition, use of drip method of irrigation are major components of water conservation in sugarcane. Under prevailing drought conditions, application of FYM @ 10 t/ha in furrows before planting, soaking setts in saturated lime water, trash mulching 60 days after planting, foliar spray of urea and KCl @ 2.5% at 90, 105 and 120 days after planting and an additional application of 60 kg K_2O/ha at 150–180 DAP are recommended to improve cane productivity.

Use of Trash mulching in sugarcane cultivation: Stop the burning of sugarcane trash

- **Mechanization of sugarcane agriculture**:

Sugarcane is a labour intensive crop which remains in the field for more than a year. The cost of cultivation of sugarcane has gone up significantly due to increase in cost of labour and inputs. Labour availability for major operations like harvest become scarce due to migration of labourers seeking urban employment. Sugarcane cultivation can be sustained only if profitability can be ensured through reduction in cost of cultivation and improvement in productivity. Settling Transplanting Technology, with wide row planting as an essential component, provides an opportunity for complete mechanization of sugarcane agriculture from planting to harvesting as tractor drawn implements for preparatory tillage, furrow opening, sett cutting, settling transplanting, inter culture operations, spraying of weedicides and insecticides, harvesting and ratoon operations are available.

Sugarcane Planter

Sugarcane Harvester

- **Scientific Ratoon management:**

Every year out of total sugarcane area 40% is under ratoon crop. Both farmers and mill owners are benefited by ratoon crop, by keeping the ratoon crop to save the production cost by 35-40% with increasing sugar recovery and cane yield. Following points to be considered for sustainable ratoonability (a) After harvesting of plant cane don't burn the remaining trash, it can be used as mulch in ratoon (b) To obtain better yield from ratoon, stubbles which remains above the ground level after harvest, needs to be shaved immediately at soil surface level. Infected stubbles must be removed and burned (c) Form one hectare of land we get 8-10 tons of trash which is a good source of organic manure, help in built of organic carbon and increases beneficial microbial population and nutrient availability (d) Wide row planting (4' and more), paired row planting (2.5' or 3') system are better to manage the trash in situ (e)

For faster decomposition of trash apply 80 kg urea, 100 kg SSP and 2.5 lit of decomposing culture per ha, also apply well decomposed manure, press mud @ 5-7 t/ha which accelerates the rate of decomposition.

- **Use of Drone Technology in sugarcane cultivation :**

Artificial intelligence and machine learning can be combined with NDVI (Normalized Difference Vegetation Index) imaging technology-based high resolution images captured by drones to develop understanding of soil conditions, plant health and crop yield prediction. Every individual plant can be located separately and analyzed using image processing algorithms, if it is stressed. Using this result, farmers can take preventive action to cease the spread of diseases to other crops. Timely actions can be taken to prevent losses from biotic stresses such as insect- pests and diseases, optimize fertilization, rationalize irrigation and reduce the impact of climate change and unpredictable weather using analyzed insights from data collected by drones and satellite-basedremotesensing.

Artificial intelligence (AI) has been seeing a lot of direct application in agriculture farming. In view of the importance use of Drone technology in agriculture for enhancing the productivity as well as efficiency of the Agriculture sector, Ministry of Agriculture & Farmers Welfare, Govt of India has published Official Memorandum and guidelines for providing agricultural services through drone application under the scheme Sub-Mission on Agricultural Mechanization (SMAM) including financial assistance (Drone Demonstration) & for establishment / upgrading the custom hiring centers/ hi-tech hub.

Conclusions:

India is the third largest fuel importing country in the world. With a view to reduce dependence on fuel imports, the central government has decided to mix 20 percent ethanol in petrol from 2023. By 2023, approximately one thousand crore liters of ethanol will be required for blending in petrol. About 625 crore liters of ethanol will be produced from molasses and sugar (50 LMT sugar diversion for ethanol) and the remaining ethanol (350-375 Crore liters) will be made available from surplus grain. In the country till 2013-14 the proportion of ethanol blending was between one and half percent. But now, as the government has increased the purchase of ethanol up to 380 crore liters, the factories are getting a huge financial reward.

According to central government statistics, the blending of ethanol in petrol is currently 10 percent. However, 18000 crore rupees have been made available to the sugar industry from ethanol. If the amount of mixture actually goes beyond 20 %, the same financial turnover will go up to almost Rs 50,000 crores. Therefore, the sugar industry is looking towards more future production of ethanol. At the same time, the problem of excess sugar production every year will be resolved. Sugar and ethanol production from sugarcane will benefit sugarcane growers too.

Due to National Biofuel Policy 2018, large scale production of ethanol will satisfy sugarcane farmers, sugar millers and the government at the same time. Most importantly, the use of ethanol blended petrol will help to control pollution and earn foreign exchange while rejuvenating the Indian sugar industry.

To alleviate the financial challenges & sustainability of the industry, in recent years, many sugar mills have shown interest in adoption of scientific approaches for Doubling Farmers Income in Sugarcane

Based Cropping System and diversifying their processing facilities to promote green energy production viz., Cogen, Bio-CNG, Bio-ethanol, etc.

References

1. Ramesh Chand and Yogesh Suri, 2021. Indian Sugar: Strategic Market Policy Reforms and Ethanol Driven Production, Proc. of National Seminar on Global Challenges and Innovative Approaches for Enhancement of Indian Sugar Industry, 27-28 March, 2021: 1-17 (Unpublished)
2. Road Map for Ethanol Blending in India 2020-25, NITI Aayog Report June, 2021
3. Cooperative Sugar Journal, Vol.54, September 2022, Sugar statistics.
4. Bakshi Ram (2019). Sugarcane varieties suitable for different states and impact of the extraordinary variety Co 0238 in sub-tropical India. Proc.of National Seminar on Challenges to Deliver Sustainability in the Indian Sugar Industry, NFCSF, New Delhi: pp21-30.
5. Reports Department of Food and Public Distribution, Govt of India,2019
6. Reports Ministry of Petroleum and Natural Gas, Govt of India, 2020
7. Annual Reports, 2019-20. Indian Institute of Sugarcane Research, Lucknow.
8. Reports Directorate of Economics and Statistics, Ministry of Agriculture and Farmers' Welfare, Govt of India, 2019-20.
9. Reports Cooperative Sugar Press News, Vol.50, No.44, Dec., 2019.

Chapter No. 39: Inclusion of pulses in sugarcane for sustaining crop yield and farmers' income

A.K. Tripathi[1], S.K. Shukla[2] and S.K. Dubey[3]
[1]Department of Agronomy, Banda University of Agriculture and Technology, Banda
[2]ICAR-Indian Institute of Sugarcane Research, Lucknowa
[3]ICAR-Agricultural Technology Application Research Institute, Zone III, Rawatpur, Kanpur
E-mail: aktripathiak@gmail.com

ABSTRACT

Crop diversification/ intensification provides a good opportunity for farmers to augment their income, fulfilling their multiple needs, avoid monsoon threats, and make the crop production system sustainable. Inclusion of various crops with spring/autumn planted sugarcane brings forth cultivation of these crops in irrigated agro-ecosystem and considerably improves the yields of all the component crops. In other words, exploiting the intercropping windows with sugarcane can enhance the area and productivity of the entire system besides improving profitability from the given land area. Adoption of crops like pulses, oilseeds, cereals, vegetables, potato, spices, flowers, etc. with two rows of autumn (October) planted cane (90 cm apart) also provided great scope for increasing crop productivity and farmers' income besides optimizing input use efficiencies in the system. Cost of production can be reduced and farmers' income may be increased with introduction of these crops in irrigated agro-ecosystem of country like India. Pulses constitute an important component of sugarcane-based cropping systems adopted by across the country with region specific variations in preferences and suitability to production conditions of different agro-ecosystems. Besides, inclusion of pulses as intercrop with sugarcane improve soil fertility and create a favorable environment for the further growth of sugarcane crops. Sprouting in winter-initiated sugarcane ratoon could be enhanced by including fodder legumes such as Indian clover and Egyptian clover. Resource use efficiencies, nutrient use, water use, and weed control could be increased by adopting suitable crops in intercropping systems. Intercropping of rajmash in autumn planted cane generate mid-season income and enhance the profitability of the system for small and marginal cane growers. Dual-purpose legumes viz., cowpea and mungbean as intercrops with spring-planted cane increase the pool of soil microbial biomass nitrogen capitalize allelopathic effects and sustain soil health. Significant increment in area and productivity of pulse crops is possible by intercropping of pulses with sugarcane. Thus, in irrigated agro-ecosystem, there is a great scope of increasing area under pulse crops through crop diversification/intensification besides improving their productivity.

Key words: Crop productivity, Farmers income, Intercropping, Pulses, Sugarcane

INTRODUCTION

Sugarcane is an important agro-industrial crop of India and plays vital role in national economy by contributing about 1.9 per cent to Indian GDP. India ranked 2nd after Brazil among sugarcane producing countries of the world and contributes about 18.80% in area and 20.73% in production of world (DAC&FW 2021). The area under sugarcane in India turns around 5.0 million ha at the national level with sugarcane productivity of about 78 t/ha during 2020 (Co-operative Sugar 2021) and total sugarcane production 392.80 million tonnes (PIB 2020–21). From 1980 to 2021, the total cropped area of pulses in India increased from 22.46 to 28.83 Mha. In 2020, production of pulses and also sugar have increased providing pulse 16.0kg per capita and sugar 18.8 kg per capita annually. Plateauing yield level, declining factor productivity and increasing production cost in recent years have posed serious concerns before cane growers and mill owners. In view of changing market scenario, consumers' preferences and global competitions, new income generating opportunities need to be created through crop diversification in sugarcane. This would help in increasing the land utilization efficiency, reducing the production cost, economizing the use of market purchased costly inputs and making plant-ratoon system sustainable.

Promotion of pulses as an intercrop or mixed crop viz., short duration thermoinsensitive varieties of mungbean/ urdbean with spring sugarcane offer great scope for additional production/income as well as nutritional security to farmers from the cultivated holdings.Introduction of pulses in the system also favours the growth of soil microbes, decreasing the risk of plant diseases and use of pesticides. Their integration in the crop rotation with cereals also helps in breaking the pest cycles, thereby contributing to improvement in the overall system productivity. Inclusion of pulses in crop rotations reduces the risks of soil erosion and depletion. Pulses as a cover crops contribute significantly towards higher rates of accumulation of soil carbon than cereals or grasses; and pulses inclusive crop rotations have a higher soil carbon sequestration potential than that of monocrop systems. Adoption of pulse crops with autumn-planted cane in furrow-irrigated raised-bed system keeping 90 cm row spacing of sugarcane apart where sugarcane crop is planted in furrows and component pulse crop like mungbean,urdbean, cowpea etc. is planted on raised beds, which offers great scope for increasing crop productivity and optimizing input use efficiencies in the system. Thus, cost of production could be reduced and profitability may be augmented with the inclusion of pulse crops in between two wider rows of sugarcane through additive series in irrigated agro-ecosystem, besides also improving soil fertility and sustainability for longer period in the system.

The Prime Minister of India gave a call to the nation of doubling farm incomes by 2022 by spelling out six point's strategy. Accordingly a Task Group has been formed by the Ministry of Agriculture to come out with a detailed plans and its operationalization. There is however, almost unanimity that the net income of farmers can surely be doubled well within the period of six years. A total of 40 recommendations for increasing incomes of farmers, have been divided into five parts, as increasing incomes by improving productivity, water and agri-input policies, integrated farming system, better market price realization, and special policy measures. In present paper, authors presented the opportunities of agronomic interventions for pulse crops in sugarcane-based system to improve the crop productivity, income and sustainability.Significant boost in area and productivity of pulses can possible by growing it as intercrop with sugarcane which is grown in more than 5.15 million ha area in the country. Thus, there is a tremendous scope of increasing area under pulses through crop diversification in sugarcane under Indian tropics and subtropics.Thus, there is a great scope of increasing area under pulses in irrigated agro-ecosystem through crop diversification/ intensification besides improving their productivity.

INTERCROPPING AND ITS EXPERIMENTAL DESIGNS

Intercropping is the practice of producing multiple crops in a given space and time with the aim to utilize available sunlight, water, nutrients, space and labour more efficiently. An intercropping system is one where two or more crops grow on the same piece of land simultaneously adopting a definite row arrangement. In many developing countries, more than half of the rainfed crops are normally intercropped. The system usually ensures that at least one crop will survive climatic problems to maturity, and it allows for a better distribution of labour requirements through the growing season (Willey, 1979a). In the last quarter of the twentieth century, agronomists and researchers started to realise that intercropping can often achieve a higher productivity per unit area per unit time than sole cropping system where each crop is grown alone, and that this system allows for a greater diversity of food production for consumption and for sale (Templ, 1976).

In intercropping, when two crops are to be grown together, they are chosen in such a way that there is variation in their growth duration. The peak periods of growth of the two crops species should not coincide. In such arrangements, a quick maturing crop completes its life cycle before the other crop starts. Willey (1979a&b) described the concept as temporal complementary *i.e.* greater differences in maturity and growth demands of the crop components; more opportunity is provided for greater exploitation of growth factors and over yielding. This will be achieved either by genetic difference in crop species or manipulation of planting dates. Normally short and long duration crops are grown together.

Based on the per cent of plant population used for each crop in intercropping system, it has two experimental designs viz., additive series and replacement or substitutive series:

(i) Additive series of intercropping

This system or design of intercropping is mostly adopted in India, where one crop is sown with 100% of its recommended plant population in pure/sole stand which is known as the main/base crop. Second crop known as intercrop is accommodated in between rows of base crop by adjusting or changing crop geometry. This system provides risk cover from natural calamities and bonus yield from intercrop without affecting base crop yield so that maximum land equivalent ratio (LER) may be achieved. LER of additive series is greater than replacement series. Additive series is more efficient than replacement series in intercropping system. For *e.g.*: sowing of pulses/potato/oilseeds/cereals/ vegetables/ spices in the field of autumn/spring-planted sugarcane between the two rows of cane.

(ii) Replacement or substitutive series of intercropping

In replacement design, both the crops are called component crops. In this design, by scarifying certain proportion of plant population of one component, another component is introduced. It means the plant population of both component crops is less than their recommended population in pure stand. This type of intercropping is practiced in developed countries. For *e.g.*: Cane (spring) + mungbean/urdbean (1:2), Cane (autumn) + potato (1:2), Cane (autumn) + wheat (1:3), Cane (autumn) + fieldpea (1:2).

INTERCROPPING WITH CANE

Intercropping in sugarcane is as old as 1887. Sugarcane offers a unique potential for intercropping in both the seasons i.e. autumn and spring particularly in Indo-Gangetic belt of Northern India. To ensure the optimum productivity of component crops in an intercropping system, one must ensure that the peak periods of growth of the two component crops do not coincide, so that one quick-maturing crop completes its life cycle before the main period of growth of the other crop starts (Saxena, 1972). Limitations are likely to be interspecies competition between the sugarcane and the intercrops for nutrients and water, as identified by Govinden and Arnason (1990), who affirmed that cane based intercropping systems can only overcome the problem of reduced cane yields by ensuring adequate irrigation of both the crops.

The autumn planted sugarcane based intercropping systems involving pulses, oilseeds, cereals and vegetables with their productivity and profitability levels have been identified in India.Pulses as intercrop in sugarcane could be recognized from the fact that they supplement nitrogen, suppress weeds, improve soil properties and sustain plant– ratoon system. Garside and Bell (1999) concluded that well-managed legume crops are best adopted to play an important role in sugarcane-based cropping systems. Intercropping of pulses in sugarcane add substantial quantity of nitrogen through mineralization after incorporation of the stalks of intercrops (Prakash and Hunsingi, 1994). Moreover, intercropping of winter pulses is tool to promote autumn planting of sugarcane giving 25-30% higher cane yield and 0.5 unit more sugar recovery than spring-planted cane and 40-50% more cane yield than late-spring planted crop (Rana *et al*., 2006). On the other hand, intercropping of mungbean/ cowpea in spring-planted cane can bring an additional one million hectare area under pulses in northern states with their increased productivity because of high yielding irrigated environment.

In cane intercropping, recommended optimum plant population of base crop i.e. sugarcane is suitably combined with an appropriate additional plant density of the associated crop, and there is crop intensification in both space and time dimensions. Andrews and Kassam (1976) have analyzed the prospects of intercropping and stated that world food supply through 'intercropping' in developing countries must be seen in prospective, i.e. it is the only one element that fights against poverty. The researches on intercropping have confirmed that small farmers in developing countries have been doing it for centuries and it makes efficient use of resources and generally provides yield advantage as compared to sole cropping (Willey, 1979b).

RESEARCH BACKSTOPPING

Intercropping permits more intensive cropping in a crop like sugarcane which is traditionally grown in 'single cropping system'. In normal sugarcane planting, the row spacing is usually 90 cm or more. The vacant space in between the rows can quickly be covered by weeds, which when allowed growing might eventually offer severe competition to the main crop. Instead of such a waste of available spaces, intercropping would offer opportunity for profitable utilization of such space while cutting down on the direct cost of cultivation of the main crop by reducing the expenditure on weed control. Number of workers (Webster and Wilson, 1966; Walters, 1971; Enyi, 1973) have reported that the more complete cover provided by intercropping reduces weed growth by competition. This results in the reduction in labour requirement for weeding. Sugarcane, characteristically widely spaced, initially slow-growing and long-duration crop, lends ample scope for intercropping with short-duration, high-value and mid-season income-generating crops for nutrition and economic security especially for small and marginal cane growers in India. The profits in intercropping with different intercrops have ranged from 12 to 34% (Lakshmikanthan, 1983). Some of the important pulse crops suitable for intercrop with sugarcane are given in Table 1.

Table 1. Pulse crops suitable for intercrops in sugarcane [*Source*: Shukla *et al*. (2016)]

Potential intercrop	Scientific name	Potential intercrop	Scientific name
(A) Tropical belt		*(C) Sub-tropical belt (Spring planting)*	
Mungbean	*Vignaradiata*L. Wilczek	Mungbean	*Vignaradiata*L. Wilczek
Urdbean	*Vigna mungo* L. Hepper	Urdbean	*Vigna mungo* L. Hepper
Cowpea	*Vignaunguiculata* L.	Cowpea	*Vignaunguiculata* L.
Soybean	*Glycine max* L. Merril	Dhaincha	*Sesbaniasesban*
(B) Sub-tropical belt (Autumn planting)		*(D) Sub-tropical belt (Ratoon cane)*	
Lentil	*Lens esculentus*Moench	Berseem—Egyptian clover	*Trifoliumalexandrinum*
French bean	*Phaseolus vulgaris* L.	Shaftal—Persian clover	*Trifoliumresupinatum*
Peas	*Pisumsativum*L.	Lucerne (Alfalfa)	*Medicago sativa*

Intercropping of Pulses with Autumn-Planted Sugarcane

About 15% of sugarcane area comes under autumn(October) planting in subtropical India. Here, after germination, the minimum temperature (>8–10°C) prevails inDecember and January due to the winter season. Crop growth triggers after improving the minimum temperature in the spring season (After February). In autumn, sugarcane, in subtropical India, tillering is almost ceased during the winter season (November–January), and it favours the growth of any other component crop/ intercrop. Although through several experiments, it has been proved that autumn crop could increase sugarcane yield by 20–25% over spring planting besides increasing sugar recovery by 0.5–1.0 units (Shukla *et al*.,2016). However, autumn planting could not be adopted to a more significant extent because of losing one winter season crop. In subtropical India, the duration of the autumn crop (15–16 month) vis-a`-vis the spring crop (12 month)focused much attention on farmers (Shukla *et al*., 2022).

Pulses are a rich source of protein and are known for quality food grains among the vegetarian community of the country. A significant increment in area and productivity of pulse crops could also be possible by intercropping these crops with autumn sugarcane.Intercropping of winter pulses may promote autumn planting of sugarcane on account of higher returns and better resource use efficiency. Legume intercrops in cropping systems enhance soil fertility through the excretion of amino acids into the rhizosphere. The nitrogen fixed by the legume intercrop may be made available to the associated sugarcane in the current season itself, as sugarcane remains in the field for over nine month after the harvest of the legumes. A further possibility of soil fertility improvement is through the addition of crop residues, which on decomposition adds to the fertility of the soil. Since considerable addition of nutrients occurs through intercrop, there is a possibility of reducing N application through fertilizer. Intercropping of pulses, viz. rajmash, chickpeaand lentil with autumn (October)-planted cane in the furrow-irrigated raised-bed system (FIRBS) fits well to improve the crop yields. Here, sugarcane is grown in furrows, and intercrops are planted on raised beds. The system provides excellent scope for increasing crop productivity and optimizing input use efficiencies. Intercropping french beans with autumn sugarcane has been found profitable at IISR Lucknow (Singh *et al*., 2020).

Autumn sugarcane intercropped with two rows of lentil (DPL 15) receiving 150 kg N ha^{-1} in combination with *Azospirillum* produced the highest sugarcane equivalent yield which was, however, comparable to suboptimal dose of 112.5 kg N ha^{-1} ((Lal and Singh, 2004)). These observations indicate that intercropping sugarcane with two rows of lentil could effect a saving of 37.5 kg N ha^{-1} (Shukla *et al*., 2016).Chickpea can be managed efficiently with autumn planted sugarcane and resulted in 25% N economy (Lal and Singh, 2004). Resource use efficiencies (nitrogen use efficiency, weed control efficiency, water use efficiency, etc.) and land equivalent ratio could be improved through intercropping pulse crops with sugarcane.

Intercropping of two rows french bean (PDR-14) showed distinct positive effect on sugarcane growth similar to potato in terms of shoot count at grand growth stage. Autumn planted sugarcane + rajmash has been reckoned remunerative as well as sustainable one due to nutrient synergies in the system and positive associative effects of rajmash on sugarcane growth and yield. Moreover, intercropped rajmash in autumn planted cane improved soil fertility through full leaf fall at pod maturity besides root mass addition. Sugarcane + rajmash intercropping system recorded the highest B: C ratio (2.16), followed by sugarcane + mustard (1.87), which was 45 and 25.5% higher than pure cropping of sugarcane (Shukla *et al*., 2016). At IISR, Lucknow, under National Agricultural technology Project on 'Intercropping of different crops with sugarcane', the highest cane equivalent yield (112.85 t ha^{-1}) was obtained in sugarcane + rajmash system as compared to other systems involving lentil, mustard and toria; however, the sole sugarcane recorded the lowest cane equivalent yield (76.33 t ha^{-1}) and B/C ratio (1.49) (Shukla *et al*., 2016). Further, rajmash grown as intercrop, being of shorter duration and heavily manured leave sizeable amount of unutilized plant nutrients for sugarcane. All these exhibited positive associative effects on sugarcane through development of synchronized tillers, longer, thicker and heavier millable cane.

Geetha*et al*. (2019) at Coimbatore recorded the profitability of the sugarcane + soybean intercropping system among the five legume intercrops in sugarcane. Sugarcane + soybean recorded a higher cane equivalent yield (CEY) of 132.0 t/ha, followed by sugarcane + mungbean (119.4 t/ha). Sugarcane + sun hemp has recorded a higher land equivalent ratio (LER) of 1.39, followed by mungbean (1.37) and soybean (1.21) when compared to the sole crop of sugarcane. Weed smothering efficiency (WSE) was significantly higher in the sugarcane + cowpea (36.3%) intercropping system, followed by sun hemp (32.3%) and soybean (32.0%) over the sole sugarcane (control).However, intercropping of winter pulses with autumn sugarcane optimizes higher net return with improved resource use efficiency. The compatibility of pulses as intercrop in autumn planted sugarcane for enhancing system productivity as well as profitability has also been documented (Table 2).

Table 2. System productivity and economic evaluation of autumn planted cane based pulse intercropping systems in sub-tropics.

Intercropping system	Sugarcane yield (t/ha)	Intercrop yield (t/ha)	Cane equivalent yield (t/ha)	B:C ratio	Source
Sugarcane sole	***85.2***	**-**	***85.2***	***1.63***	DAC&FW (2017)
Sugarcane + rajmash	86.8	1.94	132.8	2.54	
Sugarcane + lentil	76.5	1.16	99.0	1.73	
Sugarcane sole	***76.33***	**-**	***76.33***	***1.02***	IISR (2007-08)
Sugarcane + lentil	65.00	-	83.53	1.10	
Sugarcane + rajmash	83.00	-	112.85	1.53	
Sugarcane sole	***81.00***	_	***81.00***	**-**	Shukla *et al.* (2017)
Sugarcane + fieldpea	79.29	0.53	88.77	-	
Sugarcane + chickpea	77.08	1.17	95.20	-	
Sugarcane + rajmash	83.13	0.86	105.49	-	
Sugarcane sole	***81.00***	**-**	***81.00***	**-**	Sharma *et. al.*, 1992
Sugarcane + fieldpea	80.34	0.62	92.09	-	
Sugarcane + rajmash	78.14	0.72	99.85	-	
Sugarcane + chickpea	77.58	1.14	96.11	-	

Intercropping of Pulses with Spring-Planted Sugarcane

The pulse crops such as mungbean, urdbean and cowpea can grow as intercrops with spring planted sugarcane in northern India (Table 3). It is estimated that about one million hectare additional area can be brought under pulses by intercropping mungbean and urdbeanin spring-planted sugarcane especially in UP, north Bihar, Punjab and Haryana (Shukla *et al*., 2016). Experiments conducted at IISR Lucknow proved that after picking green pods for vegetable and/or mature pods for grains, the legume plants with longer leaf area duration are incorporated in the soil between the inter-row spaces of sugarcane as green manure. These systems effect nitrogen economy in sugarcane to the extent of 35–40 kg ha^{-1} besides producing bonus yield of pulses (Shukla *et al*., 2016). Among dual-purpose legumes, the highest net monetary return ($ 1208) worked out for sugarcane + mungbean (K-851 for grains) system, followed by sugarcane + cowpea (PusaKomal for green pods), i.e. $ 1134/ha (Singh *et al*., 2020).Findings at IISR, Lucknow have indicated 13% increase in the cane yield of first ratoon due to the residual effects of *Sesbania* intercropped green manuring without adversely affecting the plant cane (Shukla *et al*., 2016).

Intercropping of spring-planted cane with grain legumes such as mungbean, urdbean, cowpea increases soil organic matter, total N and available P, but its effect was not conspicuous on cane yield in many cases. The compatibility of intercrops varies with the row arrangements (Yadav *et al*., 1987) and genotypes selected as intercrop in the system (Lal *et al*., 2000). At Lucknow, sugarcane + mungbean in 1:2 row arrangements caused 23% reduction in tillering, while urdbean in same row system reduced tillering only by 6% (Yadav, 1991). In another field study from IISR Lucknow, mungbean as an intercrop with spring-planted sugarcane yielded 2.6 quintals grain/ha, almost equivalent to 4.18 tonnes of cane/ ha. Sugarcane growth and yield were also not affected adversely.

Table 3. System productivity and economic evaluation of spring planted cane based pulse intercropping systems in sub-tropics.

Intercropping system	Sugarcane yield (t/ha)	Intercrop yield (t/ha)	Cane equivalent yield (t/ha)	B:C ratio	Source
Sugarcane sole	77.3	-	77.3	1.38	DAC&FW (2017)
Sugarcane + cowpea (green pods)	75.2	2.90	90.4	1.48	
Sugarcane + mungbean	76.6	0.57	91.6	1.54	

Sugarcane Ratooning and Intercropping

Sprouting of winter initiated ratoon is the major constraint in ratooning under subtropical conditions. The problem is more acute in high-sugar early-maturing varieties. The management strategy lies in keeping the metabolic activities of stubble buds alive till the commencement of favourable temperature regime. Intercropping of high-density early-bulking forage crops (Egyptian clover/Indian clover) enhances bud sprouting in winter initiated ratoon by regulating rhizospheric thermal regime through root respiration and serving as live mulch to protect sprouts from frost/cold damage during severe winter and encourage the sprouting of subterranean buds during the winter season (Shukla *et al*., 2007). Studies reported from IISR, Lucknow further revealed that subsequent ratoon raised from mungbean intercropped, plant crop recorded 18-20 t ha^{-1} higher stalk yield than that raised from sole sugarcane.In winter-initiated ratoon, intercropped berseem (*Trifoliumalexandrinum*) after cutting for fodder left the highest amount of available nitrogen in soil (243.5 kg/ha in 0 to 15 cm and 233.60 kg/ha in 15 to 30 cm soil layer) (Shukla *et al*., 2016).In a recent study, intercropping of lentil in autumn-planted sugarcane increased the number of millable canes and yield of successive ratoon as compared to ratoon initiated from sole sugarcane (Singh *et al*., 2005; Shukla *et al*., 2013). Further, intercropping of dual-purpose legumes viz., cowpea and mungbean in spring-planted sugarcane showed significant carry-over effect in increasing the ratoon yield at IISR, Lucknow (Shukla *et al*., 2016). Intercropping of pulses in winter initiated ratoon provides scope of intervention which can increase ratoon cane yield also besides increasing area and production of pulse crops (Table 4).

Table 4. System productivity and economic evaluation of winter initiated ratoonbased pulse intercropping systems in sub-tropics.

Intercropping system	**Sugarcane yield (t/ha)**	**Intercrop yield (t/ha)**	**Cane equivalent yield(t/ha)**	**B:C ratio**	**Source**
Sugarcane ratoon sole	***73.2***	**-**	***73.2***	***1.40***	DAC&FW (2017)
Sugarcane ratoon + berseem	79.4	56.8	109.3	2.43	
Sugarcane ratoon + shaftal	77.9	54.7	106.7	2.35	
Sugarcane ratoon + Lucerne	72.6	41.2	94.3	1.96	

Intercropping and Juice Quality

Results revealed that the different intercrops had no significant effect on juice quality parameters, especially sucrose content in cane juice which varied from 15.93 to 19.0% in other systems. These results align with those reported by Rathi and Singh (1979), Shukla and Pandey (1999) and Li *et al*. (2011). Srivastava *et al*. (2015) analysed the positive effect on sucrose percent juice (by 0.5 units) due to the adoption of intercropping system with an autumn cane as compared to a spring cane. No adverse effect of sugarcane main crop/ratoon crop on the quality of intercrop (component crop) has been reported. Further, sugar content in ratoon cane initiated from intercropped plant cane was observed to be higher ranging from 0.38 to 0.57 U over that from sole sugarcane (Shukla *et al*., 2016).

Experiences from Farmers' Fields

Muzaffarnagar area of Uttar Pradesh falling under Indo-gangatic plains is a predominant sugarcane growing belt of the country. In this region, the working experiences with farmers on intercropping different winterand springcrops in sugarcane has been found tremendous. On-farm demonstrations conducted across the districts of Muzaffarnagar (western part of the country) had confirmed that whereas sole sugarcane crop yielded the net profit of ₹ 102 thousand ha^{-1}, the additional income were to the magnitude of ₹ 130 thousand ha^{-1} when intercropped with french bean (Table 5). As a result, this combination has become popular among 12450 cane growers of 201 villages of the district covering about 7650 ha area. Similarly, intercropping of mungbean with sugarcane also gave the additional income of ₹ 25 thousand ha^{-1}; whereas urdbean gave the additional income of ₹ 17 thousand ha^{-1}. However, farmers preferred to grow urdbean over mungbean owing to their prevailing dietary preferences.

Table 5. On-farm experiences of sugarcane based intercropping systems (case of Muzaffarnagar, India) (2010-15)

S. No.	Intercropping systems	Net Return (000 ₹ ha^{-1})	% increase in net return over sole cane	Remarks
1	Sole sugarcane (autumn planted) Sugarcane + french bean	102.00 232.00	- 127.4	Popular among 12450 growers of 201 villages covering 7650 ha of area
2	Sole sugarcane (spring planted) Sugarcane + mungbean Sugarcane + urdbean	87.00 112.00 104.0	- 28.7 19.5	Farmers have more preferences for sugarcane + urdbean intercropping system

Source: Field studies by ICAR-ATARI, Kanpur-unpublished

Likewise, in Narsen block of Haridwar district of Uttarakhand, the on-farm demonstrations were laid for intercropping of *kharif*urdbean with sugarcane in the area of 5.0 ha. . The Inter-row distance for sugarcane was kept at 125 cm and on vacant space in between two rows of sugarcane, two lines of urdbean was sown at the distance of 30 cm width with all recommended package of practices for sugarcane. The results showed the average demonstration yield obtained for intercropped urdbean as 9.5 q/ha with sugarcane yield of 8.45 t/ha (Anonymous, 2012)

CONCLUSIONS

Since last five decades in India, improvement in productivity of most of the field crops has been significant but there is need to put more area of these crops under cultivation to meet the future demand of food of ever increasing population of the country. In irrigated agroecosystem, there is an excellent scope of the increasing area under pulse crops through crop diversification/intensification through space and time dimensions besides improving their productivity. Resource use efficiencies (nitrogen use efficiency, weed control efficiency, water use efficiency, etc.) and land equivalent ratio could be improved through intercropping pulse crops with sugarcane. Intercropping also controls weed growth and can minimize chemicals besides economizing other inputs. Sugarcane growers can take advantage of this and grow various short-duration crops like cereals, pulses, vegetables, and spices as intercrops to obtain an interim return. It would be anticipated that successful cane based intercropping systems would allow the small scale growers to produce food crops for consumption and for sale in the rural areas, which would considerably improve their income, cash flow situation, and might encourage some of them back into fulltime farming. Cost of production could be reduced and profitability could be increased by adopting mechanization as various tractor-drawn implements for planting of sugarcane and component crops have been developed. Intensification of crop on time and space dimension in the system by selecting short duration, non-competitive crops and method of planting adopted had not suppressed growth of base crop (sugarcane) and produced statistically as much as equal sugarcane yield. In addition, production of pulse crops, which favoured higher economic return**.** Despite the fact that intercropping is one of the productive and profitable option that can utilize natural resources like sun and soil efficiently. Its technology has been almost perfected, but the system is not being followed by sugarcane growers on a large scale in India. Now, it is the high time for practicing this highly profitable systems by the cane farmers so that our government mission of "doubling farmers' income" can be achieved.

ACKNOWLEDGMENTS

Authors are grateful to Department of Agronomy, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, ICAR-Agricultural Technology Application Research Institute, Kanpur and ICAR-Indian Institute of Sugarcane Research, Lucknow, for providing research information on the subject.

REFERENCES

Andrews, D.J., and A.N. Kassam. 1976. The importance of multiple cropping in increasing world food supplies. In Multiple cropping, ed. R.K. Papendic, P.A. Sanche and G.B. Triplett, 1–10. Madison: American Society of Agronomy.

Anonymous 2012. Annual Report. Zonal Project Directorate, Zone IV, Kanpur

DAC&FW. 2017. Doubling Farmers' Income, Volume VIII. Production enhancement through productivity gains. Department of Agriculture, Cooperation and Farmers' Welfare, Ministry of Agriculture & Farmers' Welfare, pp. 94.

DAC&FW. 2021. Agricultural Statistics at a Glance 2021. Government of India, Ministry of Agriculture & Farmers Welfare, Department of Agriculture, Cooperation & Farmers Welfare, Directorate of Economics & Statistics.

Enyi, B.A.C. 1973. Effect of plant population on growth and yield of soybeans. *Journal of Agricultural Sciences* 18: 131–138.

Garside, A.L., and M.J. Bell. 1999. The potential for legumes in sugarcane cropping system in Australia. Proceedings ISSCT, New Delhi, 23: 100–106.

Geetha, P., A.S. Tayade, C.A. Chandrasekar, T. Selvan, and Rajesh Kumar. 2019. Agronomic response, weed smothering efficiency, and economic feasibility of sugarcane and legume intercropping system in tropical India. Sugar Tech 21: 838–842.

Govinden, N., and J.T. Arnason. 1990. The relative importance of competition for water and for light in intercropping of sugar cane with maize. Agriculture Water Management 17: 233.

IISR. 2007–08. Annual Report, Report of NATP PSR 21. Managementof intercrops with sugarcane, Indian Institute of SugarcaneResearch, Lucknow. 7–13.

Lakshmikantham, M. 1983. Technology of sugarcane growing. New Delhi: Oxford and IBH Publication.

Lal, Menhi, and A.K. Singh. 2004. Technology package for sugarcane-based intercropping systems. Lucknow: Published byIndian Institute of Sugarcane Research.

Li, Z.X., J.W. Wang, W.T. Yang, Y.H. Shu, Q. Du, L.L. Liu, and L. Shu. 2011. Effects of reduced nitrogen application on the yield, quality, and economic benefit of sugarcane intercropped with soybean. Ying Yong Sheng Tai XueBao 22: 713–719. (Chinese).

PIB. 2020–21. PIB Press release. https://economictimes. indiatimes.com/news/economy/agriculture/isma-keeps-indias-2021-22-sugar-production-unchanged-at-310-lakh-tonnes/article show/84405713.cms; https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1721692.

Prakash, H.R., and G. Hunsigi. 1994. Effect of incorporation of intercropped legumes and nitrogen levels on yield of sugarcane. In: Proceedings. Seminar: emerging technologies for sustainable crop production, edsShivashankar, K. and Singlachar, M.A., University of Agricultural Sciences, Bangalore, pp. 44–45.

Rana, N.S., Sanjai, Kumar, S.K. Saini, and G.S. Panwar. 2006. Production potential and profitability of autumn sugarcane-based intercropping systems as influenced by intercrops and row spacing. *Indian Journal of Agronomy* 51(1): 31-33.

Rathi, K.S. and R.A. Singh. 1979. Companion cropping with autumn planted sugarcane. *Indian Sugar Crop Journal* 69: 76–82.

Saxena, M.C. 1972. Concept of parallel multiple cropping. Proceedings of a Symposium on multiple cropping, New Delhi. Indian Society of Agronomy.

Sharma, R.K., K.S. Bangar, S.R., Sharma, H.B. Grewal, and O.P. Rathore. 1992. Comparative performance of intercropping pulses in sugarcane under south western M.P. *Indian Journal of Agronomy* 37: 95 -96.

Shukla, S.K., A.K. Archna Suman, RL Yadav. Singh, and Menhi Lal. 2007. Organic nutrition for sustaining soil health, improving rhizospheric environment, and sugarcane yield in India. In Sugar Beet Crops: Growth, Fertilization & Yield, ed. Claus T. Hartsburg, 1–29. USA: Nova Science Publishers Inc.

Shukla, S.K., and M.B. Pandey. 1999. Feasibility of inclusion of mustard (*Brassica juncea*) genotypes in intercropping andsequential cropping sytems with sugarcane (*Saccharumofficinarum*). *Indian Journal of Agricultural Sciences* 69: 247–250.

Shukla, S.K., K.K. Singh, A.D. Pathak, V.P. Jaiswal, and S. Solomon. 2016. Crop diversification options involving pulses and sugarcane for improving crop productivity, nutritional security and sustainability in India. *Sugar Tech* 19(1): 1–10. DOI 10.1007/s12355-016-0478-2.

Shukla, S.K., Lalan Sharma, V.P. Jaiswal, A.P. Dwivedi, S.K. Yadav and A. D. Pathak. 2022. Diversification Options in Sugarcane-Based Cropping Systemsfor Doubling Farmers' Income in Subtropical India. Sugar Tech.https://doi.org/10.1007/s12355-022-01127-1.

Shukla, S.K., S.K. Awasthi, R. Singh, M. Nigam, A. Gaur, and A.K. Singh. 2013. Integrated nutrient management in sugarcane-based production systems: A review. *Current Advances in Agricultural Sciences* 5: 1–7.

Singh, A.K., A.D. Pathak, T.K. Srivastava, R.K. Singh, A.K. Singh,A.K. Singh, Ekta Singh, R.K. Singh, A.K. Sharma, and M.M.S.P.Rai Singh. 2020. Sugarcane based integrated farming systemmodels for enhancing farmers' income and livelihoods. *IndianFarming* 70 (05): 02–06.

Singh, A.K., Menhi Lal, and A.K. Singh. 2006. Production potential and economic viability of sugarcane (*Saccharum* spp. Hybrids)—based crop diversification options in the North zone of sub-tropical India. *Indian Journal of Sugarcane Technology* 2: 23–26.

Singh, A.K., Menhi Lal, and M. Singh. 2005. Productivity and profitability of autumn-sugarcane based plant-ratoon system through lentil intercropping, nitrogen nutrition and biofertilizers. *Indian Journal of Sugarcane Technology* 20: 1–5.

Srivastava, T.K., A.K. Singh, and I. Singh. 2015. Sugarcane. In textbook of field crops production: Commercial crops, ed. R. Prasad, 441–468. New Delhi: ICAR Publication.

Temple, S.R. 1976. Adapting varieties for intercropped systems in the tropics. pp 235-254 In: RI Papendick, PA Sanchez and GB Triplett (Eds) Multiple Cropping. American Society of Agronomy, Madison, Wisconsin, USA.

Walters, R.F. 1971. Shifting cultivation in Latin America. Food and Agricultural Organisation, Forest Development, paper 17, p 305, FAO, Rome.

Webster, C.C., and P.N. Wilson. 1966. Agriculture in tropics. London, Longman, U.K.

Willey, R.W. 1979a. A scientific approach to intercropping research. Proceedings of an International Workshop on Intercropping, ICRISAT, Hyderabad, India.

Willey, R.W. 1979b. Intercropping—its importance and its research needs. I Competition and yield advantage. Field Crops Abstracts 31: 1010.

Yadav, R.L. 1991. Agronomy of sugarcane: Principles and practices. Lucknow: International Book Distributing Company, Ltd. p31.

Yadav, R.L., S.R. Prasad, and K. Singh. 1987. Fertilizer requirement and row arrangement of pulses in sugarcane based cropping systems. *Indian Journal of Agronomy* 32: 80–84.

Chapter No. 40: Sugarcane based integrated farming system for sub-Tropical India

A.P. Dwivedi, S.K. Shukla, Ambuj Kumar Shukla,RajendraKumar, Ankur Tripathi[2], Shivam Tripathi[3]
ICAR- Indian Institute of Sugarcane Research, Lucknow, Uttar Pradesh.
[2]Research Scholar-ANDUA&T,Ayodhya;
[3]Research Scholar-CSAUA&T,Kanpur,U.P.

Introduction:

Integrated farming system is one of the important principles for achieving the goal of higher yields of different component crops and enterprises, livelihood security, soil health management, nutritional security, by-product recycling, eco-friendly farming/agri-system, employment generation throughvarious component/enterprises throughout the year by adapting principles of the sustainable agriculture.Sugarcane cultivation in India dates back to pre-Vedic period and presently the country stands second largest producer of sugarcane (355.0mt) and sugar (more than 32.0mt) in the world after Brazil. In India Evolution of‘ Co’cane sand scientific interventions in terms of its production and protection technologies as well as farm mechanization and use of new farm implements, tools have revolutionized the sugarcane cultivation with the result than present productivity level ranges from 78t/ha in subtropics to 85t/ha in tropics on total acreage of over 4.77 mha with productivity of 74.4t/h area lizedat the national level. Cost of inputs in this long duration crop is very high. The profitability of sugarcane farmers and its productivity may be increased by crop diversification, intercropping, additional more local feasible need-based enterprises and crops resulting livelihood security, soilhealthimprovement, nutritional security, by-product recycling, eco-friendly farming/sugarcane basedagri-system.This system will help employment generation through various components/enterprises through out the year.

Model of Sugarcane Based Integrated Farming System:

Keeping above points, ICAR-IISR, Lucknow has planned and execute the sugarcane based integrated farming systems in celastthree years (2019-20 to 2021-22).The highlights of recommendations up to this stage are presented below-

Autumn planted Sugarcane Based Integrated Farming System -

- Sugarcane alone-Rs, 262600/ha.
- Sugarcane + Vegetables (Garlic, Fenugreek, Coriander, Tomato, Cauliflower,Spinach, Carrot, Fababean, Onion) fetched net income of Rs.317214 /ha.
- Sugarcane + Vegetables (Garlic, Fenugreek, Coriander, Tomato, Cauliflower, Spinach, Carrot, Fababean, Onion) + Horticultural Crop (Banana) +Backyard Poultry (Breed-Asheel, Nirbheek, Kadaknath, Quail) + Mushroom + Fisheries (Rohu, Catla, Nain) + Vermicompost (*Eisenia fetida*) + Apiculture+ Mushroom fetched net income Rs.344110 /ha.
- Sugarcane + Vegetables (Garlic, Fenugreek, Coriander, Tomato, Cauliflower, Spinach, Carrot, Fababean, Onion) + Horticultural Crop (Banana) +Backyard Poultry (Breed-Asheel, Nirbheek, Kadaknath, Quail) + Mushroom + Fisheries (Rohu, Catla, Nain) + Vermicompost (*Eisenia fetida*) + Apiculture + Dairy Unit (02 Cows) fetched net income Rs.436806 /ha. and fetched additional income of Rs.**208386**/ha.

Spring planted Sugarcane Based Integrated Farming System -

- Sugarcane alone (Var. CoPk 05191)-Rs.256000/ha.
- Sugarcane + Vegetables (Bottle gourd, Sponge gourd, Tomato, Brinjal, Pumpkin, Onion,) fetched net income of Rs.312677 /ha.
- Sugarcane + Vegetables (Bottle gourd, Sponge gourd Tomato, Brinjal, Pumpkin, Onion) +

Horticultural Crop (Banana) + Backyard Poultry (Breed- Asheel, Nirbheek, Kadaknath, Quail) fetched net income of Rs.334247 /ha.

- Spring planted Sugarcane Based Integrated Farming System- The results clearly indicate that Spring planted Sugarcane Based Integrated Farming System as Sugarcane+Vegetables (Bottlegourd, Spongegourd, Tomato, Brinjal, Pumpkin, Onion, Maize, Fenugreek, Pachoi, Chinesegobhi) + Horticultural Crop (Banana, Karonda, Papaya) + Backyard Poultry (Breed- Asheel, Nirbheek, Kadaknath, Quail) + Fisheries (Rohu, Catla, Nain) + Vermicompost (*Eiseniafetida*) + Apiculture + Mushroom + Dairy Unit (02 Cows) fetchednetin come of Rs. 462412/ ha. and fetched additional income of Rs.**165561**/ha.

Table: 1 (a). Productivity and Profitability of different components of the cropping/farming system integrated with sugarcane (Autmn planted Sugarcane).

S. No.	Cropping/Farming systems	Cost of Production (Rs/ha.) 2019-20	Cost of Production (Rs/ha.) 2020-21	Cost of Production (Rs/ha.) 2021-22	Cost of Production (Rs/ha.) Mean	Gross Income (Rs/ha.) 2019-20	Gross Income (Rs/ha.) 2020-21	Gross Income (Rs/ha.) 2021-22	Gross Income (Rs/ha.) Mean	Net Income (Rs/ha.) 2019-20	Net Income (Rs/ha.) 2020-21	Net Income (Rs/ha.) 2021-22	Net Income (Rs/ha.) Mean
1.	Sugarcane (Sole) var. CoLk 09204	165000	165000	165000	165000	432500	424200	426100	427600	267500	259200	261100	262600
2.	Sugarcane + Vegetables (including horti.crops) Throughout year	173400	185450	186900	181916	476540	509552	511300	499130	303140	324102	324400	317214
3.	Sugarcane + Vegetables (including horti. crops) Throughout year + Backyard poultry	182500	195450	196300	191416	497870	552312	556400	535527	315370	356862	360100	344110
4.	Sugarcane + Vegetables Throughout year (including horti. crops) + Backyard poultry + Fisheries + Vermicopost + Apiculture + Mushroom + Dairy Unit	198900	203900	204100	202300	572880	666312	667123	635438	373980	462412	463023	433180
Total additional income 2019-20. Rs.106780, 2020-21 Rs. 203212 ;2021—22 Rs.201923/ha ;AV. Rs. 208386 /ha.,													

Table: 1 (b). Productivity and profitability of different components of the cropping/farming system integrated with sugarcane (Autmn planted Sugarcane)

S. No.	Cropping/Farming systems	Income from component crop/enterprise (Rs/ha.) or enterprises/unit 2019-20	Income from component crop/enterprise (Rs/ha.) or enterprises/unit 2020-21	Income from component crop/enterprise (Rs/ha.) or enterprises/unit 2021-22	Income from component crop/enterprise Mean	B:C Ratio 2019-20	B:C Ratio 2020-21	B:C Ratio 2021-22	B:C Ratio Mean
1.	Sugarcane (Sole) var. CoLk 09204	-	-	-	-	2.62	2.57	2.58	2.59
2.	Sugarcane + Vegetables (including horti.crops) Throughout year	35640	64902	63300	54614	2.74	2.74	2.73	2.74
3.	Sugarcane + Vegetables (including horti. crops) Throughout year + Backyard poultry	12230	32750	35700	22495	2.72	2.82	2.83	2.79
4.	Sugarcane + Vegetables Throughout year (including horti. crops) + Backyard poultry + Fisheries + Vermicopost + Apiculture + Mushroom + Dairy Unit	58610	105550	102923	89027	2.88	3.26	3.26	3.14
		106780/ha.	**203212/ha**.	**201923/ha**	**154996/ha.**				

Table : 2(a). Productivity and Economic feasibility of different components of the cropping/farming system integrated with sugarcane in Autumn Season

Sr. No.	Crop/enterprises	Area allocation (ha.)	Production (kg/q/t/ha.) 2019-20	Production (kg/q/t/ha.) 2020-21	Production (kg/q/t/ha.) 2021-22	Production (kg/q/t/ha.) Mean	Cost of production (Rs./ha.) 2019-20	Cost of production (Rs./ha.) 2020-21	Cost of production (Rs./ha.) 2021-22	Cost of production (Rs./ha.) Mean
1.	Sugarcane (Sole) CoLk 11206	0.8ha.	80 t.	82 t.	82.5 t.	81.5 t.	165000	166200	166980	166060
2.	**Vegetables Crops**									
	Garlic, Fenugreek Coriander, Brinjal, Green, Chili, Cabbage, Pea, Soya, Sauf, Bottle guard,Tomato, Cauliflower, Spinach, Carrot, Fababean, Onion, Okra, Cowpea, Banana (Vegetable purpose), Papaya, Cucurbit	0.09ha.	**8 q.**	8.23 q.	8.01 q.	8.08 q.	17500	18600	18900	18333
3.	Maize	0.01ha.	2223 nos.	**2245 nos.**	2260 nos.	2242 nos.	2300	2352	2385	2345
Total		0.1 ha					19800	20952	21285	20679
Grand Total all crops and enterprises including		1.0ha.					184800	187152	188265	186739

Table: 2(b). Productivity and Economic feasibility of different components of the cropping/farming system integrated with sugarcane in Autumn Season

Sr. No.	Crop/enterprises	Gross Income (Rs./ha.) 2019-20	Gross Income (Rs./ha.) 2020-21	Gross Income (Rs./ha.) 2021-22	Gross Income (Rs./ha.) Mean	**Net Income (Rs/ha.) 2019-20**	**Net Income (Rs/ha.) 2020-21**	**Net Income (Rs/ha.) 2021-22**	**Net Income (Rs/ha.) Mean**	**B:C Ratio 2019-20**	**B:C Ratio 2020-21**	**B:C Ratio 2021-22**	**B:C Ratio Mean**
1.	Sugarcane (Sole) CoLk 11206	332500	348500	349100	343366	**167500**	**182300**	**182120**	**177306**	1.62	2.01	2.09	2.06
2.	**Vegetables Crops**												
	Garlic, Fenugreek Coriander, Brinjal, Green, Chili, Cabbage, Pea, Soya, Sauf, Bottle guard,Tomato, Cauliflower, Spinach, Carrot, Fababean, Onion, Okra, Cowpea, Banana (Vegetable purpose), Papaya, Cucurbit	33500	56392	59601	44946	**16000**	41442	**41442**	**28721**	0.91	1.91	3.15	2.45
3.	Maize	3598	3650	3705	3651	1298	1298	1320	1306	0.18	1.55	1.55	1.55
	Total	37098	408542	63306	48597	17298	42740	42762	30027	0.90	1.82	2.26	2.02
	Grand Total all crops and enterprises including	359598	408543	412406	391963	184798	225040	224882	243621	1.94	2.18	2.19	2.09

Table: 3(a). Productivity and Profitability of different components of the cropping/farming system integrated with sugarcane (spring planted Sugarcane)

S.No	Cropping/Farming systems	Area (ha.)	Cost of Production (Rs/ha.) 2019-20	Cost of Production (Rs/ha.) 2020-21	Cost of Production (Rs/ha.) 2021-22	Cost of Production (Rs/ha.) Mean	Gross Income (Rs/ha) 2019-20	Gross Income (Rs/ha.) 2020-21	Gross Income (Rs/ha.) 2021-22	Gross Income (Rs/ha.) Mean	Net Income (Rs/ha.) 2019-20	Net Income (Rs/ha.) 2020-21	Net Income (Rs/ha.) 2020-21	Net Income (Rs/ha.) Mean
1.	Sugarcane (Sole) var. CoLk 09204	1.60	160000	160000	160000	160000	416000	415800	416200	416000	256000	255800	256200	256000
2.	Sugarcane + Vegetables (including horti. crops) Throughout year	1.79	171000	172480	174300	172593	458990	497520	499300	485270	287940	325040	325000	312677
3.	Sugarcane + Vegetables (including horti. crops) Throughout year + Backyard poultry	1.89	178500	182480	183500	185636	478470	540280	540899	519883	299970	357800	357399	334247
4.	Sugarcane + Vegetables Throughout year (including horti. crops) + Backyard poultry + Fisheries + Vermicompost + Apiculture + Mushroom + Dairy Unit	2.0	185930	190930	192100	189653	569920	654280	655179	626459	355830	453350	463079	436806
Total additional income 2019-20. Rs.99830, 2020-21 Rs.197550 ; 2021-22 Rs.199304/ha; AV. Rs. 165561/ha.														

Table: 3(b). Productivity and Profitability of different components of the cropping/farming system integrated with sugarcane (spring planted Sugarcane)

S.No	Cropping/Farming systems	Income from component crop/ enterprise (Rs/ha.) or enterprises /unit 2019-20	Income from component crop/ enterprise (Rs/ha.) or enterprises /unit. 2020-21	Income from component crop/ enterprise (Rs/ha.) or enterprises /unit. 2021-22	Income from component crop/ enterprise (Rs/ha.) or enterprises /unit. Mean	B:C Ratio 2019-20	B:C Ratio 2020-21	B:C Ratio Mean
1.	Sugarcane (Sole) var. CoLk 09204	-	-	-	-	2.6	2.59	2.60
2.	Sugarcane + Vegetables (including horti. crops) Throughout year	31940	69240	70105	57095	2.68	2.88	2.81
3.	Sugarcane + Vegetables (including horti. crops) Throughout year + Backyard poultry	12030	32760	33201	25997	2.68	2.96	2.80
4.	Sugarcane + Vegetables Throughout year (including horti. crops) + Backyard poultry + Fisheries + Vermicompost + Apiculture + Mushroom + Dairy Unit	55860	95550	95998	82469	2.91	3.37	3.30
		Rs. 99830/ha.	**Rs. 197550 /ha.**	**Rs.199304/ha**	**Rs. 165561/ha.**			

Table: 4(a). Productivity and Economic feasibility of different components of the cropping/farming system integrated with sugarcane in spring season.

Sr. No.	Crop/ enterprises	Area allocation (ha.)	Production (kg/q/t/ha.) 2019-20	Production (kg/q/t/ha.) 2020-21		Production (kg/q/t/ha.) Mean	Cost of production (Rs./ha.) 2019-20	Cost of production (Rs./ha.) 2020-21		Cost of production (Rs./ha.) Mean	Gross Income (Rs./ha.) 2019-20	Gross Income (Rs./ha.) 2020-21	Gross Income (Rs./ha.) Mean
1.	Sugarcane (Sole) CoLk 11206	0.8ha.	79.t	80 t.		79.5 t	168400	169200		168800	335750	340900	338325
		2. Vegetables Crops											
	Garlic, Fenugreek Coriander, Brinjal, Green, Chili, Cabbage, Pea, Soya, Sauf, Bottle guard, Tomato, Cauliflower, Spinach, Carrot, Fababean, Onion, Okra, Cowpea, Banana (Vegetable purpose), Papaya, Cucurbit	0.1ha.	1294	1348			10650	10784		10717	45060	46555	45807.5
	Maize		830 nos.	847 nos.							4150	4235	
	Total						10650	10784		10717	49210	50790	50000
	Grand Total all crops and enterprises including	1.0ha.					182500	184800		179517	384960	391690	384132.5

Table: 4(b). Productivity and Economic feasibility of different components of the cropping/farming system integrated with sugarcane in spring season.

Sr. No.	Crop/ enterprises	Area allocation (ha.)	Net Income (Rs/ha.) 2019-20	Net Income (Rs/ha.) 2020-21	Net Income (Rs/ha.) Mean	B:C Ratio 2019-20	B:C Ratio 2020-21	B:C Ratio Mean
1.	Sugarcane (Sole) CoLk 11206	0.8ha.	167350	171700	169525	0.99	1.01	1.00
2.	**Vegetables Crops**							
	Garlic, Fenugreek Coriander, Brinjal, Green, Chili, Cabbage, Pea, Soya, Sauf, Bottle guard, Tomato, Cauliflower, Spinach, Carrot, Fababean, Onion, Okra, Cowpea, Banana (Vegetable purpose), Papaya, Cucurbit	0.1ha.	34410	17885.5	26147.7	3.23	1.65	2.43
	Maize							
	Total		34410	17885.5	26147.7	3.23	1.65	2.43
	Grand Total all crops and enterprises including	1.0ha.	201760	189585.5	195672.7	1.10	1.02	1.08

Table: 5(a). Fruits Crops and other enterprises Throughout Year

S.No	**Fruits/ enterprises**		**Area (ha.)**	**Production (kg/q/t/ha.) 2019-20**	**Production (kg/q/t/ha.) 2020-21**	**Cost of production (Rs.) 2019-20**	**Cost of production (Rs.) 2020-21**	**Cost of production (Rs.) Mean**	**Gross Income (Rs.) 2019-20**	**Gross Income (Rs.) 2020-21**	**Gross Income (Rs.) Mean**
1.	Karonda planted on Boundary wall	100 Running meter		300 kg.	250 kg.	1800	**1800**		25000	10000	
	Papaya	0.05 ha.		400 kg.	358 kg.					10740	

	Banana (Vegetable Purpose)			50 kg.	60 kg.					1200	
				Total		**1800**	**1800**	**1800**	**25000**	**21940**	**23470**
2.	**Enterprises:**	**Backyard Poultry**									
	Hen undressed			56 kg.	70 kg.					14000	
	Hen eggs			690 pcs	1050pcs.		**10000**			12600	
	Quail			-	180 pcs.					10800	
	Quail eggs			-	180 pcs.	**13450**			61980	360	
	Mushroom			-	50 kg.					5000	
				Total			**10000**			**42760**	
	Fisheries			200 kg.	500 kg.					100000	
	Vermicompost			500 kg.	800 kg.		**8450**			4000	
	Apiculture			-	50 kg.					10000	
				Total		**13450**	**8450**	**10950**	**61980**	**114000**	**87990**

Table: 5(b). Fruits Crops and other enterprises Throughout Year

S.No	**Fruits/ enterprises**		**Area (ha.)**	**Net Income (Rs/ha.) 2019-20**	**Net Income (Rs/ha.) 2020-21**	**Net Income (Rs/ha.) Mean**	**B:C ratio 2019-20**	**B:C ratio 2020-21**	**B:C Ratio Mean**
1.	Karonda planted on Boundary wall	100 Running meter		23200	**20140**				
	Papaya	0.05 ha.							
	Banana (Vegetable Purpose)								
	Total			**23200**	**20140**	**21670**	**12.88**	**11.18**	**12.03**
2.	**Enterprises:**	**Backyard**	**Poultry**						
	Hen undressed								
	Hen eggs				**32760**				
	Quail								
	Quail eggs			48520					
	Mushroom								
					32760	**21670**	**3.6**	**3.27**	**2.16**
	Fisheries								
	Vermicompost				**95550**				
	Apiculture								
		Total		**48520**	**95550**	**72035**	**3.6**	**11.3**	**8.52**

Rate of different commodities and produce as per prevailing market rates/mandi rates.

Varieties /breeds of crops and enterprises taken in the systems

Sugarcane-CoPk05191, CoLk09204; Vegetables-Bottlegourd (Kashiganga), Sponggourd(Kashi khushi), Tomato (Kashi ayan), Brinjal (Kashi uttam), Pumpkin (Kashi harit), Green chili (Kashi anmol), Coriander (kashmini), Fababean (Cherry), Okra (Kashi kranti); Fruits- Banana (G-9), Papaya (Pusa Dwarf); Poultry Breed- Ashil, Kadaknath, Nirbhik; Fish Breed-Rohu, Catla, Nain; Vermicompost (*Eisenia fetida*), Apiculture (*Apismangifera*).Cow- Sahiwal.

Conclusion : Autumn planted Sugarcane Based Integrated Farming System- The results clearly indicated that autumn Sugarcane Based Integrated Farming System as Sugarcane + Vegetables (Garlic, Fenugreek, Coriander,Tomato,Cauliflower,Spinach,Carrot,Fababean,Onion,Brinjal,Greenchilli,Cabbage, Pea, Soya, Sauf, Bottle guard, Okra, Cowpea, Cucurbit, Maize) + Horticultural Crop (Karonda boundary plantation+ Papaya+ Banana) + Backyard Poultry (Breed, Asheel, Nirbheek Kadaknath, Quail) + Fisheries (Rohu, Catla, Nain) + Vermicompost (*Eisenia fetida*) + Apiculture+ Mushroom+Dairy Unit(02 Cows) fetched net income Rs.436806 /ha. and fetched additional income of Rs.**208386**/ha.

- Spring planted Sugarcane Based Integrated Farming System- The results clearly indicate that Spring planted Sugarcane Based Integrated Farming System as Sugarcane+Vegetables (Bottlegourd, Spongegourd, Tomato, Brinjal, Pumpkin, Onion, Maize, Fenugreek, Pachoi, Chinesegobhi) + Horticultural Crop (Banana, Karonda, Papaya) + Backyard Poultry (Breed- Asheel, Nirbheek, Kadaknath, Quail) + Fisheries (Rohu, Catla, Nain) + Vermicompost (*Eiseniafetida*) + Apiculture + Mushroom + Dairy Unit (02 Cows) fetchednetin come of Rs. 462412/ ha. And fetched additional income of Rs.**165561**/ha.

References:-

1. Pawanjeet, D.K. Raghav, Vikash Das, Indrajeet, Rakesh kumar and A. Upadhay. (2021). Kishan ki aay badhane ke liye ekikrat krishi pradali In Kheti, Published by DKMA, ICAR, New Delhi, issue 2021 pp 38-40.
2. Manpreet kaur, Gurdeep Singh Malhi and Kartik Sharma (2021). Integrated Farming System: an approach for agricultural Sustainability. In: Just agriculture; Vol.1 Issue-8, April 2021.
3. Ansar M and Fathurrahman (2018). Sustainable integrated farming system; A solution for national food security and sovereignty. IPO Conf. series: Earth and Environmental Science; 157(2018):012061; 10:1088/1755-1315.157/1/012061.
4. C.A. Francis, C.B. Flora and L.D. king (New York: Wiley, 1990). Sustainable Agriculture: An overview. In: Sustainable Agriculture in Temperate zones, edited. p.8.
5. Rana S.S. and Chopra P. (2013). Integrated Farming system department of agronomy, college of Agriculture, CSK Himachal Pradesh Krishi Vishwavidyalaya, Palampur. 90 pages
6. A.K.Singh,A.D.Pathak,T.K.Srivastava,Rajesh Kumar Singh,Akhilesh K Singh,Anil K Singh,Ekta Singh,Rakesh Kumar Singh,A.K.Sharma,M.M.Roy and S.P.Singh(2019).Enhancing income of small land holding farmersof subtropical Indiathrough sugarcane based integrated farming system approach.Indian Journal of Sugarcane Technology.Vol.34(2):73-77.
7. A.K.Singh,A.D.Pathak and Ekta Singh(2017).Intercropping options for higher profitability in sub-tropical sugarcane farming.Indian Farming(Sugarcane special issue):Vol.67(2):57-60

- Exposer visit of Sugarcane Based Integrated Farming System by Chief Secretary, Govt. of U.P.; DDG (Crop Production), ICAR, New Delhi; Chairman and Members of RAC for ICAR- IISR, Lucknow ; Chairman and Members of QRT for ICAR- IISR, Lucknow, Minister Cane, Govt. of Bihar, Press Media Personnel's, Scientists of 14 Country (Thailand, Brazil, Sri Lanka, Indonesia etc.) during SUGARCON-2022 (An International Seminar) and farmers (1080 no.) of Bihar, M.P., Andhra Pradesh, U.P., Maharashtra, Karnataka etc; RAWE Students (500 students), other State holders and Sugar Factories Personnel's.

A view of Sugarcane based IFS model at IISR, Lucknow, Uttar Pradesh

A view of Fish production

A view of Sugarcane based IFS model at IISR, Lucknow, Uttar Pradesh

Fish culture in small pond

Intercropping of coriander var. Kashmiri with banana var. G-9

 Backyard poultry breeds (Neerbheek & Asheel)above under sugarcane-based IFS	 Fish production (Rohu, Catla and Nain)
 Crop diversification of Banana (var. G-9) and Maize(var. RMH 4212)	 Bumper fruiting of boundary plantation of Karonda (var. Christs thorn) under sugarcane-based IFS
 Autumn planted sugarcane var. CoLK 9204(sole crop)	 Intercropping of maize (var. RMH 4212) + Cowpea (var. Kashi Nidhi)

Chapter No. 41: Value addition in sugarcane through quality jaggery production and other diversified products for enhancing farmers income

Dilip Kumar
Principal Scientist
Division of Agricultural Engineering
ICAR-Indian Institute of Sugarcane Research, Lucknow

Introduction

With about 70% population living in rural areas, rural has become synonym to agriculture. In fact, 58% of rural population is involve in farm related activities, which contributes only 15% to Gross Domestic Product of the nation. Income through farming is just 60%, for remaining 40% the rural household depends upon alternative sources viz., wages, salaries, non-farm business, interest etc. This inverse relation of manpower and GDP is reflected in form of widening gap of rural and urban India. In order to increase rural income and economy, there is need to enhance agriculture based industries. Primary and secondary food processing units, operated by unskilled and semi-skilled workforce, in production catchments is gaining momentum. Jaggery prepared from sugarcane juice fetches more price than white sugar. Awareness about food value of jaggery over sugar has created a huge market demand this traditional sweetener. Despite being more nutritious than sugar, jaggery consumption of jaggery has declined and per capita consumption of jaggery reduced from 13.87 kg in 1960 to 6.30 kg in past five decades. During the same period sugar consumption increased from 5.24 kg to 17.42 kg . Though this cottage scale jaggery production has often been criticised for unhygienic conditions and primitive technologies, but it has always rescued cane growers whenever there is surplus production or there is problem in sugar industry. In Indian market is dominated by solid jaggery which holds 80% share and remaining 20% is marketed in liquid and granular form. In terms of ease of utilization and handling, liquid and granular jaggery are more convenient. Thus, jaggery in all the three forms, viz., solid, liquid and granular, can be one of the cottage scale rural industry which has potential to increase rural income and employment.In India 36% population lives below poverty line. Per capita availability of cereals and pulses for majority is 468 gms/day which is less than needed.43% children under the age of 3 years &51.8% married women in the age of 18 – 45 years suffer from anemia.Energy rich food is needed.Food product's sweetness is the number one property in terms of consumer acceptability &flavor. Sweetness increases food palatability.Jaggery is eco-friendly nutritive sweetenerJaggery has superior medicinal and nutritional value as compare to sugar. It preserves minerals and vitamins found in cane juice, viz., calcium, iron, potassium, copper, zinc, phosphorus and magnesium. The*ayurvedic* medicine advocates that jaggery consumption purify blood, improve digestion and strengthens lungs, bones and nervous system. The low glycemic index and chain of sucrose make jaggery a slow glucose releasing sweetener. Hence, awareness should be created among the peoples for jaggery consumption benefits through mass media publicity, campaigns and advertisement.

Proximate composition of sugar and jaggery (per 100 gm)

Constitutent	Sugar	Jaggery
Sucrose, g	99.5	60-85
Reducing sugar, g	-	5 - 15
Protein, g	-	0.4
Fat, g	-	0.1
Calcium, mg	-	8.0
Iron, mg	-	11.4
Phosphorus,mg	-	4.0
Total minreals,g	0.05	0.6 – 1.0
Moisture, g	0.2 – 0.5	5-10
Energy, kcal	398	312 - 383

Gur also has 168mg carotene, 0.02 mg thiamine, 0.05mg riboflavin, 0.05 mg vitamin c

Products made by jaggery industry include

i) **Khandsari Sugar:**

At present three types of Khandsari Sugar is manufactured from Sugarcane in our country.

a) Non Sulphur Sugar

b) Sulphur Sugar

c) Bura

Khandsari sugar is mostly used as sweetener in Pharmaceuticals /Ayurved for syrup, Squash & Beverages making. It is also consumed as a basic raw-material in the micro type bakery industries for making Sweet & Salty biscuits and Cakes.

ii) Value added products of Jaggery (Gur):

Jaggery (Gur) is produced in different forms viz., solid, liquid and powder or granular forms, which are described as:

a) **Solid Jaggery (Gur):**

Crushed juice is allowed to settle before passing through multistage filtration. Heavy impurities get settled at the tank bottom due to gravity. Thus obtained decanted juice free from dispersed foreign matter is heated on bagasse fired open pans.. Boiling and concentration of juice takes place in the pans. In order to remove colloidal impurities use of clarificants from vegetable sources, deola, okra, phalsa, caster, groundnut, soybean etc., are recommended to maintain food value and keeping quality of jaggery. Deola is most commonly used for jaggery making. The juice is concentrated in pan and at striking temperature of 115-118^{o}C transferred to cooling wooden pan before final transfer of moulds. Moulds can be of different shapes and sizes. Conditioning is done to attain jaggery moisture within moisture range of 5-7% for storage purpose. For ease of handling and packaging, and increased market value, cubical moulding frames for 10 or 20 g jaggery are preferred.

b) **Liquid Jaggery (Gur):**

It is an intermediate product obtained during concentration of purified sugarcane juice during jaggery making, and is semi liquid syrup like product.Striking point temperature is key indicator for making different types of jaggery. For making liquid jaggery concentrated juice is removed from furnace at 105-106^{0}C.To prevent microbial growth preservatives are added to liquid jaggery.

c) **Granular or Powder Jaggery (Gur)**:
The process of making granular jaggery is similar up to concentration. Striking point temperature is key indicator for making different types of jaggery. For making powder jaggery concentrated juice is removed from furnace at 120-122^{0}C.Theconcentrating slurry is rubbed with wooden scrapper, for formation of grains. The granularjaggery is then cooled and sieved. Less than 3 mm sized crystals are found to be better forquality granular jaggery.

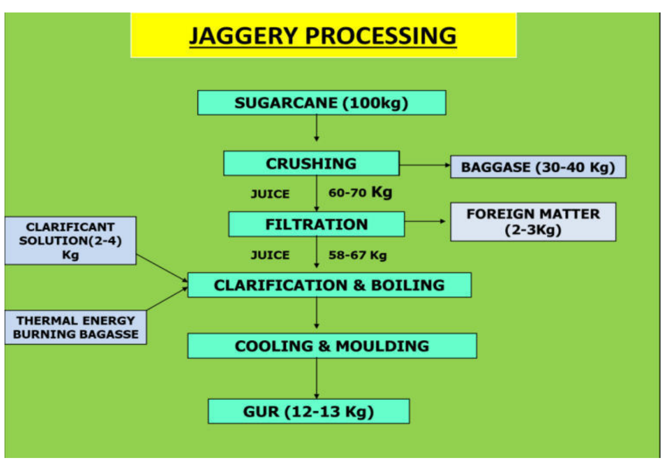
Value added products of Jaggery (Gur) like Confectionary Products, AurvedicJaggery, Gur-Patti, GurLaiaLaddu, Ram Dana Laddu, TilLaddu, GurGazak, Gur-Chocolate, GurBurfi and Gur Containing Nutritional and Medicinal Substances are beingmanufactured.

Jaggery is one of the largest andancient cottage industries of unorganized sector in India.Jaggery making plants are generally tiny in size and the machineries of the plants are fabricated by local artisans or engineering workshops.Despite being decentralized and unorganised, the jaggery industryhas not flourished much and the product is still being produced by adopting traditional ways, lacking in quality and hygiene.

All India Coordinated Research Project (AICRP) on Post Harvest Engineering &Technology(PHET), ICAR-Indian Institute of Sugarcane Research(IISR) centre has developed a model three pan jaggery unit which is a modern jaggery unit, highly efficient, compact, hygienic and cost effective and can be used for producing value added jaggery confirming to the standards of BIS and FSSAI. The capacity of the unit is scalableupto 10 quintals of jaggery per day. The jaggery can be moulded in many shapes and after packaging it is being sold at least at Rs. 60/kg.

.

By establishing jaggery making units on IISR pattern, the production of quality jaggery could be ensured. The quality jaggery so produced may find its way not only in domestic marketbut also in a couple of neighbouring countries. As the urban people are becoming more health conscious the demand for quality and hygienic jaggery will be more in time to come.



IISR Furnace

The improved design of triple pan furnace with provisions of various special features was developed at IISR Lucknow which works satisfactorily and has the overall heat utilization efficiency of 30%. The water evaporation rate was 2.18 kg per kg of bagasse. Also the hygienic environment of working was maintained and Drudgery involved in shifting hot juice from one pan to another was removed due to provisions of different elevations for gravity flow of the juice**.**

Special Features of this furnace

(i) It has provisions of grate from bottom of the feeding hole till centre of the furnace after which frame made of m.s. rod was attached which improved burning of bagasse.

(ii) It has two air inlet-m.s. pipes form chimney sides to the middle chamber for continued and smooth supply of fresh air into the combustion chamber.

(iii) The gap between grate surface and the bottom of the pan was kept as 60 cm due to which heating was more effective.

(iv) The pans were made of thick m.s. sheets with thick bottom which avoided over heating and charring of the juice concentrate.

(v) The placement of pans at different elevations made operations easy and trouble free.

(vi) Had visibly better natural draft.

(vii) Change in the kind of fuel did not result in decline of its effeciency.

(viii) The maintenance and ash removal were conveniently done.

(ix) Its operation responds quickly and also quite effective to its cumbustion as it reduced time requirement for juice concentration and hence for jaggery manufacturing.

(x) It saves significant quality of bagasse and has larger out put capacity.

Economics

Capacity of plant	110 qtls/day
Jaggery production	13.2 Qtls/day
Working period	125 days
Total investments (Machinery & working) (excluding land)	Rs 10 lakhs
Land area needed	400sq m
Covered area	9mX6m
Payback period	4 years

Market Potential :

Sugarcane is being used as natural sweetener since time immemorial. Traditionally the sweetness is preserved in form of jaggery, prepared by concentrating cane juice in open pans. Bagasse is used as fuel to heat the pans. After introduction of white sugar, due to sweetness and ease of use, handling and storage, it has almost replaced jaggery from urban Indian diets. Jaggery, apart from sucrose, glucose and fructose, is rich source of minerals and vitamins. Recently with increasing health awareness and ill-effects of sugar, demand for jaggery has shown an increasing trend. All the three forms of jaggery, viz., solid, liquid and granular, are unique in terms of texture, properties, usage and handling. India is largest producer, consumer and exporter of jaggery in the world. Apart from indigenous domestic market there is huge export potential of hygienically produced quality jaggery. By fortification of jaggery with other nutritional additives like, gooseberry, basil, ginger, black pepper, sesame seeds and spices, value added jaggery can be prepared for specific needs and requirements. Production of each product can be adopted as cottage scale units.

i. Cost benefit analysis

Cost analysis for establishment of jaggery plant :

An approximate cost analysis of jaggery plant for 1000 kg jaggery/day capacity is discussed as under :

Assumptions :

i) Plant capacity = 1000 kg/day
ii) Working days = 200 days/year
iii) Working hours = 12 h
iv) Juice recovery = 60 %
v) Jaggery production = 12 % of cane weight
vi) Cane requirement = 100 Q/day
vii) Cane price = Rs. 300/Q
viii) Interest rate = 12 %/annum
ix) Repair maintenance = 2.5 %
x) Insurance = 1 %

Cost analysis for establishment of jaggery plant per annum :

i) Cost of machines and structure = Rs. 35,00,000
ii) Raw material = Rs. 60,00,000
iii) Wages =Rs. 5,00,000
iv) Utilities = Rs. 6,00,000
v) Miscellaneous = Rs. 100,000
vi) Working capital = Rs. 72,00,000
vii) Interest & Insurance = Rs. 10,44000
viii) Total Variable cost = Rs. 82,44000
ix) Total capital (Fixed + working) = Rs. 11744000
x) Cost of production/year = Rs. 82,44,000
xi) Cost of production/kg = Rs. 41.22
xii) Turnover (@ sale price Rs.60/kg) = Rs. 120,00,000
xiii) Net profit = Rs. 3756000
xiv) Net profit ratio = 31.3%
xv) Return on investment = 40%

Cane Jaggery specifications (IS 12923:1990)

Characteristics	Unit	Grade I	Grade II
Sucrose	%(db), min	80	70
Reducing sugar	% (db), max	10	20
Moisture	%(db), max	5	7
Water insoluble matter	%(db), max	1.5	2.0
Sulphated ash	%(db), max	3.5	5.0
Sulphur dioxide	ppm (db), max	50	50
Ash insoluble in dilute HCl	%(db), max	0.3	0.3
Total sugar as invert sugar	%(db)	90	90

Chapter No. 42: Identification of Insect-pests of sugarcane and their control measures

Arun Baitha, M.R.Singh and Sharmila Roy
Principal Scientist, Division of Crop Protection
Indian Institute of Sugarcane Research, Lucknow-226 002, India
Emai:arunbaitha@rediffmail.com

Sugarcane in India is cultivated in both subtropics and tropics which represent two different agro-climatic zones of the country from the point of view of its cultivation. Subtropics are characterized by extremes of weather conditions and short growing season and tropics with warm climate and long growing season. The productivity is affected by biotic factors like pests which can cause losses estimated to be around 20 per cent in cane yield and 15 per cent in sugar recovery. Although pests are generally more devastating in the subtropics and tropical India also causes severity of pests under specific situations necessitating deployment of strategies to maintain them below damaging levels.

Sugarcane crop in India withstands the ravages of more than 200 species of insect and non-insect pests. Out of those, about two dozen species of insects are considered as major pests. These includes the moth borers, termites, white grubs, scale insect, mealy bugs,pyrilla,white fly and woolly aphid which attack the crop at various stages of its growth. However, some of the pests i.e. stalk borer, internode borer, Plassey borer, Gurdaspur borer, green borer, scale insect and woolly aphid have been spread into new regions accidently from their area of origin as a result of the activities of man.

Pests of sugarcane can be grouped according to various criteria such as geographical distribution, taxonomic grouping, severity of damage caused, and feeding habit. Here, pests have been grouped by feeding habit as follows:

1. Pests that feed /bore on sugarcane-Borers
2. Pests that suck the sap from the plant/leaf – Sucking pests
3. Pests that feed on the subterranean parts of cane-Soil pests
4. Pests that feed on the leaves of sugarcane-Leaf feeders

1. Borers

Eleven species of borers infest the crop in different sugarcane areas, singly or in combination with one or more species, every year. These are top borer,*Scirpophaga excerptalis* F., early shoot borer, *Chilo infuscatellus* Snell., Stalk borer,*C.auricilius* Dudg.,Plassey borer,*C.tumidicostalis* Hmpson.,internode borer,*C.sacchariphagus indicus* Kapur, Gurdaspur borer, *Acigona steniellus* ,pink borer,*Sesamia inferens* Wlk.,root borer, *Emmalocera depressella* Swinh. and the green borer, *Raphimetopus ablutellus* Zell.

1.1. Early shoot borer, *Chilo infuscatellus* Snellen

Early shoot borer or shoot borer is widely distributed in all sugarcane growing areas of the country. The pest attacks the crop in its early stages of growth with peak activity during summer months (March-June) when high temperature and low to moderate humidity prevail. Borer activity deceases with the onset of monsoon. It can co-occur with other borers like pink borer, green borer, and root borer. The Iarva enters the plant laterally by making entry holes at the base of the stalk and bores downwards or upwards killing the growing point. This would sever the central leaf spindle which dries up forming a dead heart that can be pulled out easily. The cut off portion inside the bored plant decays and the dead heart emits an offensive odour when pulled out. Borer infestation during the germination phase kills the mother shoots resulting in drying up of the entire clump creating gaps in the field. Shoot borer attack often induces compensatory tillering if the mother shoot is not damaged in the affected clump.

The light straw to brownish coloured nocturnal adult moths lay eggs in clusters on the undersurface of middle portion of the first three leaves After hatching, the larva wanders for a few hours and reaches the base of the stem by crawling or hanging by silken thread. The larva enters the gap between the first leaf sheath and stem and feeds on the inner tissue of leaf sheath like a leaf miner for a few days. Later, the larva bores into the stalk and kills the growing point. A single larva can disperse from plant to plant and damage more than one plant. Grown up larva are dirty white in colour with dark brown head and five violet dorsal stripes.

1.2. Green Borer, *Raphimetopus ablutellus* (Zeller)

It is a pest of very young shoots and is localized in Punjab, Haryana, U.P. and Bihar. The caterpillars of this borer are observed to occur in very small numbers in young sugarcane crop during April-June. It occurs in association with other species of sugarcane shoot borers, *Chilo infuscatellus*, *Sesamia inferens* & *Emallocera depresella* during summer. As a result of the injury caused to the growing point of cane shoots, the central leaf whorl dries up. The attack of the species can be found out only by digging the affected plants & examining the larva. The fully grown larva is copper coloured above and greenish below. Its activity ceases completely with the break of monsoon rains and the larvae become completely green. There are about two broods during the hot weather. The post generally infests the young crop resulting in the drying up of the central whorl to form a dead heart, which when pullet out gives an offensive smell. Eggs are deposited in a loose on soil below the cane shoots. These are oblong with a greenish tinge. The eggs are laid in cluster, but they do not overlap each other. The egg is dull white in colour and is broadly oval in shape. On an average, a female moth laid 37 eggs. Larva abdominal segments are copper green coloured above and bluish green below. There are five larval instars. With the commencement of rain, it become completely green and this colour persists in the hibernating larvae. It has been observed that temperature above 37^0C with relative humidity raging between 20-40% is conducive for multiplication.

1.3. Pink borer, *Sesamia inferens* (Walker)

The pink borer, *Sesamia inferens* Wlk. has been recorded attacking young sugarcane crop in many parts of the country. In U.P., its attack is often met with in association with that of the shoot borer, *Chilo infuscatellus* Snell. While in most of the other state it occurs either alone or in combination with *C.infuscatellus* only. Apart from sugarcane, attack of pink borer has been recorded on jowar, maize, paddy, bajra, wheat, Sudan grass, narkal, Johnson grass and Napier grass. In north India, *S.inferens* usually attacks sugarcane in the initial stages of the crop growth and is therefore considered essentially a shoot borer like *Chilo infuscatellus*. Two distinct types of attack were observed (i) Primary and (ii) Secondary. Primary attack is confined to the late shoots or the top portion of the cane, and is caused by the newly hatched larvae which inter the internodes through the bud point. On splitting open an attacked internode longitudinally, a number of tunnels running spirally upwards (and more or less parallel to one another) can be seen. Usually, one larva is met with in each tunnel, but in some cases two larvae may also be found in the same tunnel. Normally this type of attack is confined to a single internode and the tunnels do not cross over to the adjoining internodes. The caterpillars, after completing their third instar, prepare round exit-holes (one by each caterpillar) through which they later come out. Thus in case of primary attack, an internode has a large number of exit holes spread over its entire rind surface, their number usually corresponding to the number of caterpillars which fed on the internode.

The secondary attack is caused by grownup caterpillars in their solitary phase, only one caterpillar entering a particular internode. The tunnel in this case runs straight and only two holes- the ‘entrance and the exit ‘holes- are found on the rind of internode .Minute holes, met with in primary attack are absent in this case. The entrance and exit holes are usually oblong in outline though sometimes round holes are usually oblong in outline though sometimes round holes are also seen. These holes are much bigger than those formed by the stalk borer, *Chilo auricilius* or the shoot borer, *C.infuscatellus*.A brownish mass of frass was found sticking to these holes in some canes. The tunnel, in case of secondary attack, may extend to two to three internodes were found tunnelled.

1.4. Root borer*, Emmalocera depresella* (Swinhoe)

A serious pest in the subtropical sugarcane belt and also in tropical India. It attacks the underground stalk portion of cane and the intensity of damage varies with the stage of the crop. In the early stages, i.e. during May-June, dead hearts are formed which cannot be easily pulled out nor do they emit offensive smell as in the case of shoot borer. Often one or two leaves adjacent to the central whorl also dry-up.In grownup canes the damage symptom is visible in the form of yellowing of leaves. The canes need to be uprooted to detect the damage and the presence of larva. While attack by the first brood affects tiller production, second to fourth broods reduce cane length and weight in the decreasing order of magnitude with the brood number.

Moths have straw coloured forewings and whitish hind wings. Female lays eggs singly on the upper and lower surfaces of leaves along the midrib. The first instar larva after hatching crawls to the base of the stem and enters it by making a single hole at or just below the ground level. The larva feeds in an irregular semi-circular pattern and may leave the bored stem and enter into another underground stem of the same clump or adjoining shoots. Larvae hibernate during October-February. The full grown white coloured larva cuts an opening at the exterior end prior to pupation and constructs a silky pupal tube up to the surface of soil for easy emergence of the adult. Occasionally, pupation occurs in the silken tube outside the cane. Life cycle is completed in 30-73 days depending on the season and region. The borer is active at high temperatures and moderate humidity levels. Generally ratoon is more prone to its attack. Un-irrigated fields and sandy or sandy loam soils harbour high borer incidence.

1.5. Top borer, *Scirpohaga excerptalis* (Walker)

Top borer occurs as a major and regular pest in the subtropical region but as a minor and occasional pest in the tropics. Capable of attacking the crop at all stages of growth, top borer characteristically produces leaf mines, shot holes on opened leaf, atrophied central shoot, stunting of cane and sprouting of axial buds leading to bunchy top formation . The unique early symptom of attack is tunnelling by the first instar larva into the midrib causing a white streak that subsequently turns reddish brown and becomes visible on the ventral surface of the midrib. The larva bores its way to the central core of the spindle through the unfurled leaves and as a result rows of shot-holes become visible when the leaves unfold. As the larva feeds by boring into the narrow central core towards the growing point, it also nibbles the inner half of the leaf immediately surrounding the feeding region. This leaf dries up, becomes atrophied and turns dark brown forming the dead heart when the fourth instar larva cuts the growing point. The dead heart cannot be pulled out easily. In the tillering phase of the crop, the attacked shoots die leading to the formation of side tillers. In the grand growth phase, the crop growth is arrested and the crown with the dead heart completely dries. In grownup canes, dead heart formation induces sprouting of the lateral buds giving a 'bunchy top' appearance.

Adult moth is silvery white in colour with or without one black spot on each of the forewings. The female has a tuft of crimson red, orange or buff colored anal hair. Eggs are laid in clusters of two to four overlapping rows covered with buff coloured hair mostly on the underside of the basal or middle portion of second and third laminae. The newly hatched larvae crawl actively on leaves, suspend themselves by silken threads and get dispersed to adjacent plants by wind. After three to four hours they bore into the midribs of leaves through the lower epidermis. More than one larva bores in to the midrib of a leaf and they may tunnel parallel to each other or one behind the other. After mining, they come out of the midrib only through the upper epidermis and enter into the interior of the spindle as first instar larvae. In this region, while some continue to tunnel through the soft midribs, others reach the central core of the spindle which is the essential site of feeding for their further development. The larva reaching the central core nearest to the growing point first survives while those away from the growing point and in the midrib perish. The larva feeds above the growing point up to the fourth instar after which it cuts across the growing point, causes dead heart and enters the top internodes either tunnelling down in the centre or moving superficially towards the rind. After spending 15 - 45 days in four instars, the full grown larva cuts an exit hole for the moth that would emerge after a pupal period (6-21 days). Under subtropical conditions, the pest remains active from February to October passing through five broods and undergoes larval hibernation in winter. Failure of rains in July affects the number and size of egg masses and dry weather adversely affects hatchability. Abiotic factors are important in the second brood whereas biotic factors play a prominent role in the subsequent broods.

1.6. Internode borer, *Chilo sachhariphagus indicus* (Kapur)

The internode borer is a major pest of sugarcane in peninsular India with distribution in Tamil Nadu, Andhra Pradesh, Karnataka, Maharashtra, Bihar, Uttar Pradesh and Haryana. The borer begins its activity soon after internode formation and the damage continues until harvest. The neonate larva feeds on inner side of leaf sheath by scraping the epidermis for seven to eight days. Young larva also bores into the spindle region or the topmost formative internodes below the meristem egesting out fresh frass from the bore hole while scooping the tender surface of the shoot below the leaf sheath.Meristem feeding and dead heart formation result in bunchy-top formation. Often the side-shoots are also attacked by the borer. In the bore hole damage node, the larva after entering the formative internodes, generally tunnels upwards up to meristem but rarely feeds downwards. The larva tunnels the inner tissues of the internode and pushes the frass to the exterior. The frass can be seen as a wet or dry mass hanging from the bore hole which can serve as an indicator of borer attack as well as the duration of attack.

Moths are straw colored with a light dark spot on each of the forewings; males are smaller and darker in colour than females. Female moths lay eggs in clusters of 2-3 parallel rows on both surfaces of the green leaves, dorsally on the midrib and ventrally parallel to the midrib. A single moth lays up to 414 eggs. The grown up larva has violet spots in four longitudinal stripes dorsally. Freshly formed pupa is light brown in colour becoming dark brown after six to seven days. Heavy build-up of the borer occurs during July-December after the commencement of internode formation. Lodging, high dose of nitrogen, water logged condition and presence of large number of water shoots favour pest buildup.

1.7 Stalk borer, *Chilo aurilius* Dudgeon

One of the most destructive pests of sugarcane in subtropical India, the stalk borer, is a major pest in Uttar Pradesh, Haryana, Punjab and Bihar. Soon after hatching, the larvae move on the upper surface of the leaf and later move downward and take shelter inside the top leaf sheaths (+4 to +8) or in the central whorl. They feed by scraping the inner surface of these leaf sheaths for about a week where they complete two instars.Usually two to six larvae mine in one leaf sheath due to which the leaf sheath decays and subsequently the entire leaf dries. As a result of feeding by the newly hatched larvae, leaves show distinct longitudinal orange yellow streaks extending from tip to base on both sides of the midrib towards leaf margins. It is the third instar larva which bores into the shoot and internodes of the canes. The grown up cane shows no visual symptoms of infestation unless the leaf sheaths are removed when the bore holes may be seen clearly on the internodes. An infested cane may harbour 3-15 larvae at a time and the damaged internodes show symptoms of reddening which sometimes emit a rancid odor.Often in mature canes, three well marked regions of borer infestation, *viz.* the lower, middle and top portions may be discerned during August- December. However, in epidemic conditions, larvae may be found in all the internodes of the infested cane during November-January.

Moths have straw colored forewings with a number of golden spots on the periphery and light straw colored hind wings with silvery fringe. The eggs are laid in masses on the underside of the leaves arranged in two to five parallel rows. The newly hatched larva is creamy white in color which normally passes through five instars but in summer and winter there can be as many as eight instars. The fully grown larva has five violet stripes along the length of the body. The pupation takes place inside the tunnel formed by the larva. The borer completes five generations in Haryana, five to six in Uttar Pradesh and seven in Bihar.

1.8. Gurdaspur borer, *Acigona steniellus* (Hampson)

It is an important pest of sugarcane in Punjab, Haryana and western U.P. It is also reported from Sriganganagar in Rajasthan and some parts of Himachal Pradesh. The pest exhibits both gregarious and solitary phases. After hatching, larvae wander about for a few hours in search of a suitable site and enter the cane gregariously through a single hole. The entrance hole is always made on a sheath less internode and never below the third internode from the top. They feed gregariously in galleries in a spiral manner making minute punctures on the rind from within. Externally the tunnel appears as a dark spiral made up of a series of punctures .As many as 125 larvae may feed gregariously in one cane. After feeding two thirds of internode in a spiral manner, the larvae bore deeper and feed upward by making a straight tunnel. Third instar larvae start dispersing to other canes singly or in groups of two to three and in the later stages one caterpillar is found infesting the internodes in each plant. Leaves wither due to larval feeding just below the rind but as the infestation advances and the central tunnel is formed, the entire whorl of leaves turns yellow and dries up. As a result of the attack, canes fail to grow, damaged internodes become weak and infested stalks break off easily. Nodal buds in the remaining portions of canes are stimulated and side shoots are formed.

Adult moths lay creamy white eggs in clusters on the upper surface of leaf in and along the grooves of midrib near the leaf sheath. Mature larvae possess four violet stripes, the lateral being comparatively thicker. Before pupation, larvae form a pupal cell in the cane. The pupae are yellowish brown in color with reddish brown stripes and numerous microscopic spines on abdominal segments. After the completion of two broods during June-September, more than 80% larval population comprising full grown third brood larvae moves downwards to the belowground portion of the cane by November for hibernation. The pest flourishes well under moderate temperature and high humidity conditions. Early monsoon, heavy rains and water logging also favour its multiplication.

1.9. Plassey borer, *Chilo tumidicostalis* (Hampson)

The borer derives its name from its occurrence in an epidemic form at Plassey (West Bengal) in 1956. It is an important pest in some parts of West Bengal, Bihar and Assam. The incidence of the borer can be easily recognized by the presence of dried crown of infested sugarcane. Borer attack occurs in two distinct forms. Primary infestation is caused by as many as 180 newly hatched larvae aggregating in the top three to five internodes. Due to such gregarious feeding, fresh red colored frass is seen projecting out of the bore holes and the top leaves of the canes ultimately dry up. Affected internodes break off easily and nodes adjacent to the infested internode develop sett roots which completely envelop the stalk; sprouting of nodal buds also occurs. In the case of secondary infestation, the grownup larvae disperse to either the lower healthy portion of the canes showing primary attack or the neighbouring canes. Larvae feed by tunnelling the internodes. One larva may bore into one to five internodes in a cane but cane tops do not dry up in this form of damage.

Moths are cinnamon brown with terminal series of black spots broken externally by small silvery white points. Egg masses are deposited on the underside of top one to three leaves in two to four tiers. Occasionally, eggs are also laid on leaf sheath and stalk. Larvae from one egg mass hatch synchronously in seven days and penetrate into one of the tender internodes. After 10 days of primary infestation, the larvae disperse to adjoining canes each one boring into a separate internode. There is a well marked polymorphism and larvae are of four different types. However, a typical larva possesses four broad pinkish stripes present sub-dorsally and laterally in pairs. The pest remains active from end of February to middle of November. All stages of this pest are simultaneously met with from April to October showing overlapping generations. Larvae hibernate from mid November to February. The fourth and fifth broods overlap during February-June. Rainfall appears to favour its multiplication. The incidence is high in heavy soils and under waterlogged or flooded conditions.

2. Sucking pests

2.1. Pyrilla

Pyrilla is a serious pest of sugarcane in many parts of the country, often reaching epidemic levels in the subtropics. Adults and nymphs suck phloem sap from leaves and excrete honeydew on the foliage leading to sooty mould development. Such direct and indirect damage affects sugar yield and quality.

Adult *Pyrilla perpusilla* is a pale tawny-yellow soft bodied insect with the head prominently drawn forward. The adult life span varies from 14 to 200 days and females live for a slightly longer period than males. Eggs are laid during the day on the abaxial and adaxial surface of the leaves along the midrib. They are deposited in four to five rows and are covered with a waxy filamentous material secreted by the female. During the winter, eggs are laid between the stalk and the dried leaf sheath which apparently gives protection from adverse climatic conditions. The female usually uses a lower, shady, concealed site for oviposition. About 20- 50 eggs are laid at a time with a life time fecundity of 37-880. Newly emerged nymphs milky white in color and pass through five instars to reach maturity. Each nymphal instar bears characteristic anal filaments which are slightly longer than the body. Under subtropical conditions, overwintering nymphs develop into adults on the sprouts of ratoon crops during the second fortnight of March. Egg laying begins after the first week of April and continues up to the middle of May. Mortality of nymphs is usually very high during the hot dry weather and the surviving nymphs develop into adults by the first week of July. First and second broods are well defined whereas subsequent broods overlap; all stages of the pest occur up to December. The pest completes 4-5 generations in different parts of the country. Copious irrigation during hot months and high foliar density are conducive for the build-up of *Pyrilla*.

1.2. Woolly aphid, *Ceratovacuna lanigera*

The woolly aphid, a pest restricted to north eastern India since the late 50's, appeared in an epidemic form in peninsular India in Sangli (Maharashtra) and Belgaum (Karnataka) in 2002 and later spread rapidly in the sugarcane growing areas of Maharashtra, Karnataka, Tamil Nadu ,Andhra Pradesh,Uttarakhand,Haryana and U.P. Woolly aphid desaps the plants colonizing the underside of leaves . The attack generally begins in the middle leaves and extends to upper leaves. Within a leaf, colonies appear in the middle portion and extend to both ends. As the aphids grow and reach later instars, their body is covered with white waxy filaments giving the appearance of a white waxy coating to the infested leaves. A crop that has been attacked for about two months can be identified from a distance by the presence of white patches of plants contrasting with the green canopy background. The wax filaments that detach from the body of thousands of aphids drop down and cover the ground with a powdery coating giving it a white appearance which easily catches the attention of one's eye upon entering the field. The large volumes of honeydew excreted by the innumerable aphids settle on the upper surface of leaves located directly below the infested leaves. These leaves with the deposits not only gleam against bright light but also attract a variety of insects such as bees, wasps and flies, though regular attendance by symbiotic ants is seldom noticed. Sap sucking activity of huge colonies of nymphs and apterous adults causes stunted growth. The indirect damage includes the development of sooty mould on the honeydew deposits which interferes with photosynthesis; infested cane tops are believed to affect the health of cattle when fed to them. The pest generally begins colonizing five-month or older crop though younger crop is also known to support aphid attack in an epidemic situation. The pest remains almost until harvest and causes serious direct and indirect damage affecting both cane yield and quality.

Under tropical conditions, the aphid invariably reproduces asexually (parthenogenesis) by giving birth to young ones (vivipary) that are composed of females only. The aphid normally produces wingless (apterous) forms but towards the end of the season and under competition for food and space, winged (alates) females are produced. These are black in color with two pairs of transparent wings, clear wing venation and no waxy secretions on the body. Winged females generally initiate the attack in a new crop by producing pale greenish nymphs.With a short life span of 7-9 days, alates produce 8-43 young ones which develop into wingless forms. These apterous forms multiply profusely producing large colonies of thousands of individuals on the under surface of leaves protected from direct sunlight. While winged forms are responsible for plot-to-plot or long distance dispersal, the active first instar nymphs disperse to adjacent leaves or plants in the contiguous canopy in the morning hours. Another form of dispersal is through congregations of young nymphs on the leaf tip which are blown off by wind in a process called ballooning. The first and second instar nymphs are naked, i.e. without the white woolly filaments; dorsal side of the body of the third and fourth instar nymphs produces waxy filaments.

1.3. Whitefly, *Aleurolobus barodensis* and *Neomaskellia bergii*

Whiteflies damage sugarcane by extracting large quantities of phloem sap from leaves which can result in greater than 50% yield reduction. The whitefly *Aleurolobus barodensis* occurs in Andhra Pradesh, Bihar, Tamil Nadu, Haryana, Punjab, Gujarat and Maharashtra. Large colonies of *Aleurolobus barodensis* nymphs suck the sap from the under surface of the leaves which turn yellow; in severe cases of infestation the leaves show pinkish discoloration and the infested leaves gradually dry up. Honeydew deposited on lower leaves encourages sooty mould growth which adversely affects photosynthesis. Whitefly infestation not only retards plant growth but also reduces sugar content in canes. *Neomaskellia bergii* is sporadic in occurrence and the colonies are restricted to small areas on leaves.The emergence of *Aleurolobus barodensis* commences with the formation of a 'T' shaped split in the dorsum of the puparium. Adults have pale yellow body with dirty white wings; females are larger and less active than males The conical eggs with a rounded base and supporting peduncle are laid in long linear rows. Fresh egg is creamy yellow in color but changes to light brownish grey and finally turns black in about 90 min. The neonate nymph is tiny, pale yellow in color with three pairs of legs and a pair each of compound eyes and ocelli. The colour of newly hatched nymph gradually changes to shiny black after it settles on the leaf surface. Secretion of white wax appears in the form of a pair of white rounded specks on either side of the mid-dorsal line of the nymph. Freshly moulted second instar nymph is slightly larger than the first instar, flat with a slightly convex dorsum. Total life cycle is completed in 25-47 days but is prolonged to 119-130 days in winter. There are nine generations in a year.

***Neomaskellia bergii*:** The sluggish adults have long and thick forewings with prominent black transverse patches in both sexes. The abdomen of female is broad with a short ovipositor. Eggs are laid in concentric, opposite semicircles and are attached to the leaf surface by a peduncle. Eggs are shiny pale yellow but turn dusky yellow; apices turn brown and acquire a chocolate colour. First and second instar nymphs are pale brown whereas the third instar is elliptical with distinct transverse striations on the slightly convex dorsum; the three instars last 5-7 days. The fourth instar or pupal stage is thick, translucent and dark brown with a prominent cretaceous fringe on the margin.

Drought during summer and dry spells during monsoon profoundly influence whitefly buildup. In semi-dry alkaline patches, heavy incidence of the pest is observed due to physiological stress. Generally, crops subject to water-logging, especially in low lying areas of eastern Uttar Pradesh, Bihar, Tamil Nadu, Gujarat and Haryana, are heavily infested by whitefly. Water-logging leads to physiological starvation of the crop and is characterized by symptoms of nitrogen deficiency which promotes pest buildup. Similarly, leaching of nitrogen due to heavy rains also promotes infestation levels. High levels of humidity generally favour its multiplication. In general, higher whitefly incidence is observed in neglected crops and unmanured ratoons as compared to manured ratoons. Varieties which have long and broad leaves are highly susceptible to the pest.

1.4. Black bug, *Cavelerius sweeti* and *Dimorphopterus gibbus*

Of the three species of black bugs infesting sugarcane, *Cavelerius sweeti* is the most predominant pest of ratoons in north India. While *Dimorphopterus gibbus* is of sporadic occurrence. The nymphs and adults of *Cavelerius sweeti* are found in the leaf whorls and under the sheathing bases of leaves. The leaves of affected plants turn pale yellow with brown patches. In severe infestation, they become riddled with holes, owing to several bugs puncturing the same spot. The tips and margins of the leaves dry up gradually and the entire plant may wither. The growth of the plant is arrested and the quality of juice is adversely affected. Both nymphs and adults suck the sap resulting in stunting of the ratoon crop.

Adult *Cavelerius sweeti is* black in color with legs and antennae being ochraceous. Fresh eggs are cigar shaped smooth and creamy white turning vinaceous brown later. Black bug incidence is heavy in ratoon fields where trash is retained for a long time. Mild weather and large numbers of overwintering individuals are responsible for the outbreak of the pest during the pre-monsoon period. The loss due to bug damage is severe in unirrigated fields.

2.4. Scale insect, *Melanaspis glomerata*

The several species of scale insects that attack sugarcane, the armored scale insect *Melanaspis glomerata* is economically important. The symptoms of attack in the field become evident only when heavy populations of the pest cover the entire cane, the encrustation giving a greyish black appearance. When large colonies of different stages desap the cane, the crop loses general vigour, shrivels up and exhibits stunted growth with reduction in intermodal length. Consequently, cane yield, percentage of juice extraction, juice quality and jaggery production suffer reduction.

Adult female lays 270-400 elongate, narrow and ovoid eggs which are rounded at the anterior and posterior ends. They are light yellow in color and gradually turn to pinkish red as the embryonic development advances. The first three instars show no morphological differences between males and females. Female passes through five instars with no difference between the fifth instar and the adult except for the size and outer scale. The scale encrustation is thick, round, grey to light black in color and convex with white waxy coating on the outer surface. The adult female is oval in shape and yellow in color. The male insect passes through four nymphal instars and a pupal stage before reaching the adult stage. Reproduction is generally by fertilization and occasionally by parthenogenesis. High temperature and high humidity prevailing during July-September favour population build-up. Well spread but non-bearing rains coupled with high humidity from September onwards promote the growth of scale populations. Rainwater and high velocity winds disperse crawlers to new areas.

2.5. Mealy bug

The mealy bugs derive their name from the whitish, powdery/filamentous mealy coating on their body. They are ubiquitous in all sugarcane growing tracts of the world but seldom assume major pest status. Of the six species of mealy bugs that occur in India, adults of five species, including the common pink mealy bug, are soft bodied with well developed legs .The adult males are delicate, alate insects and are not observed as commonly as the relatively large and apterous females. Depending on the species, severe infestation results in stunting of canes and yellowing of leaves. Loss of sap may even kill the young shoots or may result in a marked setback in cane growth, ultimately leading to the total drying of the crop. As a result of infestation, the stem gets covered with sticky honeydew which serves as a medium for the development of black sooty mould around the insect colonies.

Three species of mealy bug are commonly encountered in the field and glasshouse. The pink mealy bug *Saccharicoccus sacchari* is the most commonly occurring species throughout the sugarcane growing areas of the country. Their infestation starts as discrete colonies just below the node on the side opposite the bud, later spreading to the internodes as well. Germinating aerial buds also harbour the mealy bug. Colonies on the underground portion of the cane are not uncommon. The adult females are distinctly pink in color, with a round or dumb-bell shaped, clearly segmented body. The body of adult female is soft and legs are moderately long and not hairy. The yellow mealy bug *Kiritshenkella sacchari* commonly infests the nodal regions but it is also known to colonize leaf-sheaths, internodes, underground portions of stalk and roots as well. Adult females are flattened and covered by a white mealy secretion. Gregarious in habit like the pink mealy bug, they are pale yellowish or light pink in color. *Dysmicoccus carens* generally infests the leaves in a severe form in potted plants under glasshouse conditions. The adult females are elongate, oval and small sized with a waxy white secretion covering the body. There are short waxy filaments along the margins of the body. Legs are long and slender. Drought appears to be a major factor that influences mealy bug populations. Rainfall dislodges populations and encourages entomopathogenic fungi. They are often found in large numbers on stunted canes. Varieties with loose clasping leaf sheaths harbour higher levels of mealy bug populations than those with tight clasping leaf sheaths.

3. Soil pest

3.1. Termite, *Odontotermes obesus* and *Microtermes obesi*

The mound forming *Odontotermes obesus* and the non-mound forming *Microtermes obesi* are important among the 13 species of termites known to attack sugarcane from germination until harvest. Termite infestation occurs soon after planting when germinating setts and young shoots are affected. Newly planted setts suffer the most serious damage as termites enter through their cut ends or through the buds and feed on soft tissues replacing them with soil. The infested stools or shoots dry up soon after germination and these can be pulled out easily. Such shoots show no compensatory tillering. Occasionally 40-60% of the eye buds are destroyed leading to poor germination, gaps in the field and subsequent yield loss. In the ratoons, infestation occurs through the cut ends of the stubbles. In tillers, termites feed on the inner tissues of underground portion of the stem filling them with soil. In millable canes, termites feed on the inner tissues leaving the rind intact and the cavity thus formed is filled with moist soil containing galleries. Severely affected canes show yellowing and drying of outer leaves first followed by the inner leaves. Heavily damaged canes collapse under their own weight.

Termites are social insects with well developed yet diverse colony structure characteristic of mound forming and non-mound forming or subterranean species. The caste structure usually comprises one queen and one king, and numerous workers and soldiers. Colony establishment begins with swarming of winged reproductive adults after the first summer rains. The first batch of eggs laid by the female hatches into workers which take care of expansion activities of the nest. Subsequently, soldiers are produced which protect the colony and foraging workers. Queen termite grows unusually large, up to 3-4 inches in length and about an inch in diameter, and becomes an egg-laying machine depositing thousands of eggs every day for several years. Workers forage for food and, hence, are responsible for crop damage almost round the year. Since workers cover long distances inside their protective earthen tubular walkways, colonies need to be located some distance away from the site of crop damage for mechanical destruction. Termite activity is observed in both loamy and heavy soils; areas of low rainfall or with poor irrigation potential are known to be more prone to its damage.

3.2. White grub, *Holotrichia consangunea*

The white grub, comprising several species, is an important group of soli pest of sugarcane in India. Though inconspicuous late larval feeding activities, white grub has the potential to cause complete loss in sugarcane crop. In subtropical India, *Holotrichia consanguinea* has a life cycle similar to that of *H. serrata* but shorter in duration. In subtropical *Heteronychus sublaevis,* adults damage the underground portion of stem during April-May while peak infestation is observed in August. The pest overwinters in adult and grub stages in earthen cells from October to February. Pupation occurs in March and adult emergence takes place in the following April. Adults feed on underground portion of stem leading to drying of plants in a week after which the beetles move to other shoots.

Beetles emerge at dusk after first rains during April-June and congregate on preferred host trees like neem and *Ailanthus* where they mate, feed on the leaves and return to soil before day-break. Eggs are laid in the soil in sugarcane fields, fallow lands or grassy bunds along water channels. First instar grubs hatching feed on roots of grasses or organic matter initially and switch to sugarcane roots. After a short one month period in each of the first two instars, third instar grubs feed voraciously on sugarcane roots for three to four months. Pupation takes place in earthen cells from September and the adults emerging in early summer showers in the following year stimulate them to emerge out of the soil. *Holotrichia serrata* thrives in moist sandy soil as well as black cotton and clayey soils. Grubs can withstand drought conditions by remaining dormant inside earthen cells for over three months in different instars. High moisture is detrimental to the grub and heavy rains and waterlogged conditions force the grubs to come to soil surface.

Control Measures

Early shoot borer

- Early planting should be followed in endemic areas to avoid synchrony between the susceptible crop stage and peak borer activity period (April-June).
- Two to three rounds of light earthing-up and trash mulching operations should be given during the early stages of the crop growth. Trash mulching conserves soil moisture which is inimical to the borer Trash mulching operation may be avoided in areas prone to termites and army worm.
- Frequent light irrigations and trash mulching should be practiced instead of heavy irrigation at long intervals.
- Spiking in the shoots after removal of dead hearts by organizing campaign has suggested for the control of this pest. In those areas, where it acts as stem borer, removal of dried leaves at monthly intervals after cane formation provides effective control of pest.
- Release of egg parasitoid, *Trichogramma chilonis* Ishii @ 50,000/ha at 7 days interval in southern India and also release of *Sturmiopsis inferens* @ 125 gravid female/ha in Coastal Tamil Nadu.
- Soil application of Fipronil 0.3%GR @ 25-33 kg/ ha or Chlorantraliniprole 0.4GR @18.75kg/ha or Thiamethoxam 75 SG @160g/ha in 500-1000 lit at the time of planting in furrows over the cane setts before covering them with soil have been recommended in different states.

Green borer

- Provide light earthings 2 to 3 earthings given during the early stages of the crop are beneficial.
- Remove the infested shoots completely.
- Timely cutting of attacked shoots at or just below ground level ensure destruction of most of the caterpillars preset within the borer larva in the attacked shoot can also be pulled by first pulling out the dead heart & then thrusting the spoke of a bicycle wheel in the cavity so formed into the shoot.

Root borer

- Mechanical destruction of affected shoots along with borer larvae in the pre-monsoon period reduces pest incidence.
- Deep harvesting of cane meant for rationing helps in the reduction of this borer.
- Plough up the sugarcane field and dig the stubbles soon after harvesting, if not required to keep for ratooning.
- Give profuse and timely irrigation to ratoon and plant crops and remove borer infested shoots 3-5 cm below the ground level and kill them with pointed spokes at weekly interval.
- Collection and destruction of moths using light traps also minimizes perpetuation of the borer.
- Release of egg parasitoid, *T.chilonis* @ 50,000/ha at 10 days interval from July to October.
- Soil application of Fipronil 0.3G @ 25-33kg/ha at the time of planting in furrows over the cane setts before covering them with soil.

Top borer

- Autumn planting is to be followed as it escapes the borer attack in the ensuing winter months in subtropical India.
- Intercropping with spices like coriander, tomato, brinjal, marigold, onion, garlic, fenugreek, and fennel, and other crops such as wheat, potato and mustard reduces top borer incidence.
- Setting up of sex pheromone traps @ 50 numbers / ha for the first two roods and operated up to 30 days for each brood in subtropical states reduces moth population and brings down the severity of subsequent broods. However, trap catches appear to decline from third brood onwards

making its use uneconomical. In tropical India, traps can be set up in hot spots with lure changes decided by the extent of borer occurrence.

- Harvesting of crop (particularly those having high incidence) by the middle of February (before moth emergence) from the over wintering brood in sub-tropical India causes considerable reduction in the borer incidence due to reduction of initial incidence of first brood during March-April.
- Avoidannce of frequent irrigation during peak period of moth emergence during summer protects the crop from heavy borer incidence.
- Suitable drainage to avoid water logging, application of higher dosage of nitrogenous fertilizers and growing of resistant varieties with higher spindle length provide considerable protection of the crop.
- Release of *Isotima javensis* @ 125/ha from July to August manage the effectively.
- Pupal parasitoid, *T.howardi* @5000/ha and temperature tolerant strain of *Trichogramma japonicum* @ 100000adults/ha released against II brood to IV brood of top borer at Lucknow, reduced incidence.
- Application of carbofuran @ 33 Kg / ha. or Chlorantraliprole 0.4GR@ 18.5kg/ha or Chlorantraliprole 18.5%SC@ 375 ml/ha in 1000lit of water in first week of June.

Internode borer

- Removal of water/late shoots during September and October reduce incidence.
- Internode borer pupates outside the cane stalk in leaf trash.
- Setting up sex pheromone traps @ 25 per hectare beginning fourth or fifth month age of the crop with three to four lure changes at 30-45 day intervals reduces moth population.
- Removal of trash with a view to destroy larvae and pupae are suggested to manage the pest.
- Release of egg parasitoid, *T.chilonis* @ 50,000/ha at 10 days interval from July to October.
- Release of larval parasitoid, *Cotesia flavipes* @500 females/ha at 7 days interval from July to November.
- Releasing of pupal parasitoid, *T.howardi* have been reported to provide effective control.

Stalk borer

- Remove dry leaves and late shoots from the standing crop October onwards.
- Avoid taking seed canes from the heavily infested cane field.
- Autumn planting should be avoided in stalk borer prone areas.
- Water logging and lodging of canes should be avoided.
- All water and late shoots should be harvested along with the harvesting of the crop.
- Release of egg parasitoid, *T.chilonis* @ 50,000/ha at 10 days interval from July to October.
- Release of larval parasitoid, *Cotesia flavipes* @500 females/ha at 7 days interval from July to November.
- Spray monocrotophos 36 SL @ 1875ml / ha in 500-1000 lit water when incidence occurred.

Gurdaspur borer

- Affected canes with five to six top internodes harboring borer larvae in the gregarious phase should be cut and removed regularly. The operation should be carried out on a campaign basis from second fortnight of July to the end of September.
- Stubbles harboring hibernating larvae, easily identified by the presence of round tunnel holes at the cut ends, should be uprooted and kill the larvae.
- Ratooning of heavily infested crop should be avoided to prevent perpetuation of the pest.
- Release of egg parasitoid, *T.chilonis* @ 50,000/ha at 10 days interval from July to October.

- Release of larval parasitoid, *Cotesia flavipes* @500 females/ha at 7 days interval from July to November.

Plassey borer

- Collection of moths in light traps to minimize pest population.
- Collection and destruction of egg masses and removal and destruction of cane tops, infested by primary infestation from mid February to mid July.
- Ratooning of heavily infested crop should be avoided to prevent perpetuation of the pest.
- Release of egg parasitoid, *T.chilonis* @ 50,000/ha at 10 days interval from July to October.
- Release of larval parasitoid, *Cotesia flavipes* @500 females/ha at 7 days interval from July to November.

Pyrilla

- Cane trash should be completely removed from the field after harvesting to be utilized as compost. This operation should be carried out until the middle of March to destroy unhatched egg masses and overwintering nymphs.
- Detrashing of leaves from August onwards reduces pyrilla populations.
- Removal and destruction of the white colored puffy pyrilla egg masses or egg-bearing sugarcane leaves themselves at regular intervals minimizes buildup of populations.
- Spraying of monocrotophos 36 SL @500 ml/ha or Chlorpyrifos 20EC @1500 ml/ha in 500-1000 lit of water to combat emergency buildup of the pest.
- Egg masses or cocoons of the parasitoid collected from sugarcane fields can be colonized in target sugarcane fields at a dosage of 10,000 cocoons or 10, 00,000 eggs per hectare. Leaf bits containing egg masses or cocoons are stapled on the under surface of the leaves in the center of infested field if the parasitoid inoculum is small. If a large consignment is available, it is distributed uniformly in the field.

Woolly aphid

- Complete avoidance of transport of seed material or green tops as fodder from affected areas to minimize the risk of introduction into a new area.
- Destruction of affected leaves in the early stages of infestation and priority for harvest of affected cane to prevent spread of the pest in recently invaded areas.
- Wider spacing and paired row planting, and wrapping and propping operations render the crop canopy more amenable to monitoring and chemical control operations.
- Intensive weekly monitoring of the field is essential due to the high multiplication rates and dispersal ability of the aphid.
- At high aphid densities, a few patches in the field should be designated as refugia to conserve predators; these should be colonized with additional numbers of natural enemies and kept insecticide-free.
- Treated fields should be monitored and spot application of insecticides continued if predators have not established.
- Among the natural enemies, the predator *Dipha aphidivora* arrived along with the aphid. The parasitoid *Encarsia flavoscutellum* was introduced from Assam and soon established.
- Mass multiplication of *Dipha* by tray rearing method and field release at dosages up to 1,000 cocoons per ha. Leaf bits bearing the cocoons can be inserted in leaf axils of standing cane.

White fly

- The proper water management of crop to avoid extremes of dry conditions or water logging should be followed. This should be coupled with nitrogen management, especially in ratoon crop, for minimizing the pest.
- Detrashing and destruction of leaves bearing whitefly puparia before the emergence of the adults which can be determined by the presence of' T' shaped split in the dorsum of the puparia.

- Redistribution of the nymphal puparial parasitoid *Amitus minervae* from high-activity fields to parasitoid-free fields holds the key to successful biological control.

Black bug

- Removing of trash and crop residues after harvest, by the end of April and irrigating the fields reduce black bug infestation.
- Application of chlorpyriphos 20EC @750 ml/ha in 500-1000 lit directed towards the leaf whorls to target all stages.

Scale insect

- Prevention of water logging reduces humidity and helps minimize scale populations.
- Detrashing of crop two or three times beginning with internode formation would expose the colonizing sites as well as the crawlers that move upwards to settle underneath the tightly clasping leaf sheath.
- Wide-row spacing, wrapping and propping, and detrashing help maintain crop hygiene and facilitate insecticide application in endemic areas.
- Indiscriminate use of insecticides should be avoided if their activity is observed in the field.
- Application of monocrotophos 36SL@1.5 lit/ha in 500-1000 lit of water reduce the incidence.

Mealy bug

- Planting uninfected setts with leaf sheaths removed reduces perpetuation of mealy bugs to new areas as well as new plantings.
- In grownup crop showing considerable incidence of mealy bugs, detrashing is essential to expose the colonies to abiotic (high temperature and sunlight) and biotic (natural enemies) stresses.
- Detrashing is the single most effective practice that can easily disturb and dislodge fully developed females. This practice is incidentally useful against other sucking pests like scale insect which too grow under the shelter of leaf sheaths.
- Avoidance of overdose of nitrogen and repeated ratoons in areas prone to the pest should be ensured. Ratoons can act as the inoculums for the next season crop since the mealy bugs can multiply in the underground portions of the plant.
- Management of water stress and general health of the crop is important to reduce mealy bug incidence.
- In cases of severe infestation, insecticide monocrotophos 36 SL@1.5lit/ha in 500-1000 lit of water should be sprayed after detrashing. Insecticide should be directed towards lower and freshly exposed internodes that harbour colonies.
- Indiscriminate use of insecticides should be avoided if activity of predators is observed in the field.

Termites

- Location and destruction of termite colonies in those species that build conspicuous mounds by breaking open the nest and removing the queen termite.
- Although secondary reproductives often replace the destroyed queen, the time delay ensures reduction in overall colony buildup.
- Ploughing or disturbing high field bunds would expose and destroy colonies of subterranean termites.
- Clearing of crop residues and other debris in the crop ecosystem deprive the subterranean termites of food and reduce the activity of foraging workers.
- Application of Chlorpyriphos 20EC @6.25lit/ha or bifenthrin 10EC@ 1 lit/ha in 500 lit of water at the time of planting in furrows over the cane setts before covering them with soil.

White grub

- Large scale mechanical collection of beetles congregating on the most preferred neem trees during mass emergence , starting from the night of first showers and continued for a week, reduces beetle population in the habitat progressively over a few years.
- Alternatively, kerosene vapour (Petromax) lamps may be placed near the trees to attract the dislodged beetles. The beetles that hit the light source and drop down should be collected in double layered synthetic cement or fertilizer bags.
- Mechanical collection yields better results when carried out on a community basis with the active participation of both sugarcane and non-sugarcane farmers. Incentives may be offered for the beetles.
- Repeated deep ploughing at land preparation in February, i.e. well before summer showers, particularly in farms with neem trees nearby or fields around beetle-intense trees, exposes quiescent adults to desiccation and vertebrate predation.
- Ploughing and flooding for 24-48 h of similar fields in February, when planting is taken up during the pest activity period (June- September), would be useful in minimizing grub populations of different stages.
- Puddling and rotation with paddy can have a similar longer-lasting negative effect on grub populations. Rotation with the non-preferred sunflower is also advisable to break the continuous availability of sugarcane.
- Application of Fipronil 40%+ Imidacloprid 40%WG @ 437.5-500 g/ha in 1000-1250 lit of water .

References

Agarwal, R. A. 1964. Biology of sugarcane internode borer (*Proceras indicus* K). *Indian Sugarcane,* **14**:145-156.

Avasthy, P.N.1969.The top borer of sugarcane, *Scirpophaga nivella* (F.).In *Pests of Sugarcane*.Eds.Williams, J.R., Metcalfe, J.R., Mungomery, R.W.and Mathews, R.Elsvier Pub.C., Amsterdam.pp.189-205.

Avasthy, P. N. 1981. Stalk borer, *Chilo auricilius* Dudg management in sugarcane. *Proc. Nat. Symp. Stalk borer*, 31-42.

Baitha, Arun; Lal, R.J.; Maurya, B.L and Nigam, Rashmi.2016.Bio-intensive management of internode borer (*Chilo sachhariphagus indicus* Kapur) and stalk borer (*Chilo auricilius* Dudgeon).*Int.J.Agril.Inv.***1** (1):80-83.

Baitha, Arun and Singh, B.D.2018. Gregarious phase of Plassey borer, *Chilo tumidicostalis* in Sugarcane.*Ann.Pl.Protec.Sci*.**26** (1): 219-220.

David, H., Easwaramoorthy S and Jayanti, R.1986.*Sugarcane Entomology in India*. (Eds.).Sugarcane Breeding Institute, Coimbatore.p.564.

Gupta, B.D.1959.Insects of sugarcane in India, III- Top borer. *Indian Sug*. **9**:127-150.

Gupta, B. D. 1960. The insect-pests of sugarcane in India-IV The stalk borer, *Chilotraea auricilia* Ddgn.*Indian Sug.,* **10** (1):1-11.

Jaipal, Saroj and Singh, Jaipal.2010.Integrated insect pest management for low external input sugarcane production.*Proc.9th Joint Convention of STAI and SISSTA*: 109-125.

Kalra, A.N. and Prasad, M.1980.Assessment of losses caused by top borer of sugarcane. *Indian Sugar Crops Journal* 7:79-81.

Mazumder, S.K.D.2018.*Top borer of Sugarcane*.OnlineGatha-The Endless Tale, Lucknow.p.280.

Mazumder, S. K. D. 2020 .*Moth borer of Sugarcane*. Daya Publishing House, New Delhi.p.639.

Tanwar, R.K and Varma, Ashok 1997.*Scirpophaga excerptalis* Walker, infestation in relation to its natural parasitoids and sugarcane cultivars in Eastern Uttar Pradesh. *Uttar Pradesh J. Zool.,* **17** (1):33-37.

Varma, Ashok, Kalra, A.N. and Ram Kishor (1982) Some observations on field biology, migration and carryover of stalk borer (*Chilo auricilius* Dudg.) attack. *Indian J. agric. Res*., **16** (20):99-103.
Varma, Ashok and Mitra, Krishna (1981) Recent researches leading to evolve a suitable control programme for stalk borer, *Chilo auricilius* Dudg.*Proc.Nat.Symp.Stalk borer*, pp- 63-68.
Williams, J.R., Metcalfe, J.R., Mungomery, R.W and Mathews, R.1969. *Pests of Sugarcane*. Elsevier Pub. Co., Amsterdam.p.568.

Chapter No. 43: Insect Pest Management in Sugarcane

Sharmila Roy
Principal Scientist, Division of Crop Protection
ICAR-Indian Institute of Sugarcane Research, Lucknow-226 002
E-mail: sharmila.roy@icar.gov.in

INTRODUCTION

In India, sugarcane is grown in two different agroecological zones - the tropical peninsular zone with moderate temperature and the subtropical zone with extremes of weather conditions.Insect pest complex vary in both these zones mainly due to the variation in climatic factors, edaphic factors, variety composition, cultivation practices.

In subtropical region of India sugarcane is one of the major crops grown in rotation with wheat and rice. About 288 insect pests were recorded on the sugarcane including insects, mites and vertebrate pest. Out of theses around 24 insects were reported as major pests causing considerable economic losses among them borers, sucking pests, subterranean pests are of major importance. Losses due to various pests in sugarcane are in the tune of about 20% and sugar recovery about 1-2 units. However, variations in losses in cane yield and sugar recovery depends on type and intensity of pests, sugarcane variety, season and cropping location.Crop protection package includes cultural, mechanical, chemical and biological measures. But being an economical crop the first choice for the cane growers are the chemical pesticides due to its quick perceived effects, easy availability and simplicity in application.

INSECT PESTS

Based on the feeding habit sugarcane insect pests may be classified as borers, sucking pests, subterranean pests, defoliators and non-insect pests. As per economicimportance,sugarcaneinsectpestsmay also be grouped asmajorpests causingseriousdamage,minororsecondarypestsincur less damage and sporadic pests appear occasionally.These insect-pests damage below ground and above ground parts of the plant.

Amongst the insect pests attacking the aerial parts of sugarcane, about a dozen borers and sucking pests are important. Amongst borers, early shoot borer, *Chiloinfuscatellus*; root borer, *Polyochadepressella*; top borer, *Scirpophagaexcerptalis;*stalk borer, *Chiloauricilius;* internode borer, *ChiloSacchariphagus indicus* are of national importance while gurdaspur borer, *Acigonasteniellus*and plassey borer, *Chilotumidicostalis* is of regional importance. Pink borer, *Sesamia inference*; green borer *Rhaphimetopusablutella* also found attacking sugarcane in pockets.

Amongst sucking pests,Pyrilla,*Pyrillaperpusilla;* mealy bugs; black bug, *Cavelariussweeti*and *Dimorphopterus gibbus;* scale insects, *Melanaspis glomerata and* sugarcane woolly aphid,*Ceratovacunalanigera* is of national importance.

Subterranean insect-pests of sugarcane, termites and white grubs are most damaging throughout the world. In general, termites are regular pest of sugarcane from planting till harvest, while white grubs are sporadic in distribution but during some years serious damage is inflicted to the crop in wider area. Root aphids and mealy bugs are reported as minor subterranean pests of the crop causing negligible damage to the crop.As many as 13 species of termites and 33 species of white grubs are reported to damage sugarcane in India. The most damaging species of termite is *Odontotermes obesus* and white grub is *Holotrichiaconsanguinea,* besidesfew more species are also causing severe loss to the crop.

Table 1 Major pests of sugarcane in India (recreated from David and Nandgopal 1986)

Borers	Sucking pests	Subterranean pests
Early Shoot Borer, *Chiloinfuscatellus*	Pyrilla,*Pyrillaperpusilla*	Termites, *Microtermesobesi, Odontotermes obesus*, *O. wallonensis, O. assmuthi, Trinervitermesbiformis Capotermesheimi*
Internode borer, *Chilosacchariphagus indicus*	Woolly aphid, *Ceratovacunalanigera*	White grubs, *Holotrichia serrata, H. consanguinea, Lepidiotamansueta, Leucopholislepidophora*
Top borer, *Scirpophagaexcerptalis*	Whitefly, *Aleurolobusbarodensis Neomaskelliabergii*	
Stalk Borer, *Chiloauricilius*	Scale Insects, *Melanaspis glomerata*	
Root borer, *Emmaloceradepressella*	Pink mealy bug, *Saccharococcus sacchari*	
Plassey borer, *Chilotumidicostalis*		
Gurdsapur borer, *Acigonasteniellus*		

MANAGEMENT OF INSECT PESTS

Althoughfarmers are having more reliance on pesticidesfor the management of the pests in sugarcane, there are more effective, economical and eco-friendly tools which are required to be promoted in a big way for better productivity of the crop. It has become more relevant when we are focusing on doubling the farmers income for which a major thrust is given on minimizing the input cost of cultivation. Various management strategies are mentioned hereunder.

1. **Habitat modification**
   - Planting flowering plants or compatible cash crops in and around the field by arranging shorter plants towards main crop & taller plants towards the border to attract natural enemies as well as to avoid immigrating pest population
   - Keeping weed plants like *Tridax procumbens*, *Ageratum*sp, *Alternanthera* sp. etc. which act as habitat and nectar source for natural enemies of pests
   - Crop rotations with leguminous plants to enhance nitrogen content and destroy hibernating pests
   - Keep soils covered year-round with living vegetation and/or crop residue
   - Add organic matter in the form of farm yard manure (FYM), vermicompost, crop residue which enhancebelow ground biodiversity
   - Reducing tillage intensity to protect hibernating natural enemies

2. **Host plant resistance**
   - Use resistant or moderately resistant varieties
   - Selection of seed: Seed should not be selected from the fields; even having low level (5%) of disease & insect pests' infection
   - Apply mychorrhiza& plant growth promoting rhizobacteria (PGPR)
   - Seed treatment with *Trichoderma* spp. &*Pseudomonas fluorescens* as setts, nursery treatment

3. **Cultural & mechanical methods**
   - Treat the setts with recommended pesticides especially biopesticides
   - Moist Hot Air Treatment (MHAT): Seed canes must be treated at 54°C & 95-99% RH for 2½ hours to eradicate sett-borne diseases
   - Follow proper spacing
   - Soil health improvement (mulching & green manuring as per need)
   - Nutrient management especially organic manures & biofertilizers as per soil test

- High nitrogenous fertilizers make crop susceptible to insects & diseases
- Follow irrigation schedule
- Follow crop rotation
- Monitoring field situation at weekly interval for soil, water, plants, pests, natural enemies, weather factors etc.
- Removal of diseases & insect infested plants
- Remove & destroy the lower leaves bearing egg masses
- Monitoring & mass trapping of adults through pheromone trap. For monitoring 4-6 traps/ ha & for mass trapping 16-20 traps/ ha may be used
- Yellow pan water/sticky traps for control of woolly aphids & whitefly @ 4-5 traps/acre
- Rapid roving surveys for monitoring pests/diseases & assess biocontrol potential.

- Use light traps to capture adult population of insect pests
- Detrashing of leaves helps in management of mealybugs & black bugs from the cane stalk
- Destruction of crop residues & avoidance of ratoon crop is recommended in the heavily infested areas

4. <u>Biological control</u>

A number of natural enemies recorded on important pests. Mortality caused by various natural enemies are quite reassuring. Enrichment of field population of natural enemies through inundated or inoculative releases lead to effective management of pests

For borers

- Use of Trichocards (*Trichogramma chilonis* @ 50,000 adults/ ha) at 7 days interval
- Release of larval parasitoid *Cotesiaflavipes* @ 500 gravid females/ ha and/or *Sturmiopsis inferens* @ 125 gravid females/ha and/or *Isotima javensis* @ 125 gravid females/ ha at 7 days interval from July to October
- Spraying of shoot borer granulosis virus (G.V.) 10^7-10^9 I.B./ ml

Pyrilla

- Remove & destroy the lower leaves bearing egg masses during April-May
- Release of 4000-5000 cocoons/ ha of *Epiricania melanoleuca* during July-August
- Foliar spray of *Metarhiziumanisopliae* @ 10^7 spores/ ml or release of 250 adults of Pyrilla/ ha loaded with *Metarhiziumanisopliae* spore dust

Sugarcane woolly aphid

- Release*Diphaaphidivora* @1000 larvae or *Micromusigorotus* 2000 larvae & adults/ haat fortnightly intervals to contain the pest effectively

Sugarcane mealy bug & black bug

Release of 5000 adults/ ha seeded with spores of *Beauvariabassiana* to check carry over population of black bug

White Grub

- Jarring & shaking of host trees & killing of beetles
- Use insect trap (IISR-Combo Insect Trap) for monitoring & mass trapping of beetles
- Application of bio-agents (*Beauveria bassiana*/ *B. brongniartii*/ *Metarhiziumanisopliae*/ *Bacillus* spp./ EPN) as per availability & feasibility

5. **Need based application of pesticides:**

- Pesticides should be used as a **last resort under strict recommendation** of the experts. Dosage, time & method of application should be given due attention for better results
- CIBRC registered 18 pesticides for sugarcane. However, State Agriculture Department of Uttar Pradesh recommended 16 pesticides for sugarcane, of which, five were not registered by Central Insecticides Board & Registration Committee (CIBRC) listed in table 2.

Table 2 Registered pesticides for sugarcane

Pesticides registered for crop by CIBRC	Pesticides recommended in the state for crop	Pesticides registered s by CIBRC but not recommended in Uttar Pradesh	Pesticides recommended in Uttar Pradesh but not registered by CIBRC
18	16	7	5
2,4 D, Atrazine, Bromadiolone, Carbofuran, Chlorantraniliprole, Chlorpyrifos, Cypermethrin, Dichlorvos, Diuron, Fipronil, Hexazinone, Imidacloprid, Lindane, MEMC, Metalaxyl, Monocrotophos, Phorate, Quinalphos	2,4 D, Atrazine, Carbofuran, Chlorpyrifos, Dichlorvos, Fipronil, Imidacloprid, Lindane, Monocrotophos, Phorate, Quinalphos, Carbaryl, Fenvelarate, Dimethoate, Copper Oxychloride, Sulphur	Bromadiolone, Chlorantraniliprole, Cypermethrin, Diuron, Hexazinone, MEMC, Metalaxyl	Carbaryl, Fenvelarate, Dimethoate, Copper Oxychloride, Sulphur

6. **Regulatory Management:**

In order to restrict entry, establishment and spread of some of the important sugarcane diseases and insect pests causing severe losses elsewhere in the world, Government of India has made certain provisions/ restrictions under Plant Quarantine (Regulation of Import into India) Order, 2003 on importsof sugarcane and its plant parts. Details are mentioned in table 3.

Table 3 Regulations on sugarcane imports under Plant Quarantine Order, 2003

Schedule-IV: (Prohibited Imports)				
Sl. No.	**Plant species/ variety**	**Categories of plant material**	**Prohibited from the countries**	**Justification for prohibition**
(12)*	Sugarcane (*Saccharum*	Cuttings or setts of	Fiji, Papua New Guinea, Australia, Philippines and	Due to incidence of destructive Fiji virus

	spp.)	planting	Indonesia		
Schedule-V: (Restricted Imports)					
Sl. No.	**Plant species/ variety**	**Categories of plants & plant material**	**Additional declarations required to be incorporated into PSC**	**Special conditions of import**	**Responsibility of authorized Institutions**
(13)*	Sugarcane (*Saccharum* spp.)	Cuttings of setts for planting	Freedom from: a) Fiji virus of sugarcane b) Gummosis (*Xanthomonas vasculorum*) c) Sugarcane white leaf (*Phytoplasmas*) d) Sereh e) Sugarcane downy mildew (*Peronosclerosporasa chhari*) f) Mottled stripe (*Pseudomonas rubrisubalbicans*) g) Sugarcane viruses *viz*., bacilliform, mild mosaic, mosaic & streak h) American sugarcane borer (*Diatraeasaccharalis*)	i) Growing of consignment under post-entry quarantine for a period of one year. ii) Hot water treatment of setts at 52^{0}C for 20 min followed by dipping in systemic fungicide solutions *viz*., Benelate at 0.2% just prior to planting iii) All pack-ages & packing material shall be disposed off by burning.	Subject to the recommendation, supervision, monitoring and testing by Director, Sugarcane Breeding Institute, Coimbatore (Tamil Nadu)
		True seed or fuzz	As stated above at b) & e).	iv) Hot water treatment of fuzz at 58^{o}C for 5 min. in water with 50 ppm Tween-20 followed by a short dip in a 10ppm solution of suitable fungicide just before sowing.	
		Tissue cultured plants	Certified that the tissue cultured plants tested and found virus free.	The above conditions i) to iv) shall not apply	

* Figures in parentheses are actual serial number in Plant Quarantine Order, 2003

Further reading:

Central Insecticide Board & Registration Committee, Govt. of India, www.cibrc.nic.in/mup.htm

David, H. and V. Nandgopal. 1986. Pests of sugarcane-Distribution, symptomology of attack and identification. In: *Sugarcane entomology in India*. eds. David, H., S. Easwarmoorthy and R. Jayanthi. ICAR- Sugarcane Breeding Institute Coimbatore. pp 1-29.

Govt. of India, 2003. Plant Quarantine order (Regulation of import into India). Gazette notification S.O. 1322 (E), dated 18th November, 2003 and subsequent modifications. 3328p.

Chapter No. 44: Integrated Pest Management for increasing crop production

Prof. N.K. Bajpai
Director Extension
Banda University of Agriculture & Technology, Banda (U.P.)

The varied climatic conditions allow the cultivation of different agricultural crops throughout the year in different parts of the country. By the time, the uptake of newer technologies in the form of high yielding crop varieties, chemical fertilizers and pesticides, as well as from the expansion of cropped area have led the remarkable growth in agriculture. Nevertheless, the growth in agricultural production needs to be sustained to meet the food demand of burgeoning population. India's population has been growing at an annual rate of 1.8 percent, and isexpected to touch 1.3 billion by 2020. At this population growth rate,the country would require an additional foodgrains of about 2 million tonnes ayear (Paroda, 1999).Crop protection is one of the major concern while discuss about the improvement in crop productivity. Insect-pests, diseases and weeds cause enormous losses to the potential agricultural production. Evidences indicate that pests cause 25 percent loss in rice, 5-10 percent in wheat, 30 percent in pulses, 35 percent in oilseeds, 20 percent in sugarcane and 50 percent in cotton (Dhaliwal and Arora, 1996).

The effectiveness of chemical pesticides in reducing the losses caused by insect-pests has diminished in recent years. A number of insect pests have developed manifold resistance to the pesticides intended to control them. Further, with the destruction of natural enemies of insect pests, a number of new pests have also emerged. At the same time, there is a rising public concern about the potential adverse effects of chemical pesticides on the human health, environment and biodiversity. In addition, intensive use of chemical pesticides is leading to increased cost of pest control and reduced farm profitability. In recent years, the central government has banned a number of pesticides for use in agriculture in consideration of their adverse effects on environmentand human health. Despite this, many of these are available in the market.For example, DDT and BHC, which are permitted for use for malaria control,are widely used in agriculture. Further, many pesticides that have beenbanned elsewhere in the world are available to Indian farmers.

Changing pest scenario and consequential indiscriminate and injudicious pesticide applications adversely affected the environment. National Centre for Integrated Pest Management(NCIPM) was established in 1988 with major mandate to develop and refine integrated pest management (IPM) modules in major agricultural and horticultural crops through holistic approach on sustainable basis in tune with emerging problems across agro-ecological regions of the country. Deleterious impact of climate change is also challenging the food security in terms of quantity and quality. In the context of these challenges and population burden, Integrated Pest Management (IPM) offers solution by giving rational approach equipped with modern tools and technologies for higher productivity at lower cost.

WHAT IS IPM?

Integrated control is defined as a pest management system that, in the context of the associated environment and the population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible a manner as possible and the maintains the pest populations at level below those causing economic injury (FAO 1967).

Based on an analysis of a number of definitions over the years, the following is offered in an attempt to synthesize what seems to be the current thought:

"IPM is a decision support system for the selection and use of pest control tactics, singly or harmoniously coordinated into a management strategy, based on cost/benefit analyses that take into account the interests of and impacts on producers, society and the environment".

Integrated Pest Management (IPM) is a process consisting of the balanced use of cultural, biological, and chemical procedures that are environmentally compatible, economically feasible, and socially acceptable to reduce pest populations to tolerable levels.

Integrated means that many strategies are used to avoid or solve a pest problem. These strategies come from different disciplines, such as disease information from plant pathologists, weed information from agronomists, and insect information from entomologists.

Pests are unwanted organisms that are a nuisance to man or domestic animals, and can cause injury to humans, animals, plants, structures, and possessions.

Management is the process of making decisions in a systematic way to keep pests from reaching intolerable levels. Small populations of pests can often be tolerated; total eradication is often not necessary.

WHY IPM?

1) To maintain the natural balance of ecosystem.
2) To check the insecticidal pollution to environment.
3) To check the development of insecticidal resistance in insects.
4) To check the destruction of natural enemies and pest resurgence through the injudicious use of insecticides.
5) To check the health hazards and avoid the ill-effects through pesticide use.
6) To conserve natural enemies.
7) To reduce the pesticide residues in feeds, fodder’s and water.
8) To increase awareness about natural enemies.
9) To reduce the injudicious use of insecticides.
10) To sustain the toxic free productivity of crops.

PESTICIDE TREADMILL

Indiscriminate, excessive and continuous use of pesticides acted as a powerful selection pressure for altering the genetic make-up of thepests. Naturally resistant individuals in a pest population were able to surviveonslaughts of the pesticides, and the survivors could pass on the resistancetraits to their generations. This resulted in a much higher percentage pestpopulation being resistant to pesticides.

Table: State-wise consumption of pesticides (technical grade)

States/UTs	Total consumption (tonnes)			Per ha (kg)
	2003-04	2008-09	2015-16	2016-17*
Punjab	6780	5760	5743	0.74
Haryana	4730	4288	NR	0.62
Maharashtra	3385	2400	11665	0.57
Kerala	326	273	1123	0.41
Uttar Pradesh	6710	8968	10457	0.39
Tamil Nadu	1434	2317	2096	0.33
West Bengal	3900	4100	3712	0.27
Chhattisgarh	332	270	1625	0.26
Andhra Pradesh	2034	1381	2713	0.24
Odisha	682	1156	723	0.15
Gujarat	4000	2650	1980	0.13
Bihar	860	915	831	0.11
Karnataka	1692	1675	1434	0.10
Rajasthan	2303	3333	2475	0.05
Madhya Pradesh	62	663	732	0.03
All India	41020	43860	54121	0.29

Note:NR refers to not reported; *GCA based on 2014-15.

Source: Ministry of Chemicals and Fertilizers, Govt. of India.

LOSSES CAUSED BY INSECT-PESTS

Insect pests, diseases and weeds are the major constraints limiting agricultural productivity growth. It is estimated that herbivorous insects eat about 26 percent of the potential food production. Emerging problems of insecticide resistance, secondary pest outbreak and resurgence further add to the cost of plant protection. Annual crop losses due to insect pests and diseases in India are estimated to be 18 percent of the agricultural output. Losses caused by specific pests may be higher. *Helicoverpa*spp. in cotton causes losses up to 50 percent. According to Raheja and Tewari (1997), *H. armigera*(American bollworm) alone causes an annual loss of about Rs1000 crores. The production losses have shown an increasing trend over the years. In 1983, the losses due to insect pests were estimated worth Rs 6,000 crores (Krishnamurthy Rao and Murthy, 1983), which increased to Rs 20,000 crores in 1993 (Jayaraj,1993) and to 29,000 crores in 1996 (Dhaliwal and Arora, 1996). New pests have appeared due to the changes in the cropping patternsand the intensive agricultural practices.

CONCEPTS OF PEST MANAGEMENT

1) **Understanding the agricultural ecosystem-** Agricultural ecosystems contain lesser diversity of animal and plant species than do natural ecosystems such as forest. Usually there are a few major species and numerous minor species and in a pest out break, usually one pest species at a time (often a major species) is present in large numbers. A typical agricultural unit may contain only 1 to 4 major crop species and 6 to 10 major pest species. This lack of diversity in species of plants and species of insects makes agro-ecosystem more susceptible to insect pest damage.

2) **Planning the agricultural ecosystem-** In IPM agroecosystem planning should anticipate pest problem and ways to avoid them. For E.g. susceptible varieties to pest attack should not grow and try to reduce the synchronization between host stage and insect pest.

3) **Cost/Benefit and Benefit/Risk-**Many pest control activities have social and environmental impacts. Therefore, agriculturist can no longer think solely in terms of costs and benefits but must consider environmental effects as well the benefit/risks of pest control.

A) **Cost/Benefit-**By using pesticides the possibility of pest problems can be greatly diminished and catastrophic damage can be prevented. In agriculture the implication of yield increase, often used to show benefit from treatment, is usually erroneous. The use of pesticides rarely increases yield, rather, use prevents loss of yield. Improving capabilities for predicting pest problems and defining economic thresholds will place increased emphasis on cost and benefits.

B) **Benefit/Risk-** Benefit/risk analysis provides a means for assessing the relevant economic benefit versus the risks in pest control. A grower carefully considers the hazard of highly toxic pesticides and takes actions to ensure safety for himself and his workers in handling and in application. Similarly, a grower must consider the effects of pesticides on society and on the environment that is applied.

4) **Tolerance of Pest Damage-** Complete freedom from insect attack is neither necessary in most cases for high yields nor appropriate for IPM. Nearly all plants can tolerate a substantial degree of leaf destruction without appreciable effects on plant vigor. One needs only to examine the holes, blotches, and mines in the leaves of healthy forest trees to appreciate this statement. Quantitative studies of the degree of damage versus reduction in crop yield are urgently needed so that threshold can be established for allowable damage.

5) **Leaving a Pest residue-** The natural enemies are often effectively removed by the direct contact with broad spectrum insecticides regularly applied to fields and also destroyed by starvation when their prey is totally eliminated by chemical control. There are an important concept of pest management is the necessity for leaving a permanent pest residue, below the economic threshold, in an area where control measures are conducted.

6) **Timing treatments-** Treatment should be based on need, and a single spray properly timed can often prevent excessive spraying. More efficient use result forms the careful timing of treatments based on improved techniques of pest population and crop development.

7) **Public understanding and acceptance**- Bringing people to an understanding of pest management is the best way to deal with insect pest problems. No program is any more successful than the degree of commitment made by the people involved. Therefore, extension entomologists should educate growers and the public in the methodologies of pest management and the reasons for using them(Metcalf and Luckmann, 1982).

TOOLS OF IPM

Monitoring: Crop monitoring, that keeps track of the pests and their potential damage, is the foundation of IPM. This provides knowledge aboutthe current pests and crop situation and is helpful in selecting the bestpossible combinations of the pest management methods. Pheromone trapshave got advantage over other monitoring tools such as light and stickytraps. Being selective to specific pest, they have proven their usefulnessin large scale IPM validations in cotton, basmati rice, chickpea andpigeonpea.

Pest resistant varieties: Breeding for pest resistance is a continuousprocess. At the same time the pests also, particularly the plantpathogens, co-evolve with their hosts. Thus, gene transfer technologyis useful in developing cultivars resistant to insects, plant pathogensand herbicides. An example of this is the incorporation of geneticmaterial from *Bacillus thuringiensis* (Bt), a naturally occurringbacterium, in cotton, corn, and potatoes, which makes the plant tissuestoxic to the insect pests. Scientific community is impressed by its hugepotential in managing the pests, but is also concerned about thepossibility of increased selection pressure for resistance against it andits effects on non-target natural fauna. However, due to ethical,scientific and social considerations, this potential technology has beensurrounded by controversies.

Cultural pest control: It includes crop production practices that makecrop environment less susceptible to pests. Crop rotation, fallowing,manipulation of planting and harvesting dates, manipulation of plant and rowspacing, and destruction of old crop debris are a few examples of culturalmethods that are used to manage the pests. Planting of cover crops, nectarproducingplants and inter-planting of different crops to provide habitatdiversity to beneficial insects are important management techniques. Covercrops, often legume or grass species, prevent soil erosion and suppressweeds. A cover crop can also be used as a green manure, which isincorporated in the soil to provide nitrogen and organic matter to thesubsequent crop. When incorporated in the soil, some cover crops of the*Brassica* family have the ability to suppress nematode pests and wilt diseases.Left in the field as residues, rye and wheat provide more than 90 percentweed suppression. Cultural controls are selected based on knowledge ofpest biology and development.

Physical or mechanical controls: These are based on the knowledge ofpest behaviour. Placing plastic-lined trenches in potato fields to trap migratingColorado potato beetles is one example of the physical control. Shaking ofthe pigeonpea plant to remove *Helicoverpa*larvae is a common practice inpigeonpea growing areas. Hand picking of insect pests is perhaps the simplestpest control method. Installation of dead as well as live bird perches incotton and chickpea fields has proved effective in checking the bollworminfestation. Using mulches to smother weeds and providing row covers toprotect plants from insects are other examples.

Biological controls: These include augmentation and conservation ofnatural enemies of pests such as insect predators, parasitoids, parasiticnematodes, fungi and bacteria. In IPM programmes, native natural enemypopulations are conserved, and non-native agents may be released withutmost caution. *Trichogramma*spp. is the most popular parasitoids beingapplied on a number of host crops. A number of microorganisms such as*Trichoderma* spp., *Verticillium* spp., *Aspergillus* spp., *Bacillus* spp.

andPseudomonas spp. that attack and suppress the plant pathogens have beenexploited as biological control agents.

Chemical controls: Pesticides are used to keep the pest populations beloweconomically damaging levels when the pests cannot be controlled by othermeans. Pesticides include both the synthetic pesticides and plant-derivedpesticides. Synthetic pesticides include a wide range of man-madechemicals. These are easy to use, fast-acting and relatively inexpensive.Ideally, pesticides should be used as a last resort in IPM programmes becauseof their potential negative effect on the environment. Pesticides with theleast negative impacts on non-target organisms and the environment aremost useful. Fortunately, new generation pesticides with novel modes of action and low environmental effects are being developed and registeredfor use. Pesticides that are short-lived or act on one or a few specificorganisms fall in this class.Economic threshold assessment is based on the concept that most plantscan tolerate at least some pest damage. Much research has been done todetermine the damage thresholds for a variety of crops and pest situations,yet the studies are inconclusive. In an IPM programme where the economicthreshold is known, chemical controls are applied only when the pest'sdamaging capacity is nearing to the threshold, despite application of otheralternative management practices.Botanical pesticides can be prepared in various ways. They can be assimple as raw crushed plant leaves, extracts of plant parts, and chemicalspurified from the plants. Pyrethrum, neem, tobacco, garlic, and pongamiaformulations are some examples of botanicals. Some botanicals are broadspectrumpesticides. Botanicals are generally less harmful to theenvironment, because of their quick degrading property. They are lesshazardous to transport. The major advantage is that these can be formulatedon-farm by the farmers themselves.

STRATEGIES FOR IPM IMPLEMENTATION

The IPM packages tested at several research centres*vis-a-vis* the farmers'practices indicate superiority of the former. IPM practices enabled reductionin the number of chemical sprays. IPM system also resulted in increase ofnatural enemies by three-fold, reduced the insecticide and environmentalpollution (Dhaliwal and Arora, 1996).An integrated strategy for the management of major pests and diseases ispossible by (i) breeding new varieties with built-in resistance, (ii) evolvingefficient methods of pest control through pest surveys and monitoring, and(iii) biological control of pests with the help of conservation and augmentation20of natural enemies like parasites, predators and insect pathogens.Economically viable integrated pest management strategies have beendeveloped for the control of major pests in rice, cotton, pulses, sugarcane,etc. Control of Pyrilla and top borer of sugarcane, mealy bug of coffee,lepidopterous pests affecting cotton, tobacco, coconut, sugarcane, etc. area few examples where success has been achieved through the release ofbiocontrol agents. A major achievement has been the development of massrearing technology for biocontrol agents such as *Trichogramma*spp.,*Chrysoperla*spp. and nuclear polyhedrosis viruses (NPV) of *Heliothis*and *Spodoptera*.

BIOLOGICAL CONTROL AGENTS

Common names	Formulations	Target organisms	Recommended dose
Trichogramma chilonis Ishii (Hymenoptera: Trichogrammatidae)	Parasitized egg cards	Sugarcane borers *Chiloinfuscatellus*, *C. sacchariphagus indicus*, *C. auricilius*, *Acigonasteniellus*; Cotton (Non Bt) bollworms *Helicoverpaarmigera*, *Pectinophoragossypiella*&*Earias* spp.; Maize stem borer *C. partellus*, Diamond back moth *Plutellaxylostella*; Tomato fruit borer *Helicoverpaarmigera*	50,000/ha on sugarcane and vegetables; 100,000/ha on maize and 1,50,000/ha on cotton
*Telenomusremus*Nixon (E) (Hymenoptera: Scelionidae)	Parasitised egg cards	Tobacco caterpillar *Spodoptera litura*	1 lakh /ha

Goniozusnephantidis(Muesebeck) (I) Hymenoptera: Bethylidae	Cocoons	Coconut blackheaded caterpillar *Opisinaarenosella*	10 adults per palm
*Chelonusblackburnii*Cameron (E) (Hymenoptera: Braconidae)	Adults	Potato tuber moth *Phthorimaeaoperculella*	50000 adults /ha in the field; 2 adults per kg of potatoes in godowns
Cryptolaemus montrouzieri Mulsant (E) (Coleoptera: Coccinellidae)	Adults / Grubs	Mealy bugs *Maconellicoccushirsutus*, *Planococcuscitri*, *P. lilacinus*	10 beetles or 50 grubs /infested plant or tree or 5000 beetles/ha
Coccinella septempunctata Linnaeus (I) (Coleoptera: Coccinellidae)	Adults / Eggs	*Aphis craccivora*on legumes and *Lipaphiserysimi*on oilseed crops	5000 larvae or 500 adults per ha
Chrysoperla carnea (Stephens) (I) (Neuroptera: Chrysopidae)	Eggs / First instar larvae	Sucking pests on cotton, tobacco, sunflower, groundnut& some fruit crops	10,000 first instar larvae/ha
Bacillus thuringiensis	Bt crystals and Bt spores 5%	Lepidopteran, coleopteran and dipteran pests of crops	1kg/ha
*Spodoptera litura*Nuclear Polyhedrosis virus (Sl NPV)	Polyhedral bodies of the NPV Virus 1 X 10^9 PIB/ml	*Spodoptera litura*	250 Larval Equivalent (LE) /ha
*Helicoverpaarmigera*Nuclear Polyhedrosis virus (Ha NPV)	Polyhedral bodies of the NPV Virus 1 X 10^9 PIB/ml	*Helicoverpaarmigera*	250 Larval Equivalent (LE) /ha
Beauveria bassiana, Metarhiziumanisopliae	Spore cum mycelia formulation 1X10^8 CFU/g/ml	Several insect pests of crops	2.5-5.0kg/ hafor foliar spray 2.5-5.0 kg+250-500kg FYM /ha for soil application
Verticillium lecanii	Spore cum mycelia formulation 1X10^8 CFU/g/ml	Sucking pests of various crops	2.5-5.0 kg/ha for foliar spray
Paecilomycesfumosoroseus	Spore cum mycelia formulation 1X10^8 CFU/g/ml	For mite control	2.5-5.0 kg/ha for foliar spray

Source: Compendium of Bioagents in Agriculture, NBAII, Bangalore

Alternative technologies such as biopesticides could provide some solutions. Research has generated a number of technologies using plants and pathogens. Many of these have, however, not been commercialized perhaps due to lack of their proven economic feasibility, short shelf-life, slow effect and incompatibility with chemical pesticides. Technologies such as, *Trichogrammachilonis*and *Crysoperlacarnea*despite their proven effectiveness, do not find favour with industry as well as farmers because of their short shelf-life, sensitivity to chemical pesticides and higher cost of application. Plant-based pesticides are often slow in action. This suggests that the research should target overcoming these technological problems.

BOTANICALS USED IN PEST MANAGEMENT

Botanicals	Target insect-pests
Neem products	Armyworms, cutworms, stem borers, bollworms, leaf miners, caterpillars, aphids, whiteflies, leafhoppers, psyllids, scales, mites and thrips
Rotenone	Bugs, aphids, potato beetles, spider mites, carpenter ants
Sabadilla	Grasshoppers, codling moths, armyworms, aphids, cabbage loopers, squash bugs
Ryania	Codling moths, potato aphids, onion thrips, corn earworms
Nicotine	Aphids, thrips, caterpillars
Pyrethrum	Caterpillars, aphids, leafhoppers, spider mites, bugs, cabbage worms, beetles

NEWER MOLECULES OF INSETICIDES

In recent years, several new insecticide groups having new chemistries *viz.,* neonicotinoids, oxadiazines, diamides, ketoenols, phenylpyrazoles, pyridines, flonicamid, METI (Mitochondrial Electron Transport Inhibitor) acaricides, diafentiuron, tetrazines, thiazolidinones, oxazolines, and insecticides from soil microorganisms such as avermectins, milbemycins, spinosyns, pyrrole insecticides and IGRs have been discovered and commercialized for uses in modern crop protection. The ability of these new groups of insecticides to be effective at low rates or doses, high level of selectivity, greaterspecificity to target pests along with low toxicity tonon-target organisms and the environment, replacedmany conventional compounds. Most of the new insecticide groupsregistered in India during the recent past are safer, highly suitable and fit well intointegrated pest management (IPM).

Table: Recommended dosages of newer molecules of insecticides in major crops

Crops	Name of insect	Dosages (g a.i)/ha	Crops	Name of insect	Dosages (g a.i)/ha
Neonicotinoids			**Phenoxypyrazoles**		
Clothianidin 50 WDG			*Fenpyroximate 5EC*		
Rice	BPH	10-12	Tea, Chilli	Mite	15-30
Cotton	Jassid, whitefly	15-20, 20-25	Tomato	Leaf miner, aphid, fruit borer	90
Imidacloprid 17.8 SL			**CSI**		
Chilli	Jassid, aphid, thrips	25-50	*Novaluron 10 EC*		
Rice	BPH, WBPH, GLH	20-25	Cotton	Bollworm	100
Cotton	Jassid, whitefly, thrips	20-25	Tomato	Fruit borer	75
Okra	Jassid, aphid, thrips	20	**Tetranic acid derivative**		
Tomato	Whitefly	30-35	*Spiromesifen 22.9 SC*		
Imidacloprid 48FS			Vegetables,tea	Yellow mite and red spider mite	96
Cotton, okra , sunflower	Jassid, aphid, thrips, whitefly	300-500/kg seed	**Thiourea compounds**		
Millets	Shoot fly, termites	720/kg seed	*Diafenthiuron 50 WP*		

Thiamethoxam 25 WG			Cotton	Jassid, aphid, thrips, whitefly	300
Rice	Stem borer, leaf folder, BPH, WBPH, GLH	25	Cabbage	DBM	300
Cotton	Jassid, whitefly, thrips	25-50	Chilli	Mites	300
Mango	Hoppers	25	**Pyrroles**		
Tea	Mosquito bug	25	*Chlorfenapyr 10SC*		
Potato	Aphid	25	Cabbage	DBM	75-100
Phenyl pyrazole			Chilli	Mite	75-100
Fipronil 50 SC			**Mectins**		
Rice	Stem borer, gall midge, BPH, WBPH,	50-75	*Emamectin benzoate 5SG*		
Cabbage	DBM	40-50	Cotton	Bollworm	10
Cotton	Jassid, aphid, thrips, whitefly	75-100	Brinjal	Shoot& fruit borer	10
Diamide group			Legume	Pod borer	11
Chlorantraniliprole 18.5 SC			**Spinosyns**		
Rice	Stem borer, leaf folder	30	*Spinosad 45SC*		
Cotton	Bollworm	30	Cotton	Bollworm	75-100
Soybean	Stem fly	30	Legume	Pod borer	70
Okra	Fruit borer	25	Chilli	Fruit borer, thrips	75
Pigeon pea	Pod borer	30	**Oxadiazines**		
Sugarcane	Early & top shoot borer	75	*Indoxacarb 14.5 SC*		
Flubendiamide 20 WG			Cabbage	DBM	30-40
Rice	Stem borer, leaf folder	25	Cotton	Bollworm	75
Cotton	Bollworm	50	Legume	Pod borer	50-60
Cyantraniliprole 10OD			**Pyridine carboxamide**		
Grapes	Thrips	70	*Flonicamid 50WG*		
Cabbage	Aphid, DBM	60	Cotton	Jassid, whitefly	150

Source: Reddy and PushpaLatha, 2015

MAJOR OBSTACLES IN IPM

- Low awareness and innovativeness among different stakeholders.
- Inadequate interaction between research and extension agencies on output of IPM strategies.
- Problem of timely and adequate supply of quality inputs, including bio-control agents and bio-pesticides.
- Complexity with IPM versus simplicity of chemical pesticides.
- The dominant influence of pesticide industry.
- Non-availability of location-specific IPM modules for many crops.

FACTORS RESPONSIBLE FOR SUCCESSFULNESS OF IPM ADOPTION

- Technological characteristics are the important determinants
- Role of agriculture extension system
- Community participation
- Supply of bio-pesticides
- Enforcement of pesticide regulations
- Economic incentives to encourage farmers
- Development of market for pesticide-free products

Conservation of natural enemies of pests and their augmentation is of prime importance in successfulness of IPM. Hence, to maintain ecological balance and to manage the pests, the use of bio-agents and biopesticides/botanicals must receive priority attention. Holistic planning provides farmers with the management tools they need to manage biological complex farming systems in a profitable manner. A successful IPM programme requires time, money, patience, short- and long-term planning, flexibility and commitment. The research managers must spend time on self-education and making contacts with extension and research personnel to discuss farming operations, which vary widely. This would aid in developing integrated plans. The government could create policy environment for promotion of IPM. The central and state governments must take lead in changing the pest control picture through measures that would make chemical control less attractive through legislation, regulatory and fiscal measures.

REFERENCES

Dhaliwal, G.S and Ramesh Arora. 1996. Principles of insect pestmanagement. National Agricultural Technology Information Centre,Ludhiana.

FAO. 1967. Report of the first session of the FAO Panel of Experts on Integrated Pest Control, Rome (Italy), Sept. 18-22, 1967, 19 pp.

Jayaraj, J. 1993. Biopesticides and integrated pest management forsustainable crop production. In: Agrochemicals in sustainable agriculture(Ed. N.K. Roy). New Delhi, APC Publications.

Krishnamurthy Rao, B.H. and Murthy, K.S.R.K. 1983. Proceedingsof National Seminar on Crop Losses due to Insect Pests. Indian J. Ent.(Special issue) (Eds.) B.H. Krishnamurthy Rao and K.S.R.K. Murthy, vols I-II, Hyderabad.

Metcalf, Robert L. and Luckmann, William H. 1982.The Pest Management Concept. In: Introduction to Insect Pest Management IInd Edition. (Eds.) Robert L. Metcalf and, William H. Luckmann. 1 - 32p. John Wiley and Sons. New York.

Paroda, R.S. 1999. For a food secure future. Survey of Indian Agriculture.The Hindu.

Raheja, A.K. and Tewari, G.C. 1997. Awareness programme on pesticidesand sustainable agriculture. 69 pp. Indian Council of AgriculturalResearch, New Delhi.

Reddy, D.S. and Pushpa Latha, M. 2015. Pesticides.New Vishal Publications, New Delhi. p.256.

Chapter No. 45: Red Rot in Sugarcane: Present Status and Management in India

Lalan Sharma, S.K.Shukla, V.P. Jaiswal, Asha Gaur and R. Vishwanathan
ICAR-Indian Institute of Sugarcane Research, Lucknow, Uttar Pradesh (India)

Abstract
Red rot is a fungal disease of sugarcane caused by the *Colletotrichumfalcatum*. Almost all high yielding sugar rich varieties are susceptible to this pathogen. The pathogen is sett borne nature and causing economic damage to the crop mainly subtropical region of the country. It causes damage to crop from germination to crop establishment and reduces juice quality as well. The affected plant/clumps leads to completely drying of plant. This pathogen is variable in nature. Thirteen pathotypes are identified in India based on host differential pattern. For red rot management, resistance genotypes are recommended. Besides this, planting cane seed should be free from red rot infection. Do not plant sugarcane in the disease affected fields for one year because of poor soil survival of the pathogen. Crush the affected crop early and plough up the fields soon after harvesting the crop. Collect and burn the stubbles. Rogue out and bury or burn the diseased canes. Uproot the entire clumps and not merely the affected stalks. Do not ratoon the diseased crop. Advanced molecular approaches are being adopted to develop transgenic cane and efforts have been made against Cf08 and Cf09 pathotype. Recently, sett treatment device (STD) has been developed at ICAR-SBI, Coimbatore for efficient delivery of fungicides and micronutrients and results are impressive for red rot management.

About Sugarcane
Sugarcane is a perennial crop and being cultivated in both tropical and subtropical regions of the world. Nearly one hundred twenty countries grow sugarcane as major crop for sugar production which shares about 80% of total sugar production of the world. The atmospheric conditions are critical factor for growth and development of sugarcane crop. The crop passes through varied climatic conditions during its germination, tillering, elongation and maturity phases. The ideal climatic conditions for sugarcane cultivation are hot and humid conditions which is suitable for better sprouting /germination, fairly dry sun shine and hot weather for higher tillers formation, hot and prolonged humid conditions for higher cane node formation and accumulation of biomass, fairly dry, sunny and cool, frost free cool season for maturity / ripening and harvesting and, cool and dry weather for higher sugar recovery.
In India, state agricultural universities and state research organizations, two ICAR institutes *viz*., ICAR-Indian Institute of Sugarcane Research, Lucknow and ICAR –Sugarcane Breeding Institute, Coimbatore are contributing research activities for development of high yielding and high sugar varieties as well as breeding for resistance to biotic and abiotic stresses. Besides this, All India Coordinated Research Project (AICRP) on Sugarcane is coordinating sugarcane research at the national level. The sugarcane varieties have also been developed for tolerance to red rot disease. They are performing well and can tolerate abiotic stresses up to critical stage. Sugarcane varieties have been widely adopted and occupied larger share in sugarcane area viz., (Co 86032 (70%) in Pennisular zone, Co 0238 (>80%) in North Western Zone and Central Zone, and CoLk 94184 (28%), BO 91 (20%), Co 6907 (20%) and Co Bln 9104 (18%) in Eastern Zone of the country.

Sugarcane variety - Co 0238
An early maturing, high yielding variety Co 0238 (Karna-4), a cross between CoLk 8102 x Co 7755 was released about a decade ago for cultivation in North West Zone. This variety was moderately resistant (MR) to red rot with good ratoonability in winters besides tolerant to both water stress as well as water logging and presently occupying about 85% cane growing area of the state. In last two years, the breakdown of resistance against red rot has been observed in this variety. Red rot incidence (up to 100%) was noticed in this variety in the command area of Parle Sugar Mill, Parsendhi (Bahraich); IPL Sugar Chemical, Jarwal (Baharaich); Simbhaoli Sugar Mills, Chilwariya (Baharaich); KM Sugar Mills, Masaodha (Fizabad), BalrampurChini Mills Groups located in Balrampur and Gonda; Chini Mills of

DSCL group located in Hardoi and LakhimpurKheri; Oudh Sugar Mills, Hargaon (Sitapur) and SeksariaChini Mills, Biswan (Sitapur) of Uttar Pradesh. Therefore, there is an urgent need to take up immediate steps to check the further spread of the disease in healthy areas.

Red Rot of Sugarcane

Red rot of sugarcane was first reported as a disease in sugarcane in Java in 1893. Within a decade after Went's description of the disease and its economic damages to sugarcane milling in Java (Now Indonesia), its occurrence was reported in several other parts of the world. Red rot is one of the most serious diseases of sugarcane in many countries including India, Pakistan, Bangladesh, Thailand, Myanmar, Nepal, Vietnam and other countries. Red rot (*Sereh*) of sugarcane was recorded around 130 years before in Java, and it is one of the most devastating diseases of sugarcane.Since the cultivated sugarcane (*Saccharumofficinarum*) has failed across the sugarcane countries.However, systematic inter-specific hybridization between *S. officinarum* and the wild species *S. spontaneum* referred as 'nobilization' was done to develop resistant varieties and the disease was managed in most of the countries. Varietal breakdown to red rot caused severe epiphytotics, by which the resistant varieties failed in the field at regular intervals, 1938-39 onwards. Extensive cultivation of a single variety over large areas led to extensive crop damages due to 'vertifolia' effect in different decades in India. The current epiphytotic on the ruling variety Co 0238 has caused loss of more than one billion US dollars in the current season in the country

In India, Dr C.A. Barber did foundation work on the disease when it struck for the first time in the then Madras Presidency. E.J. Butler, the Imperial mycologist, at the Imperial Agricultural Research Institute, Pusa, Bihar (India), studied extensively on the causal organism and its portals of entry into the cane stalk. Based on the most distinctive feature of rotting of the internal stalk tissues with reddish discolouration, he named the disease as 'red rot'. Both Barber and Butler recognized the importance of the disease and devised management strategies of healthy seed and avoidance of waterlogging to reduce the crop damage in India. Severe red rot epiphytotics in the Godavari delta and North Indian plains caused extensive damages to sugarcane; however, this scenario resulted in the establishment of Sugarcane Breeding Institute (SBI) at Coimbatore, India, in 1912 by Dr Barber to develop red rot–resistant varieties through interspecific hybridization. Development of interspecific hybrids involving *S. officinarum* and *S. spontaneum* from Coimbatore started from Co 205 in 1918 and later hundreds of 'Co' varieties were released for commercial cultivation and adopted in India and in many other countries. Dr Barber was instrumental in developing many such interspecific hybrids.

Major sugarcane varieties succumbed due to red rot in subtropical regions of India had maximum sugarcane area and productivity, are Co 210 – 15% during 1932-33, Co 213 – 45% during 1938-39, Co 312 – 33% during 1948-49, Co 313 – 15% during 1952-53, CoS 245 – 12% during 1959-60, Bo 17 – 14% during 1970-71, Co 1148 – 39% during 1975-76, Co 1158 – 40% during 1989-90, Co 0238 – 70% during 2015-16, and Co 0238 – 85% during 2020-21. This could happen because of high virulent nature of pathogen. Dark growth type isolates of *C. falcatum* prevalent in the country before 1938-39, epidemics. During epidemics, two morphologic races, light and dark growth type were recorded. Later on R series / ABCDEFGHI stains were designated by various researchers of the country. Based on varietal differential pattern (Baragua, Khakai, SES 594, CoS 767, BO 91, CoC 671, Co 7717, Co 997, CoJ 64, Co 1148, Co 419, Co 62399, Co 975, CoS 8436, Co 7805, Co 86002, Co 86032, CoV 92102, and CoSe 95422), thirteen pathotypes have been identified. The pathotypes are designated as Cf01 – isolate of Co 1148, Cf02 – isolate of Co 7717, Cf03 – isolate of CoJ 64, Cf04 – isolate of Co 419, Cf05 – isolate of Co 997, Cf06 – isolate of Co 671, Cf07 – isolate of CoJ 64, Cf08 – isolate of CoJ 64, Cf09 – isolate of CoS 767, Cf10 – isolate of CoA 89085, Cf11 – isolate of CoJ 64, Cf12 – isolate of Co 94012 and Cf13 – isolate of Co 0238. *C. falcatum* infects nodal tissues and kills the buds; hence, it causes losses in bud germination and crop establishment in the field. This leaves gaps in the field and a poor crop stand leading to losses in cane production.

C. falcatum culture grown on PDA

Prominent midrib lesions (blackish) on the dried top leaves

Reddish discolouration of ground tissue with white spots

Complete destruction of sugarcane crops due to red rot

Red Rot Screening Methods in AICRP (S) programme

Under AICRP(S), red rot pathotypes to be used viz., North West Zone - CF08 & CF13, North Central & North Eastern Zone - CF07 & CF08, East Coast Zone - CF06**,** Peninsular Zone CF06 & CF12. The freshly sporulating, 7-day-old, culture, in Petri-dishes will take. The spore mass will wash with 100 ml of sterile water and collected in a flask. The conidial suspension at a spore concentration of one million spores per ml will prepare for inoculation. Fresh inoculum should always be used for inoculation. To maintain the virulence of pathotype, it should be inoculated in susceptible variety and re-isolated and purified.Two screening method are adopted in AICRP(S) plant pathology programme for red rot. 1. Plug Method: The inoculation is done in the middle of the 3rd exposed internode from bottom and two drops of the spore suspension (10^6 spores/ml) is injected with a large syringe in each cane and sealed with plastic clay (plasticine) or modeling clay. 2. Nodal Cotton Swab Method: The canes after removing leaf sheath (lower most green leaf sheath) are used and immediately placing cotton swab (dipped in freshly prepared inoculum suspension) around the cane covering nodal region. The cotton swab should be held in place by wrapping parafilm around the cane stalk. How to Score - The canes to be split open longitudinally sixty days after inoculation along the point of inoculation. Inoculated canes free from borer infestation and other damages are taken for evaluation. This is graded on the international scale of 0-9 as follows: the reaction is as 0.0 to 2 - R, 2.1 to 4 – MR, 4.1 to 6 – MS, 6.1 to 8 – S, Above 8 – HS. Note: Average score is taken into account for assigning the disease reaction.

No. of canes evaluated	Condition of tops*	Lesion width ** (LW)	White spot ‹ (WS)	Nodal transgression ※ (NT)	Total Score	Remarks
1.						
2.						
3.						

* 1.Condition of top: Green (G)-0; Yellow (Y)/Dry (D)-1.
**2. Lesion width above to inoculated internode is assigned the score 1, 2 or 3
‹ 3. White spot is assigned score of 1 or 2 according to whether it is restricted or progressive.
※4. N.T. No. of nodes crossed above the inoculated internode and given the score as
1- if one node crossed; 2-if two nodes crossed; 3. if three nodes are crossed (maximum)
Average Score = Total Score/No. of canes evaluated
In Nodal Cotton Swab Method, remove cotton swab and scrap the node with a knife. Record presence/absence of lesions. In case lesions are progressing into stalk, the reaction is to be recorded as S (susceptible) and if no lesion development, then R (resistant).

Management

For red rot management, resistance genotypes are usually recommended. Do not plant sugarcane in the disease affected fields for at least one year. Crush the affected crop early and plough up the fields soon after harvesting the crop. Collect and burn the stubbles. Rogue out and bury or burn the diseased canes. Uproot the entire clumps and not merely the affected stalks. Do not ratoon the diseased crop. An sett treatment device has been development at ICAR-SBI, Coimbatore for efficient delivery of fungicides and micro-nutrients. The results showed that sett treatment using sett treatment device (STD) with fungicide Thiophanate methyl (0.1%)followed by soil drenching with Thiophanate methyl (0.1%) at 45th & 90th day was most effective against red rot. It has been reported reported that treating setts in the STD with the combination of thiophanate methyl and *Paenibacillusalvei* at 50% concentration was found to be significantly superior (0% PDI) as against 66.6% PDI in inoculated control. Further mechanized sett treatment with both the bio-control agents and fungicide individually or in combination were found to be not deleterious and were effective in reducing the disease incidence, improving plant growth and yield attributes.Nayyar and co-workers reported the expression of β-1,3- glucanase gene from *Trichoderma* spp. in red rot–susceptible sugarcane cvCoJ 83 with CaMV 35S promoter through *Agrobacterium* mediated in planta genetic transformation. The transgenic lines have expressed resistant reaction to the *C. falcatum*pathotypes CF08 and CF09 under *in vivo* conditions. Inside the parenchymatous tissues, the expressed gene caused inhibition of fungal growth by lysis. They further reported that upregulation of the transgene after *C. falcatum* inoculation up to 2.0-fold in leaves and 5.0-fold in roots and the expressed protein cleaved β-1,3- glycosidic bonds, which leads to lysis of the invading fungus. Detailed study is required on genetic based pathotypes identification and developed of red rot resistant genotypes using advanced molecular approaches.

Chapter No. 46: Integrated pest management in sugarcane

Maha Ram Singh
Principal Scientist
Division of Crop Protection
ICAR-Indian Institute of Sugarcane Research, Lucknow

FAO panels of experts in 1967 defined IPM as "**The pest management system that, in the context of the associated environment and population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible manner as possible and maintains the pest population at levels below causing economic injury".** Integrated pest management is mainly the adoption of available methods and strategies to suppress pest population below Economic Injury Level (EIL) by target pest population at Economic Threshold Level (ETL) with social, economic and ecological acceptance for methods and strategies have to be adopted. It has been realized internationally that the rush of synthetic insecticides in different field crops including sugarcane has come to an end after their excessive and/or indiscriminate use with sole objective to obtain rapid kill of the pests (Fig.1). In IPM, all kind of available pest control methods are being blended in the manner with minimum bear disruption to crop ecosystem and crop based food web. There are some important components of IPM in agriculture are 1) identification of pests to be managed in crop production system, 2) defining the management unit, 3) development of pets management strategy, 4) adoption of reliable monitoring techniques, 5) defining Economic Threshold Level (ETL) and 6) evolvement of descriptive and predictive models. Besides these components of IPM, other modifications in life cycle of pests to reduce pest population in accordance with ecology, methods and pest control strategy and social acceptance are helpful in achieving effective IPM of pests.

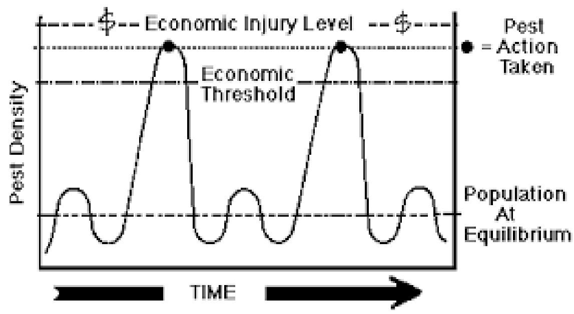


Fig.1. Economic importance of pest densities

The physical characteristics of sugarcane crop do not ease the application of insecticides once canopy of crop is closed. Therefore, individual method of pest control generally inclines to be an incomplete effort and IPM is practiced without deliberate efforts. Consequently, the pressure of insecticides in standing crop is generally is very less compared to other crops thus the disaster phase has not been reached in sugarcane. But, taking note from other crops, it is essential to adopt IPM practices in sugarcane too.

Several authorities in sugarcane entomology like Pradhan (1969), Singh (1977), Krishnamurthy et. al. (1976) and in later years Sidiqui and Agrawal (1973), Awasthy (1983, David1979 and Sithanantham (1980) suggested Integrated Approach for the management of insect pests of sugarcane.

Sugarcane Based Agro-Ecosystem:

Sugarcane based ecosystem in India is quite diverse as the cultivation of sugarcane is being done in various agro climatic conditions ranging moderate climatic conditions in tropical peninsular India to subtropics characterized by extremes of weathers. Sugarcane is a long duration crop standing in the field for at least 12 months. A sound understanding of factors interfering pest population dynamics under such variable environment and for long duration is prerequisite.

Sugarcane plant, varieties and associated crops:

One time planted crop stands in the crop for about three years (one year as plant and two years as ratoon crop) that approximates monoculture and provides a congenial environment for the development of large number of pests and their natural enemies.

In commercial cultivation, sugarcane is planted mainly in autumn (October-November) and spring (February-March) season or *adsali* and *eksali* planting and main and special season planting. Staggered planting is preferred to facilitate longer crushing period in sugar mills and *khandsaari*. With this practice of planting and harvesting, all stages cane crop is available in field for the buildup of different pests and their bio-agents.

Sugarcane varieties display different reactions against insect pests of sugarcane from resistant to moderately resistant and susceptible to particular pest in particular climate. Reaction may change as it is influenced by environmental interaction with edaphic and climatic factors. Besides these factors, morphological characters of sugarcane such as hardness of rind, tightness of leaf sheath, broadness & position of leaf, lodging habit & quick development of roots influence the pest build up.

Basic Principles of Integrated Pest Management in Sugarcane
Pests and natural enemy complex:
Subterranean Insect Pests

Termites:
Termites are known to attack the crop just after planting when setts are still in germination stage and infestation continues till the harvest of crop. Young shoots, tillers and canes are equally damaged. Termites enter through cut ends of setts and buds. Damage of buds hampers germination that results into gaps field. There are several genus and species of termite reported in sugarcane.

White grubs

This is a serious pest in Rajasthan and Gujarat. The grubs feed on roots of sugarcane but adult beetle feed on foliage of trees like *Ber*, *neem, sheeshum* etc.Plants wilt and gradually dry up due to feeding of grubs on roots. The canes in affected clumps fall down. *Holotrichia consanguinea* Blanch. and *H. serrata* Fab. are common white grubs in sugarcane but recently a white grub species (grubs and beetles) has been reported from Bihar causing severe damage to both plant and ratoon crop.

Borer pests:
Root Borer, *Polyocha depressella* Swinhoe
Though this pest does not damage the roots but its damage is restricted to underground part of cane that has roots. Larva of root borer is unstriped and creamy white with orange color mouth parts enters the cane at soil surface level. At shoot stage root borer damage results in formation of "dead hearts" and after that no dead hearts are formed.

Shoot borer, *Chilo infuscatellus* Snellen.:
The damage is caused by 5 violet colour striped larvae by boring into cane stalk laterally by one or more holes. They move upward and downward and finally cut growing point and form dead hearts.Dead hearts formed by shoot borer have peculiar foul smell on pulling from spindle. The injury to shoots after the internode formation seldom results into dead hearts in sub tropical India. Larvae can be differentiated from stalk borer larvae with the presence of semicicular crochets on prolegs of shoot borer and circular in the case of stalk borer.

Top Borer, *Scirpophaga excerptalis* Walker:

In subtropical India, top borer is a key and regular pest of sugarcane infesting crop in all phases of growth. The neonate leaves enters midrib of leaf and reach to spindle of plant. The tunneling in midrib turns reddish brown. The larva feeds by boring into the narrow central core towards growing point, it also nibbles the inner half of the leaf surrounding the feeding zone. The damaged leaf dries up and forms 'dead hearts' when fourth instar larva cuts the growing point. The dead hearts thus formed cannot be easily pulled out. When central shoot has been damaged, side shoots develop and produce which is known as 'bunchy Top'.

A bored tiller can be easily identified with a reddish brown, charred and sometimes curved dead-hearts besides leaves having shot holes and galleries in the midrib of leaves indicating downward movement of larva to the growing point.

The moths emerge out from over wintering larvae during March which start egg laying in clusters on underside of the leaf and are covered with brown hairs from the anal tuft of the female moth. The larvae hatch out from these eggs within a week which takes about 1 to $1^1/2$ months for full development. The pupa forms from these larvae takes about a week to form adult moth. Top borer completes five generations in one year as following.

I Brood	-	March II week to May III week
II Brood	-	May II week to June IIweek
III Brood	**-**	**June I week to Aug. I week**
IV Brood	-	Aug. I week to Sept. III week
V Brood	-	Sept. III week to Feb. I week (Over wintering of larvae)

Stalk Borer, *Chilo auricilius* Dudgeon:

The neonate larvae wander for sometime on leaf surface and move downward to central whorl where they feed by scrapping the leaf sheath. Longitudinal orange yellow streaks are observed from tip to base on the both side of midrib. The third instar larvae bore into shoots and internodes of the canes and feed on soft tissues. Thus reduces the quantity and quality of canes.

Internode borer, *Chilo Sacchariphagus indicus* Kapur:

The newly hatched larvae feed on leaf sheath by scrapping which are visible in the form of white streaks on leaf opening. Later the larvae bore into tender cane top. The borer feeds on inner tissues and frass is pushed out to exterior. The damaged nodes get hardened thus become difficult for crushing. In grown up canes a constriction (spiral) in infested joints is clearly visible as a sign of infestation.

Gurdaspur Borer, *Acigona steniellus* (Hampson):

The pest was for the first time reported from Gurdaspur (Punjab) during 1925. The larvae pass through gregarious and solitary phases. In gregarious phase they crawl along the midrib to the cane on which they move for some times and later on segregate on first internode from top. All the newly hatched larvae from one egg mass enter into one top internode through a common hole. The larvae feed gregariously for about a week afterwards they come out and migrate to canes individually in solitary phase .The entrance hole is always made on sheath-less internode and is never below the third internode from the top. In solitary phase the larva suspends themselves from the leaves by silken threads and get disperse. Generally one larva enters the cane but sometimes 2-3 may also enter the cane.

Sucking pests:

Pyrilla, *Pyrilla perpusilla* Walker:

The damage is caused both by nymphs and adults by sucking the sap from the under surface of the lower leaves near midrib resulting into yellowish white spots. The bugs secrete a sweet fluid (honey dew) on foliage on which sooty mould (*Capnodium* sp.) develops as a result photosynthesis is hindered. Excessive desapping of cell sap renders cane useless as the recovery of *gur* and sugar gets reduced considerably.

Female lays eggs in clusters on the underside of leaves near the midrib. The eggs are covered with white cottony wax filaments from the anal tuft of the female. The nymph moults 5-6 times to become adult. The pest breeds in luxuriant crop. Long dry gaps with drought conditions during monsoon period favours fast multiplication of the pest.

Black Bugs

Two genus**,** *Cavelarius sweeti* Slater &Mugomoto and *Dimorphopterus gibbus* Fab are commonly associated with sugarcane and its severe attack is noticed during premonsoon period. The nymphs and adults are found in the leaf whorls and under sheathing bases of leaves. Both nymphs and adults suck the sap from leaves which turn pale yellow with brown patches. The tips and margins of the leaves dry up gradually and sometime entire plant wither. The quality of juice is also affected. The damage of the pest is more pronounced in fields left with trash.

Scale Insects, *Melanspis glomerata* Green

The pest is prevalent in tropical belt of our country .The scales are grayish black in color. They infest the cane in large numbers under the leaf sheath in nodal region .A thick encrustation gets deposited on the internodes, the canes shrivel up and growth is stunted.

Sugarcane Woolly Aphid: *Ceratovacuna lanigera* Zehntner

The pest appeared during 2002 in Maharashtra, later on the epidemics appeared during 2004 in Maharashtra, Karnataka and Andhra Pradesh. The pest has been reported from Bihar, Uttar Pradesh and Uttaranchal also.

The leaves of the infested plants look white due to white woolly coating of the insects. Both nymphs and adults suck the sap from the leaves which adversely affect the sugar recovery. The aphids also secrete honey dew on which sooty mould fungus develops which hinders the photosynthesis activity of the plant. Due to shading off white moulted skin on upper surface of leaves and soil surface gives an appearance of white chalk powder coating.

Minor Sucking Pests:

White flies:

There are three species of white flies, *Aleurolobus barodensis* Mask. *Neomaskellia bergii* Sign. and *N. andropogonis* Corbett among which *A. barodensis* becomes sometimes quite serious. The eaves of affected plants turn yellowish and later on dry up. During heavy infestation black sooty mould develops on leaves causing hindrance in the photosynthesis. The damage caused by the pest results into retardation in plant growth besides reducing the sugar content in the canes.

Thrips:

Stenchaetothrips saccharicidus (Ramk) is a pest of premonsoon period. The nymph rasp the upper surface of leaves and suck the oozing sap as a result leave tips are rolled. Besides above insects some occasional pest viz., leaf hoppers and aphids which cause minor loss to the crop.

Mealy Bugs, *Sacchari coccus sacchari* Cockerell Pseu*dococcus saccharifolli* Green.

The pink mealy bug (*S.coccus sacchari*) is most common pest of occurrence. The oval and flattened nymphs stick in wax over the nodal region below the leaf sheath. Both nymphs and adults suck the sap which creates cavities inside the cane and buds loose vitality.

D. Defoliators:

Grasshoppers (*Hieroglyphus* spp, *Atractomorpha* sp.,) Armyworm (*Mythimna separata* W.) and grey weevils do appear on the crop and cause minor to severe damage.

Bio-agents complex present in sugarcane

Sugarcane being a long duration crop provides enough opportunity for the survival of insect pests and their bio-agents, otherwise crop could not survive. Abiotic factors (temperature, humidity, rains etc) and biotic factors such as bio-agents (predators, parasites, microbials etc.) help in keeping pest population at equilibrium level below economic injury level. There is a large number of bio-agents present in sugarcane based agro-ecosystem.

Status of pests in relation to pest management

As per the guidelines proposed by Metcalf and Luckman (1982), on the basis of general equilibrium position of pest in relation to economic injury level, the insect pests of sugarcane may broadly be categorized as follows:

- Minor pests, population densities of species do not reach to level to cause economic losses
- Occasional pests, population densities of species exceed to Economic Injury level occasionally and cause economic losses.
- Serious Pests, pest population densities explode above economic injury level which is slightly above the equilibrium level.
- Key and Regular Pests, insect pests inflicting heavy losses to crop every year.

Survey, monitoring and identification of key pests

Over all understanding of pest situation region wise it is essential to have rigorous monitoring of the pests. For this purpose several types of the units may be used for sampling of pest population like sugar mill area wise survey may be conducted nationally for covering maximum area or absolute area.

Economic threshold level:

Economic threshold level of pest population indicates if a single individual pests is added to existing population and present population becomes able to cause economic losses to the crop is ETL level. This is the situation at which pest control measures are being kept ready to use against pests.

Table: ET Levels of different insect pests of sugarcane

Pest	**ETL**
Shoot borer	15-22% incidence
Top borer	2-3 egg masses/m row length
Internode borer	17-28% bored canes/6 m row length
Stalk borer	12-16 larvae/6 m row length
Pyrilla	3-5 nymphs +adults/leaf

Ecological basis of pest management:

Great variability is there in ecology of sugarcane pests in India in different agro climatic conditions. In some areas, same insect does not explode to Economic Injury level, whereas in other some areas it does due to several reasons. For effective control of pests it is imperative to have clear cut understanding of ecological factors which are responsible for profoundly influence or modify pest build up or their suppression. Following aspects related to above may provide strong platform for devising effective pest management.

- **Population dynamics of major pests:** A number of biotic physical factors are responsible for determining the population size and their effects on population build can be studied by constructing life table identifying key mortality factors. High mortality is reported in neonate larvae of borers (David, 1979, David and Joseph, 1984). Extremes of temperature are also recorded as key mortality factors of borers. Close monitoring of these factors may help in adaptation of appropriate pest management practice.

- **Seasonal abundance of pets:** High buildup of some pests has been observed in specific season, being influenced by biotic and physical factors. Hot and dry weather conditions are favorable to shoot borer. Moderate temperature and high humidity is favorable to top borer.

- **Pests carry over:** Sugarcane is maintained as perennial crop by phased planting and rationing enables perpetuation of many insect pests.

- **Forecasting:** With the help of available data base on insect pests, build of pest population and use of control measures can be predicted.

Components of pest management:
Cultural Control:
A method of crop protection using careful timings and a combination of agronomic practices as tillage, planting etc. which makes the environment less favourable for pest multiplication. Deep ploughing proper crop rotation, healthy seed setts, Resistant/Tolerant varieties, well rotten FYM, rouging of disease infected plants etc. are worth to be taken under consideration for raising a good crop.

Earthling up during May- Reduces shoot borer
Avoid irrigation at the time of moth emergence- reduces top borer
Heavy manuring at tillering- Infructuous attack of top borer
Late planting- Avoid shoot and top borer
Trash mulching-Protect crop from shoot borer
Potash application-Increases resistance of crop

Mechanical Control: Clipping of leaves having egg masses of borers and removal of deed hearts to be adopted for management of borer pests.

Biological Control: The manipulation of naturally occuring bio- agents for the suppression of insect-pests of crop is referred as biological control .

Parasitoids:
Egg parasitoids :*Trichogramma chilonis, T. japonicum,Telenomus beneficiens* have been most successfully used . The inundative release of these parasitoids from July to October reduces the infestation of many species of borers.

Larval and pupal parasitoids : *Cotesia flavipes ,,Stenobracon deese,Rhaconotus scirphagae, Isotima javensis, Camyloneurus mutator,* and *Sturmiopsis inferens* have been quite successfully used.

Chemical Control:
Insecticides may be used as last resort to control the pests, still their use should be need based and judicious.
Natural Insecticides

- **Plant origin insecticides**
- **Animal origin insecticides**

Synthetic Insecticides: Chlorinated compounds, OP compounds, carbamtes, synthetic pyrethroids and other modern groups. These are mainly of three types wise contact insecticides, stomach insecticides and systemic insecticides. Formulations of insecticides have information on label are Chemical name, a.i. (active ingredient), trade name, type of formulation etc.

Calculations in chemical control on concentration (a.i.) basis
Amount of formulation (Chlorpyriphos 20 EC)=(Required concentration*water)/concentration of formulation.

On active ingredient basis
Amount of formulation= (Required amount of a.i.*100)/concentration of formulation

Behavioral Control:
Pheromone Traps: Sex lure traps are quite useful for monitoring of moth borer pests. Five traps/ha are sufficient for the purpose.

Integrated management schedule for sugarcane pests:
Selection of seed: The seed should not be taken from those fields which have infestation of pests more than 20%.Such of those setts which have borer infestation, should be discarded.

Seed treatment: Moist hot air therapy treated seeds along with dipping in solution of dimethoate 0.08% for 15 minutes for scale insects.

At planting time:
Termites, and root borer:
Apply chlorpyriphos @ 1 kg a.i./ha or imidacloprid @ 100 g. a.i. ha^{-1} in 1600 litres of waters over cane setts at the time of planting.

Shoot borer:

- Drenching of cane plants below leaf whorl with Chlorantranilprol 16.5 SC @ 375 formulation/ha in 800 liters of water in the month of April.
- Release of egg parasitoid, *Trichogramma chilonis* @ 50,000 adults ha^{-1} at 7 days interval in Southern India. Spray of shoot borer granulosis virus (G.V.) 10^7-10^9 I.B ml^{-1} in Tamil Nadu and Karnataka. Release of *Sturmiopsis inferens* @ 125 gravid females ha^{-1} in coastal Tamil Nadu is recommended.

Premonsoon (March-June):
Remove egg masses and cut the infested shoots from the ground level for shoot, root and top borers. Avoid irrigation at the peak period of emergence of top borer moth.

Top borer: Apply carbofuran @ 1 kg a.i ha^{-1} or phorate @ 3 kg a.i. ha^{-1} in root zone in soil against third brood during III-IV week of June when sufficient moisture is available in the field.
Release of *Isotima javensis* in peninsular India has been found quite effective.

Release of *Isotima javensis* @ 125 gravid females ha^{-1} from July to August Release of Tricho cards containing *Trichogramma japonicum*@50,000 adults/ha at 10 days interval from July to October
Root borer, Stalk borer, Internode borer and Gurdaspur borer: Release of egg parasitoid, *Trichogramma chilonis* @ 50,000 adultsha^{-1} at 10 days interval starting from July to October.

Stalk borer, Internode borer: Release of larval parasitoid *Cotesia flavipes* @ 500 gravid femalesha^{-1} at 7 days interval from July to October.

Pyrilla:

i) Remove and destroy the lower most leaves bearing egg masses during April- May

ii) Redistribute of *Epiricania melanoleuca* from heavily parasitized field to negligible parasitized fields.

iii) Release of 4000-5000 cocoons or 4 to 5 lakhs eggs ha^{-1} of *Epiricania melanoleuca* during July-August

iv) When ever Pyrilla population is more than 5 nymphs+adults leaf^{-1} and *Epricania is* almost absent, wait for about a week for appearance of *Epiricania* which will reduce Pyrilla. Spraying of insecticides is not recommended without advice of pest specialist.

V) Foliar spray of *Metarhizium anisopliae* @ 10^7 spores ml^{-1} or release of 250 adults of Pyrilla ha^{-1} loaded with *Metarhizium anisopliae* spore dust has been found quite effective.

Sugarcane Woolly Aphid:

Release *Dipha aphidivora* @1000 larvae ha^{-1} or *Micromus igorotus* at fortnightly intervals to contain the pest.

Black bug:

i) Spray directed towards whorls with systemic insecticides.

ii) Release of 5000 adults /ha seeded with spores of *Beauvaria bassiana* to check carry over population.

Thrips: Spray with monocrotophos 0.04% or dimethoate 0.03%

Mites: Spray with miticides.

White Grub:

i) Collect beetles during night through light trap

ii) Apply phorate or quinalphos granules @ 2.0 kg/ha in soil

iii) Spray host trees like *ber, khejri , babbl,sheeshum* etc. for the control of beetles.

iv) Use of light cum pheromone traps.

Post monsoon (September to harvest):

i) Detrash the dry leaves at monthly interval and remove late water shoots.

ii) Harvest the crop quite deeply and burn the trash

REFERANCES

- Pradhan, S. 1969. Philosophy and feasibility of integrated control. *Proc. int. Sem. Integrated Control., Ent. Soc.* India New Delhi.
- Singh, O. P. 1977. Integrated control of stalk borer, *Chilo auricilius* Ddgn. *Sug News*, **9** : 36-43.
- Krishnamurthy, Rao, B H, K. Lakshminarayana, C. Sesagiri Rao and S. Venkateshwara Rao. 1976. An integrated approach for the control of sugarcane scale, *Melanaspis glomerata* Green. *Proc. All India Sem. Sug. Cane Scale Insect, Nidadavole*. Pp 49-50.
- Sidiqui, Z. A. and Agrawal, R. A. 1973.Schedule for integrated control of sugarcane pests. *Indian Sug.* **22**: 1-3.
- Avasthy, P. N. 1983. Insect management for sugarcane in India, In "*Sugarcane Pest Management in India"* (Balsubramaniuam, M. and A. R. Solayappan, eds) TamilNadu Cooperative Sugar Federation, Madras. P 71-77.
- David. H.1979. A critical evaluation of factors associated with resistance to internode borer, *Chilo sacchariphagus indicus* (K.) in *Saccharum* sp. allied genera and hybrid sugarcane. Ph.D. Thesis, Calicut University, Calicut.
- Sithanantham, S. 1980. Promising trends in ecological pest management in sugarcane. *SISSTA Sug., J.,* **6** : 31-33.

Chapter No. 47: Sugarcane Diseases: Present Status and Management

Dinesh Singh[1]*, Ajita Singh[2] and Priyem Vandana[1]

[1]Division of crop Protection, ICAR-Indian Institute of Sugarcane Research, Lucknow

[2]Department of Plant Pathology, College of Agriculture, SVPUAT, Meerut

Sugarcane (*Saccharum* spp. hybrid) accorded a premier place among commercial crops because of the vast acreage devoted to its cultivation and part and parcel of daily life. It is regarded as integral component of world trade, which is destined to be consumed either as food or as energy or used to grow the crop. India is the second largest cane growing country followed by Brazil and several others. Both Brazil and India accounts 53% of the global cane acreage in 2016-17 (Ram, 2017). India's share 13.34% in the world sugar production during 2016-17 for which three important varieties namely Co 86032, Co 0238 and CoLk 94184 are the best contributors (Ram, 2017).Sugarcane growing countries of the world lie between the latitude 36.7^{o} north and 31.0^{0} south of the equator extending from tropical to subtropical zones. Sugar contains glucose, fructose and galactose and it is widely produced by sugarcane and sugar beet. A report said that an average person consumes about 24 kg of sugar every year and the world is producing around 174 million tonnes of sugar every year. There is no country where sugar is not being used. According to a recent report there are more than 120 countries producing sugar on large scale to meet their own needs and for export. Mostally (80%) of sugar is obtained from sugarcane and the other 20% is obtained from sugar beets.

Sugarcane Production of top ten countries:

- Nearly 1700 million tons of sugarcane are produced annually across 24 million haworldwide.

Country	**Production ('000 t)**	**Area ('000 ha)**	**Yield (T/ha)**	**Country**	**Production ('000 t)**	**Area ('000 ha)**	**Yield (T/ha)**
Brazil	719, 157	9, 081	79. 1	Pakistan	49, 372	943	52. 4
India	277, 750	4, 200	70. 1	Philippian	34, 000	363	93. 7
China	114, 154	1, 695	65. 7	Australia	31, 457	405	77. 6
Thailand	68, 808	978	70. 4	Argentina	2, 900	355	81. 7
Mexico	50, 423	704	71. 6	Indonesia	26, 500	420	63. 1

There are various biotic and abiotic factors are responsible for its low yield, diseases are the major cause of concern. About hundred diseases of sugarcane have been reported from different parts of the world. Over 100 fungi, 10 bacteria, and 10 viruses and about 50 species of nematodes are pests of sugarcane in different parts of the world.

Important Diseases of Sugarcane:

1. Red rot caused by *Colletotrichum falcatum*
2. Smut caused by*Sporosoriumscitamineuma*
3. Wiltcaused by*Fusarium sacchari*
4. Pokkahboengcaused by*Giberellamoniliformis, Fusarium moniliforme*
5. Rust caused by*Pucciniamelanocephala, P. kuehnii*
6. Leaf Scald caused by*Xanthomonasalbilinians*
7. Ratoon Stunting caused by*Leifsoniaxyli* sub sp. x*yli*
8. Grassy shoot disease (GSD) caused by Phytoplasmal
9. Sugarcane mosaic virus (SCMV) caused by virus
10. Sugarcane yellow leaf disease (SYLD) caused by virus

RED ROT:
Red rot of sugarcane was first recorded from java in 1883 and in Indian subcontinent by Barber and later by Butler in 1906.

DiseaseSymptoms:
The symptoms of red rot first appear on the midrib of leaves as red bright lesions with ash grey centre. Near harvesting of the crop (September-October onwards) the leaves show drooping and colour change of upper leaves. Initially, third or fourth leaf from the top show withering and finally the whole crown droop and withers.The withering of leaves progresses downwards as the disease advances. In severe cases, pith of canes dries up and canes shrivelledloosing their weight. If such canes are split open, reddish colour areas can be seen giving an alcoholic smell which develops due to fermentation of sugar. The size of lesions and reddish areas depend on the variety.

History of red rot started with first report of Java (now Indonesia) by Went (1893). He named the fungus *Colletotrichum falcatum* as causal organism and the disease as 'het root snot' meaning 'red smut'. In India, large scale mortalities of sugarcane were first noticed in the Godavari delta of Andra Pradesh due to an discovered disease in late nineties of the 19^{th} century. The disease was first reported in India by Barber (1901) and he showed that it was caused by *Colletotrichum falcatum*. Butler (1906). He also proposed the common name 'red rot' and this name is now accepted universally. He conducted a studies on the disease, particularly on the causal organism, sources and mode of infection. Due to the vegetative nature of the crop, over time pathogen get accumulated in the plant and are transmitted through the seed cane setts. Most of the important diseases of sugarcane like red rot, smut, ratoon stunting, leaf scald, grassy shoot, yellow leaf and mosaic are essentially sett-borne and diseased cane setts play the pivotal role in the establishment of primary infection/inoculum in the field (Kishan Singh, 1973 &Duttmajumder&Agnihotri, 1992). The impervious nature of the rind and size of the setts do not provide ample opportunity for the fungicides alone to act upon the pathogen residing in deeper tissues of the stalk and thus, efficiency of fungicidal treatment in the eradication of sett-borne inoculums is not up to the desired level.

Sources of infection:
The perpetuation of red rot is through infected setts, diseased stubble/debris and by resting propagules in the soil. A major source of primary spread of the pathogen is by infected planting material (Butler and Khan, 1913; Agnihotri*et al*., 1979). The fungus is not a true soil borne organism and cannot persist more than 4½ months in soil (Chona and Nariani, 1952; Agnihotriet*et al*., 1979; Sharma *et al*., 1980; Singh and Singh, 1983). However, Singh *et al*. (1986) showed that the fungus could survive for 7 months in deep buried debris and 8–9 months when diseased debris was placed on the soil surface.

Dissemination:
Secondary spread of the pathogen takes place mainly through rain and irrigation water. Heavy dew and wind also disseminate inoculum (Chona, 1950; Abbott and Hughes, 1961). The conidia produced on the rind wash down with water and cause infection through nodes. Dissemination of inoculum by means of wind appears more difficult because of the mucilaginous nature of the spore mass. But the occurrence of the disease in the upper portion of the canes provides an indication of an aerial mode of dispersal of the inoculum.

Mode of infection:
The pathogen mainly infects canes through nodes and main portal of entry are leaf scar, growth ring, root primordia and buds (Steib and Chilton, 1951; Srinivasan and Alexander, 1966; Sing *et al*., 1977; 1983). The pathogen can also enter the stalk through root cuts, growth cracks and cut end, of the setts (Singh and Singh, 1989).

Management Challenges:
The impervious nature of the rind and size of the setts do not provide ample opportunity for the fungicides alone to act upon the pathogen residing in deeper tissues of the stalk and thus, efficiency of fungicidal treatment in the eradication of sett-borne inoculums is not up to the desired level. Bio-agents and aerated steam therapy have been found to be ineffective in the control of red rot but not up to the economical level. Therefore varietal resistance and Three-Tier Seed Programme has to be relied upon for durability of a variety and control of disease.

SMUT OF SUGARCANE:
The smut of sugarcane commonly known as whip smut is found in many sugarcane growing countries including India. The disease appears to move from wild canes to improved varieties.

DiseaseSymptoms:
The disease show a whip-like black shoot at the apex of diseased plants which may be several feet in length and curved. The smut powder covered with a thin silvery membrane is attached to the whip. The membrane is ruptured and a thick mass of millions of smut spores is scattered by wind. In case of systemic infection, the nodes or eyes produce lateral shoots on affected plants which may also develop whip but if the infection is localized, main shoot may not develop the whip. The smut masses are present in several layers on whips.

Pathogen: The causal pathogen is *Ustilago scitaminea*Syd. Which belongs to family Ustilaginaceae, order Uatilaginales of the sub-division of Basidiomycotina. The smut spores are spherical, punctuate walled, light brown in colour about 5-10 µ in diameter. Under moist condition, the spores germinate and form a septatepromycelium. The sporidia develop from each cell of the septa which are elongated and develop infection threads after their germination. Sometimes the sporidia form more sporidia in chain. The spore germinates at a temperature of 25-40 C with a relative humidity of 100%.

Disease Cycle: The sugarcane crop is available in the field throughout the year. The spores from the whip blown by wind are deposited on the junction of leaves and leaf sheaths of healthy plants and create infection at the nodal region. The infection occurs through germinating shoot on the host tissue or through the injuries made by insects. The disease perpetuates by planting diseased seed setts or through spores brought by wind on to the buds or through ratoon crops

RATOON STUNTING DISEASE (RSD):
DiseaseSymptoms:
Diseased clumps usually display stunted growth, reduced tillering, thin stalks with hortened internodes and yellowish foliage (mild chlorosis). Coryneform Xylem limited fastidious bacteriainfects the vascular bundles of canes. When mature canesare split pen, vascular bundles appear discolored. In young canes, pink colour is seen in the formof minute pin head like areas near the nodes. The disease reduces the length, girth and the number of canes per clump. Affected plants are usually stunted and have poor root system.

- Show reduced tillering and shortening of internodes.
- The diseased shoots on splitting show orange-red discolouration of fibro-vascular bundles at the maturity.

Disease cycle:
The disease spreads through use of diseased setts. The disease also spreads through cane harvesting implements contaminated with the juice of the diseased canes. Maize, sorghum, Sudan grass and Cynodonare some of the collateral hosts of the pathogen.

LEAF SCALD:

Disease symptoms:

The disease can be latent, it can develop unseen for some time and when symptoms fi rst appear, the plant is already seriously infected.The first sign of the disease is the development of "pencil lines" of white with yellow borders following the veins on the leaf that lead to necrosis (death) of tissue.The term "scald" for the disease comes from areas of the leaf that loose their color and become a pale green (chlorotic) as they fail to produce chloroplasts.In nature the disease occurs in two distinct phases'acute phaseand chronic phase. In Acute phase, affected clumps suddenly show wilt symptoms and die without displaying any of the diagnostic symptoms. Whereas in chronic phaseit aappears in plants growing under stress conditions, like drought, low temperature, poor soil fertility or in waterlogged condition.

Disease cycle:

Pathogen survives in cane stubble and on agricultural implements and this is an important mechanism of spreading the disease.It can also survive on grasses, including elephant grass and may be transmitted from them to sugarcane.Favourable conditions are stress such as drought, waterlogging, and low temperature are reported to increase disease severity.

GRASSY SHOOT DISEASE (GSD):

Disease symptoms:

Phytoplasma-infected sugarcane plants show a proliferation of tillers, which give it typical grassy appearance, hence the name grassy shoot disease. The plants appear bushy and 'grass like'due to reduction in the length of internodes, premature and continuous tillering. The leaves of infected plants do not producechlorophyll, and therefore appear white or creamy yellow.The leaf veins turn white(Albino)first as the phytoplasma resides in leaf phloem tissue. Symptoms at the early stage of the plant life cycle include leafchlorosis, mainly at the central leaf whorl. Infected plants do not have the capacity to produce food in the absence ofchlorophyll, which results into no cane formation. These symptoms can be seen prominently in thestubble crop. It is more severe in ratoon crops. Symptoms ofiron deficiency(interveinal chlorosis) are very similar to those of SCGS. It shows creamy leaves, but nochlorosisoccurs in leaf veins, and they remain green.

Disease cycle:

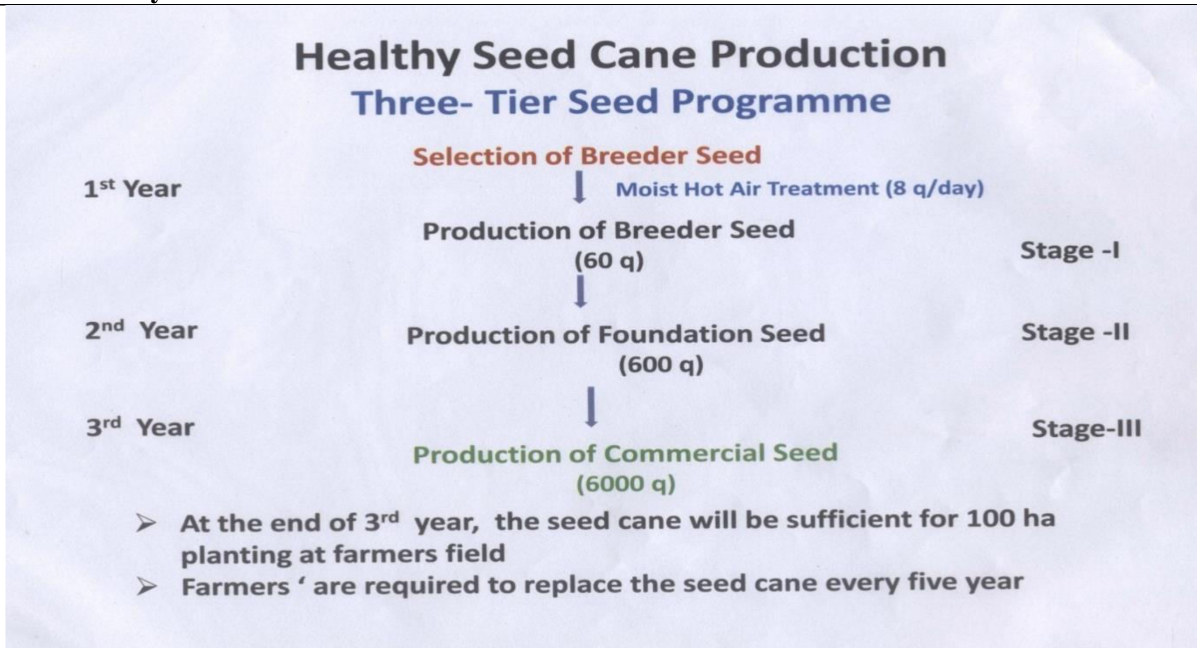
Hytoplasmas, formerly calledmycoplasma-like organisms (MLOs), are a large group of obligate, intracellular, cell wallless parasites classified within the classMollicutes. Sugarcane is avegetativelypropagatedcrop, so the pathogen is transmitted viaseedsetts/planting material and byphloemfeeding vectors as aphids, viz.,*Aphis maidis, Rhopalosiphummaidis, Longiunguissacchari, Melanaphissacchariand M. indosacchari*. In addition, leaf hopper, *Proutistamoestaalso* involves in phytoplasma transmission in sugarcane. Sorghum serves as a natural collateral host.

Integrated disease management (IDM):

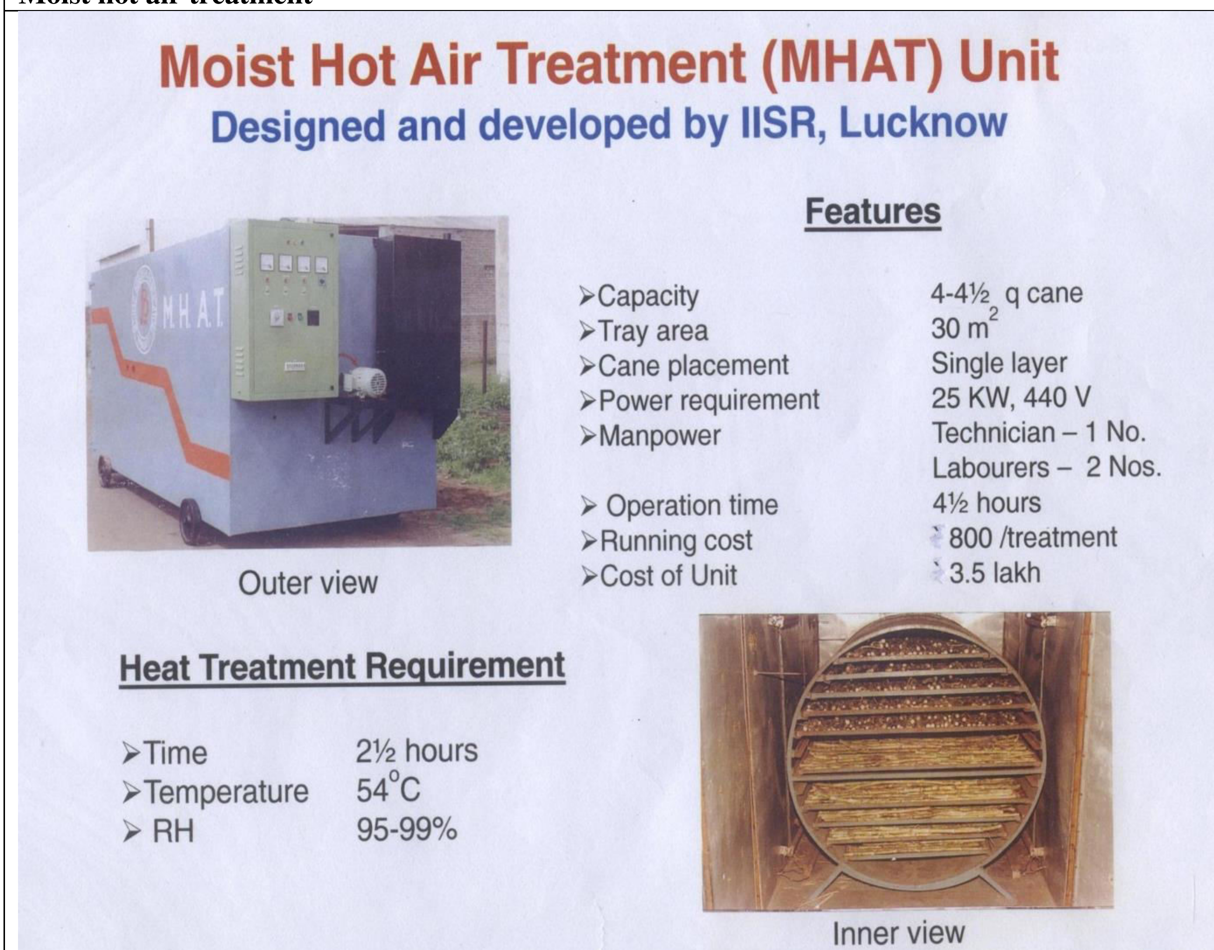
Components of IDM

- Use of healthy seed material
- Moist hot air treatment
- Selection of land
- Field sanitation
- Crop diversification
- Use of recommended (disease resistant) variety

Use of healthy seed material:



Moist hot air treatment



IISR Technology of Moist hot air seed cane treatment unit:
The MHAT unit has been designed to control seed piece transmissible diseases like primary infection of red rot, primary infection of smut, grassy shoot, ratoon shunting and leaf scald of sugarcane, which otherwise pass from one generation to another. It also helps controlling the insect, pests like scale, mealy bugs etc.

REFERENCES:

1. Abbott, E.V. (1938). Red rot of sugarcane. U.S. Department ofAgriculture Technical Bulletin, **641**: 96.
2. Agnihotri, V.P. (1990). Diseases of Sugarcane and Sugar beet.Oxford & IBH Pub. New Delhi, 283.
3. Alexander, K.C. and M.M. Rao (1972). Comparative evaluationof genotypes in the centres in India for resistance to redrot and smut. Proceedings of Diamond Jubilee Symposiumof Sugarcane Breeding Institute, Coimbatore.12-24.
4. Alexander, K.C., M.M. Rao and D. Mohanraj (1985). Diseasereaction catalogue on genetic resources II. SugarcaneBreeding Institute, Coimbatore, Tamil Nadu, India. 226.
5. Alexander, K.C. and R. Viswanathan (1996). Major diseasesaffecting sugarcane production in India and recentexperiences in quarantine. *In:* Croft, B.J., Piggin, C.M.,.
6. Bailey, J. A. and M. J. Jeger. 1992. Colletotrichum: biology, pathology and control. CAB International. Wallingford, UK.

7. Beniwal, M.S., Satyavir and K.S. Virk (1989). Pathogenicvariability in *Colletotrichum falcatum* incitant of red rotof sugarcane. *Indian Phytopathology,* **42**: 95-99.
8. Edgerton, C.W. and C.C. Moreland (1920). Effect of Fungi OnThe Germination of Sugar Cane. Baton Rouge, La.:Agricultural Experiment Station of The Louisiana StateUniversity and A., M. College.
9. Madan, V.K., M. Bikas, M.L. Ansari, A. Srivastava and N. Soni(2000). Rapd-Pcr Analysis of Molecular Variability In TheRed Rot Pathogen (*Colletotrichum falcatum*) of Sugarcane. *Sugarcane International,* **3**: 5-8.
10. Malathi, P., R. Viswanathan, P. Padmanaban, D.Mohanraj and A. Ramesh (2002). Compatibility of biocontrol agents with fungicides against red rot disease of sugarcane. *SugarTech.,***4(3&4)**: 131 – 136.
11. Mohanraj, D., P. Padmanabhan and M. Karunakaran (2003).Effect of phytotoxin of *Colletotrichum falcatum* Went(*Physalosporatucumanensis*) on sugarcane in tissueculture. *ActaPhytopatholEntomol Hung,* **38**: 21–28.
12. Mukhopadhyaya, A.N. (1996). Recent innovations in plantdisease control by eco-friendly bio-pesticides. PresidentialAddress in Agricultural Sciences Section, 83rd IndianScience Congress, Patiala, Promoting Rhizobacteria againstRed Rot Disease in Sugarcane. *Sugar Tech,* **1(3)**: 67 -76.
13. Rao, G.P., R. Viswanathan and S.B. Singh (2002). Currentsituation of sugarcane diseases in India. *In*: Sugarcanecrop management. *Eds*. SB Singh, GP Rao, S.Easwaramoorthy, 734. Houstan: SCI Tech Publishing LLC.
14. Satyavir (2003). Red rot of sugarcane current scenario. *IndianPhytopathology,* **56**: 245-254.
15. Sharma, R. and S. Tamta (2015). A Review on Red Rot: The“Cancer” of Sugarcane. *Plant Pathology & Microbiology,*1-8.
16. Singh, K. (1973). Hot air therapy against red rot of sugarcane.*Plant Disease Report,* **57**:220-222.
17. Viswanathan, R. and K.C. Alexander (1997). Management ofsugarcane diseases. *Indian Journal of SugarcaneTechnology,* **12**: 37-48.
18. Viswanathan, R. (2017). Pathogen virulence in sugarcane red rot pathogen versus varieties in cultivation: classical case of loss in virulence in the pathotype CF 06 (Cf 671). Sugar Tech. 19(3):293-299.

19. Viswanathan, R. and Rao, G.P. (2011). Disease scenario and management of major sugarcane diseases in India. Sugar Tech. 13: 336-353.
20. Wallis, E.S., Hogarth, D.M. (Eds.), Sugarcane GermplasmConservation and Exchange, Proceedings 67. AustralianCentre for International Agricultural Research, Canberra,46-48.
21. Wijesundera, R.L.C., J.A. Bailey, R.J.W. Byrde and A.H. Fielding(1989). Cell wall degrading enzymes of *Colletotrichumlindemuthianum*-Their role in the development of beananthracnose. *Physiological and Molecular PlantPathology,* **34**: 403–413.
22. Went, F.A.F.C. (1893). Het Rood Snot (Summary in English).*Archiefvoor De Java Suikerindustrie,* **1**: 265-282.

Chapter No. 48: State sponsored schemes on improving income of sugarcane farmers in Uttar Pradesh

V.K. Shukla
Additional Cane Commissioner
Department of Sugar Industry and Cane Development, U.P.
Govt. of Uttar Pradesh, Lucknow

Programs Run by the Department for Cane Development

There are different kinds of program are implemented to ensure the availability of the quality seed of sugarcane and enhancing the productivity of the sugarcane to ensure increased earning to the farmer through maximum production with low cost. The programs are given below:-

1. District Plan:- Under this plan the implemented programs are funded solely by the State Government.
2. Rashtriya Krishi Vikas Yojna (RKVY):- Under this plan the implemented programs are funded 60% by the Central Government and 40% by the State Government.
3. National Food Security Mission (NFSM):- Under this plan Under this plan the implemented programs are funded 60% by the Central Government and 40% by the State Government. The program basically aimed to increase the availability of legumes and oil seeds through inter-cropping with sugarcane.

The details of programs run under these plans are given:-

District Plan

S. N.	Program Name	Subsidy
1	Foundation nursery seed distribution Program	On Distribution of Seed produced in foundation nursery, the nursery holder will get Rs. 50 per quintal for seed distribution.
2	Primary nursery seed distributin Program	On Distribution of Seed produced in Primary nursery, the nursery holder will get Rs. 25 per quintal for seed distribution.
3	Breeder Seed Transportation Program	Subsidy of Rs. 15 per quintal will provide for transportation of Breeder Seed.
4	Foundation seed transportation Program	Subsidy of Rs. 07 per quintal will provide for transportation of Foundation Seed.
5	Seed/Soil treatment, Ratoon Management Program	50% of the cost or maximum of rupees or 900 per hectare subsidy is given for Seed/Soil treatment.
6	Use of Biofertilizer/Vermi Compost Program	50% of the cost or maximum of rupees or 600 per hectare subsidy is given for Biofertilizer/Vermi.

Rashtriya krishi vikas yojna (RKVY)

S. N.	Program Name	Subsidy
1	Breeder Seed Production and Distribution Program	This Program is implemented by U.P. Council of Sugarcane Research Shahjahanpur, and Rs. 40,000 Per hectare subsidy is given for seed Production and distribution.
2	Foundation Nursery Seed Production and Distribution Program	On Distribution of Seed produced in foundation nursery, the nursery holder will get Rs. 50 per quintal for seed distribution.
3	Primary Nursery Seed distribution program	On Distribution of Seed produced in Primary nursery, the nursery holder will get Rs. 25 per quintal for seed distribution.
4	Field Demonstration Program	Rs. 9000 per hectare is given for field demonstration for package and practices.
5	Kisan Goshthi / Kisan Mela Program	Rs. 100,000 per district is given for kisan Goshthi / kisan Mela.
6	Training Program	For training of sugar cane farmers and departmental officers/staff, per training Rs. 17000 is provided.
7	Improved cane seed distribution through rural women source program	The Group of 10 to 30 rural women in the sugarcane area are formed for the production of sugarcane seedling and Rs.1.5 per seedling for the seedlings raised from bud chip and Rs.1.30 per seedling for the seedlings raised from single-bud to be paid as subsidy to the groups against seedling distributed by them.

National Food Security Mission (NFSM)

The inter-cropping of pulses and oil seeds is done and the farmers beneficiaries having such plots are paid with Rs.9,000 subsidy per hectare. The minimum size of the plot must be 0.2 hectare or above.

Punchamrat Yojna

Being the thrust of the sugarcane cultivation the Trench Planting, Inter-Cropping, Drip Irrigation, Ratoon Management and Trash Mulcing is promoted by the Department and all 05 Components of the sugarcane cultivation taken under umbrella of Punchamrat Yojna to grap proper attention of the farmers. The farmers adopting the 05 component at the same are honored by the name of “Uttam Kisan” and the facility of yield increment is provided without any charge.

Reward Scheme

To improve the efficiency and work culture and to enhance sugarcane production, the reward scheme launched for the Sugarcane Farmers, Cane Co-operative Societies as well as Sugar Industry. For the purpose merit list is prepared on certain performance standard fixed by the department and top performer rewarded.

S.no		I	II	III
1	Sugar mills	Citation Certificate	Citation Certificate	Citation Certificate
2	Cane Societies	Rs.51,000 + Memento & Certificate	Rs.31,000 + Memento & Certificate	Rs.21,000 + Memento & Certificate
3	Women Self Help Group	Rs.51,000 + Memento & Certificate	Rs.31,000 + Memento & Certificate	Rs.21,000 + Memento & Certificate
4	High Productivity Achiever farmer	Rs.51,000 + Memento & Certificate	Rs.31,000 + Memento & Certificate	Rs.21,000 + Memento & Certificate
5	Young & Highly Educated farmer below 30 Years	Rs.51,000 + Memento & Certificate	Rs.31,000 + Memento & Certificate	Rs.21,000 + Memento & Certificate
6	Lady farmer below 30 Years	Rs.51,000 + Memento & Certificate	Rs.31,000 + Memento & Certificate	Rs.21,000 + Memento & Certificate

Chapter No. 49: Improved Sugarcane Planting and Inter-Cropping Machines

A.K. Singh
Principal Scientist, Division of Agricultural Engineering
ICAR-Indian Institute of Sugarcane Research, Lucknow, India

Abstracts

Sugarcane is an important industrial crop of India. The planting operation of sugarcane is an energy and labour intensive operation. Human drudgery is also involved when the operation is performed manually. Several methods and techniques of planting sugarcane have received attention of researchers from time to time. These methods include flat method, trench method, furrow method, spaced transplanting technique (STP), cane node method etc. However, flat method of planting is much prevalent among cane growers of north Indian plains. Numbers of machineries have been developed at IISR for mechanizing different methods of sugarcane planting. Ridger type sugarcane cutter planter, deep furrow sugarcane cutter planter and trench planter is the multitasking machine which performs all the unit operations of sugarcane planting including sett cutting simultaneously in single pass of the machine. These machines have been demonstrated at different locations. Use of these machines saves the cost of planting operation by 50 per cent and labour by 90 per cent as compared to conventional method. Low cost machineries like trencher, deep furrower, deep furrower-cum-fertilizer applicator were also developed at IISR to promote trench method or deep furrow method of planting. Trenchers are presently adopted at large scale by the farmers due to its low cost and benefits of yield increase, reduction in cane lodging and better ratooning. Pit digger has also been developed for mechanizing pit digging operation for planting of sugarcane in ring-pit method, which is high yielding technique of cane cultivation. Planting machines were also developed for planting of inter crops with sugarcane to take an additional short duration crop without adversely affecting the cane yield. There is need for popularization of these machineries among the cane growers to address the problem of labour availability and to bring cost efficiency in sugarcane cultivation.

Keywords: sugarcane, mechanization, planting, trench, planter, deep furrow, inter-cropping

Introduction

Sugarcane is an important industrial crop of India which is cultivated in an area of about 5.3 million hectares. The total annual production of sugarcane and sugar is about 366 and 28 million tonnes, respectively. In the present context of increased cost of sugarcane cultivation and shortage of labour during peak seasons of sugarcane planting operations, ways and means have to be evolved to keep pace with sugar production requirement with the population growth per unit area, time and input. The challenges can be met effectively by way of adopting the appropriate mechanical alternatives not only for increasing the productivity but inculcating cost efficiency and sustainability in sugarcane production system (Singh et al 2016 and Singh, 2017). The farm mechanization in the context of sugarcane cultivation aims at introducing timeliness of operation and reducing human drudgery on one side and improving overall production efficiency on the other. The planting operation of sugarcane is an energy and labour intensive operation. Human drudgery is also involved when the operation is performed manually. Several methods and techniques of planting sugarcane have received attention of researchers from time to time. These methods include flat method, trench method, furrow method, spaced transplanting technique (STP), cane node method etc. However, flat method of planting is much prevalent among cane growers of North Indian Plains. Planting of sugarcane comprises many unit operations such as opening of furrows, cutting of cane into pieces known as seed setts, placement of setts, fertilizer and insecticide in the furrows and providing soil cover over the setts. Furrows are opened with the help of animal or tractor drawn ridgers. Forty to forty five man-days are required in one hectare to carry out other operations. Since, arranging such a huge number of labour in a day is very difficult, the planting operation prolongs resulting into moisture loss of soil as well as seed setts. A lot of efforts have been made at ICAR- Indian Institute of Sugarcane Research, Lucknow to mechanize sugarcane planting operations.

Machineries for mechanizing sugarcane planting

Numbers of planting machines have been developed at IISR for mechanizing different methods of sugarcane planting (Singh, 2016). Details of these machines are presented below;

Machineries for mechanizing Flat method of sugarcane planting

Various models of sugarcane planters viz. Animal or tractor drawn semi-automatic (billet) planters and later tractor operated sugarcane cutter planters suiting to different agro-climatic and soil conditions have been developed at IISR. Different variants of tractor operated sugarcane cutter planters are either tractor PTO or ground wheel driven. Sett cutting is continuous and uninterrupted in PTO driven planters but proper sett metering is achieved at a particular combination of forward speed and PTO rpm. Sett metering remains same in ground wheel driven planters but precaution is required that ground wheels do not skid and remain in firm contact with soil. Tractor operated planters take four to five hours to cover one hectare. Four to five labourers are needed to operate the planter. There is saving of more than 50 per cent in the cost of planting operation by using sugarcane cutter planter as compared to traditional method.

Machineries for mechanizing Furrow method of sugarcane planting

Recently, there is awareness of water shaving in sugarcane cultivation. In north India, it is being recommended to plant the cane in furrow method to save irrigation water. Planting of sugarcane in furrow method needs machine for deep furrow opening. For this purpose tractor operated deep furrower, deep furrower-cum-fertilizer applicator (Fig. 1) and deep furrow sugarcane cutter planter (Fig. 2) have been developed at IISR during last two years. Deep furrow sugarcane cutter planter is a multitasking machine, which performs all the unit operations involved in sugarcane planting including sett cutting, in single pass of the machine (Singh and Singh 2017). It facilitates planting of sugarcane in deep furrow (20-25 cm) and maintains 5-7 cm loose soil bed underneath the planted seed setts. Planter has been field tested at IISR farm and on-farm trials also also going on at farmers field of western, central and eastern U.P. and Bihar.

Machineries for mechanizing Trench method of sugarcane planting

Planting of sugarcane in deep and wide trenches under wide spaced paired row geometry (30:120 cm) has shown promising results on cane yield, water saving, reduced lodging and better ratooning. In order to reap the benefit of trench method of planting tractor operated trencher (Fig. 3) and trench planter (Fig. 4) were developed at IISR. While trencher performs opening of deep and wide furrow for paired row planting of sugarcane manually whereas, trench planter performs all the unit operations involved in cane planting including sett cutting, like earlier developed sugarcane cutter planters, in single pass of the machine.

Machineries for mechanizing Ring-pit method of sugarcane planting

The ring pit planting technique is very good from the point of view of increased cane productivity but digging of large number of pits over the entire field was found to be very cumbersome and labour intensive. Therefore, the technique could not be pushed for large scale adoption by the farmers. Efforts were made at IISR to develop tractor drawn pit digger for mechanization of pit digging operation (Sharma and Singh 1989. The developed pit digger was able to dig one pit at a time. There was a problem of excessive vibrations and dynamic instability during the operation. Design refinements were made and modified prototypes of pit digger was developed (Sharma and Singh 2007, Singh et al 2017). The equipment dig two pits simultaneously at a time. The developed equipment was tested and evaluated in sandy loam soil at IISR farm. With the help of the equipment approximately 150 pits (75 cm diameter X 30 cm depth) at a spacing of 30 cm were dug per tractor-hour operation. Cost of pit digging operation was saved by 70 per cent by using the pit digger.

Machineries for mechanizing planting of intercrops with sugarcane

Equipment for planting of inter crop with sugarcane has also been developed at IISR. Two types of machineries have been developed for inter cropping on the raised bed with sugarcane (i) raised bed seeder -cum-fertlizer applicator (RBS) (Fig. 5) and (ii) raised bed seeder-cum-sugarcane planter (RBS cane planter). The raised bed seeder is used for making three furrows and sowing of companion crop like wheat on the two raised beds. Sugarcane is planted in the furrows at a later stage manually. With the help of raised bed seeder-cum-sugarcane planter, planting of sugarcane in the furrows and sowing of companion crop like wheat on the raised beds, are accomplished simultaneously in a single pass of the equipment. Recently, sugarcane-cum-automatic potato planter, deep furrow sugarcane cutter planter-cum-multicrop bed seeder (Fig. 6), sugarcane trench planter-cum-multicrop raised bed seeder (Fig.7) have been developed for planting/sowing of intercrop simultaneously with sugarcane. Sugarcane-cum-potato planter (Fig.8) has also been developed for mechanizing planting of sugarcane in furrows and potato on the ridges simultaneously in single pass. These equipments have been performing well during field trials at IISR and other locations.

Fig 1 IISR Deep furrow opener-cum-fertilizer applicator

Fig 2 IISR Deep furrow sugarcane cutter planter

Fig. 3 IISR Trencher

Fig 4 IISR Sugarcane trench planter

Fig 5 IISR Raised bed seeder-cum- fertilizer applicator

Fig 6 IISR Deep furrow sugarcane cutter planter-cum-multicrop raised bed seeder

Fig 7. IISR sugarcane trench planter-cum-multicrop raised bed seeder

Fig 8. Sugarcane-cum-potato planter

Machineries for Ratoon Management

About 55-60 per cent of the total sugarcane area is occupied by ratoon crop in India. It is an integral part of sugarcane cultivation being a profitable proposition. Raising ratoon crop of sugarcane has economic benefits not only for cutting down the cost of land preparation, seed material and cost of planting, but also ensure an economically high recovery in the initial phase of the crushing season because of early maturity than the plant cane. In the countries having sugar export oriented economy, taking 3-5 ratoon is quite common, but in India only 1-2 ratoon is common. Keeping a good ratoon crop is always a problem and it is often less cared for. On an average yield of conventionally grown sugarcane ratoon crop is lower than the sugarcane plant crop. Investigations reveal the fact that the productivity of sugarcane ratoon crop could be improved by applying crop inputs orderly in time and by executing cultural operations like i) shaving stubbles close to the ground surface, ii) off-barring or cutting old roots on either side of the stubbles, iii) interculturing, iv) deep tilling or breaking soil hard pan, v) applying fertilizer, manure, insecticide or pesticides and finally vi) by providing desired amount of soil cover over stubbles or to the plantlets as the case may be. These operations are not only difficult and arduous but also far too uneconomical to be carried over by using conventional tools like spades, cultivators, ridgers etc.

Efforts were made to develop independent tools like stubble shaver, stubble shaver with off-barring and fertilizer application, chemical applicator, power weeder, cultivators, earthing- up equipment, and rippers with limited success. In the present context of increased global competition in world sugar market, there is need to increase the sugar productivity at reduced cost of operation. These objectives could be achieved by breaking the myth that ratoon is a free gift of nature. Due attention is needed to be paid for raising ratoon by performing requisite cultural operations in time in cost effective manner. Mechanical alternatives for accomplishing the cultural operations may be explored to achieve these objectives. Adoption of appropriate mechanical tool to undertake majority of the cultural operations simultaneously in a single pass, will be a major step towards increasing the productivity of ratoon at reduced unit cost of operation. IISR has made concerted efforts and developed a multipurpose equipment to undertake most of the cultural operations simultaneously in a single pass (Srivastava 2000, Singh et al 2011, Singh 2017).

Concerted efforts have been made at Indian Institute of Sugarcane Research (IISR), Lucknow for development of machineries for accomplishing the requisite cultural operations of sugarcane ratoon.

Multi-purpose stubble shaver

During eighties a tractor operated two row multi-purpose stubble shaver was developed at IISR (Srivastava 1977, Sharma and Srivastava 1979, Sharma and Singh 1984). The equipment performs stubble shaving, off-barring & interculturing, and fertilizer application simultaneously in its single pass (Fig. 9). The equipment consisted of the following sub-units.

(i) Main M.S. Angle Iron frame with three point linkage system for mounting with hydraulic system of the tractor.
(ii) Gear drive unit taking drive from the tractor PTO shaft through a telescopic shaft and universal joints.
(iii) Rotating disc with blade holders.
(iv) Shaving blades (2 nos.), bolted to the blade holders.
(v) Auxiliary frame with fertilizer metering / dispensing system and 7 tynes with reversible double point shovels for off-barring / interculture.

After harvesting of the plant crop, the trash remained in the field is handled properly either for using as mulch or through burning, as the case may be. For obtaining the best performance from the machine, management of trash is essential and the moisture in the field should be optimum so that shaving is proper without uprooting of the clump (Singh et al 2012). Planting in straight rows is desirable to avoid uprooting while using the equipment. After ascertaining the field condition, the equipment is checked for the sharpness of the shaving blades and the wearing of the off-barring/ interculture shovels. In the last, but not of least importance is the skill of the operator. The driver should be properly trained because the operation requires simultaneous operation of PTO shaft while driving the tractor. If used, properly, two rows stubble are shaved, old root system chopped off so as to promote new rooting at a faster rate, interspace between the rows is tilled and fertilizer is also applied beside the clump in the close proximity of the root zone (Singh and Sharma 1986).

Fig. 9: Tractor operated two row multipurpose stubble shaver

Ratoon management device (RMD)

Of late equipment called Ratoon management device [RMD] was developed at IISR. The equipment performs all the recommended cultural operations viz. stubble shaving, off-barring & deep tilling, fertilizer, manure and chemical application, interculturing & soil-covering in its single pass. It consisted of units for performing all recommended cultural operations independently or in a single pass of the tractor. It is a two row tractor mounted type equipment that requires a minimum of 35 hp to execute operations in field (Anon 2006). Equipment has been released for its commercial use. The equipment consisted of following sub-units (Fig. 10).

Stubble shaving unit

Parts of stubbles that are left above ground surface while harvesting sugarcane are cut above ground surface through a sharp edged concave spinning disc. It is however not advisable to shave the stubbles in fields with piece meal harvesting schedule of the preceding crop.

Off-barring and deep tilling unit

Old roots of either side of stubbles are sheared without any damage. Compact or impervious or dense soil beneath the surface are break-opened by a pair of long and curved specially designed ripper having sleek shovel at its lower end. Rippers are configured or attached in a staggered manner to encounter any accumulation of crop residue in operation.

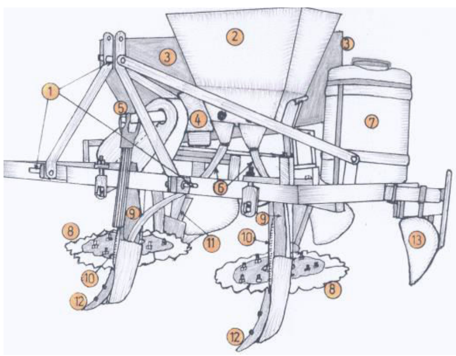


Fig. 10: Ratoon Management Device

Manure, fertilizer and liquid chemical dispensing

Manure, fertilizer and chemicals in free flowing granular form are metered through a pair of spiral mechanism (for each row) and are dropped through gravity in the slit behind the tines. Chemicals or vegetative extracts in liquid form are applied into soil gravitationally through the tubes and nozzles or holes of requisite size.

Earthing up unit

Earthing unit consisting of share mounted with mould board takes a bite of soil- chunk from in between rows of the stubbles to pulverize and to provide soil cover over the stubbles/shaved stubbles in form of a ridge. It also serves as an interculturing tool.

Fig. 11: Ratoon Management Device [RMD] in operation

Ratoon management device was field tested at IISR farm (Fig. 11). Front line demonstration of the equipment was conducted at farmers' field in Barabanki, Sitapur, Lakhimpur Khiri and adjoining districts of Lucknow. The performance of the equipment was satisfactory and output of equipment was 0.40 ha/h. Farmers found the machine very useful for managing the sugarcane ratoon crop and getting increased yield.

Disc Type Ratoon Management Device

This machine performs stubble shaving, off- barring and fertilizer application in sugarcane ratoon for widely spaced crop (Fig. 12). It covers single row and apply fertilizer at both side of the row (Singh et al 2017). Subsequent fertilizer application could be done without disturbing the trash used for trash mulching. The capacity of this machine is 0.30-0.35 ha/h.

Fig. 12. Disc Type Ratoon Management Device

Two row disc type ratoon management device were also developed for carrying out ratoon initiation operations in sugarcane ratoon field having row spacing of 75/90 cm. Developed prototypes were tractor operated and performed cultural operations such as stubble shaving, off barring and fertilizer application simultaneously in a single pass in a ratoon field having left over trash. Due to presence of discs for off barring, equipment performed efficiently even in the field having left over surface trash. Developed prototypes were of two types. First was without stubble shaver attachment and only perform off barring and fertilizer application. The second prototype has stubble shaver attachments also to perform stubble shaving along with off barring and fertilizer application. Prototype without stubble shaver is suitable for piecemeal harvesting and also for subsequent intercultural and fertilizer application after ratoon initiation. Field trials were conducted at IISR farm as well as farmers field to evaluate the performance of the developed machine. Machine performed well during field trials. Uniform and synchronized tillering was observed after stubble shaving operation. Effective field capacity of the machine was 0.30-0.35 ha/h.

Fig. 13 Two row Disc RMD without stubble shaving attachment

Fig. 14 Two row Disc RMD with stubble shaving attachment

Strategies for popularization of machineries

Most of the machineries described in the article have been demonstrated at different parts of the country. These have been found effective in saving of time and cost and have potential to make sugarcane cultivation more profitable besides reducing human drudgery. There is a need for concerted efforts by all the stakeholders involved in the pursuit of cost-effective production of sugarcane and sugar for popularization of these machines so that it could reach to the end users. All these useful time, labour and cost saving machineries can be taken to the farmer fields on a large scale in order to create awareness among the farmers. Private entrepreneurs could be encouraged to provide these useful equipments to the farmers on custom-hire basis. Machineries should be brought under the umbrella of subsidy for its larger adoption. IISR has signed Memorandum of Agreement (MoA) with the Agricultural Machinery Manufacturers of different part of India to ensure the availability of these machineries commercially. As per need of the local soil and agro techniques these machineries could be modified and adopted for mechanization of sugarcane cultivation for sustainable enhanced sugarcane production.

Conclusion

Numbers of machineries have been developed at IISR for mechanizing different methods of sugarcane planting. Ridger type sugarcane cutter planter, deep furrow sugarcane cutter planter and trench planter are the multitasking machine which performs all the unit operations of sugarcane planting including sett cutting simultaneously in single pass of the machine. These machines have been demonstrated at different places of U.P., Bihar, Maharashtra, Andhra Pradesh, Uttarakhand, Assam, Kerala etc. Use of these machines saves the cost of planting operation by 50 per cent and labour by 90 per cent as compared to conventional method. Low cost machineries like trencher, deep furrower, deep furrower-cum-fertilizer applicator were also developed at IISR to promote trench method or deep furrow method of planting. Trenchers are presently adopted at large scale by the farmers due to its low cost and benefits of yield increase, reduction in cane lodging and better ratooning. Pit digger has also been developed for mechanizing pit digging operation for planting of sugarcane in ring-pit method, which is high yielding technique of cane cultivation. Planting machines were also developed for planting of inter crops with sugarcane to take additional short duration crop without adversely affecting the sugarcane. Ratoon management machineries hace also been developed for mechanizing ratoon initiation operation after harvesting of sugarcane. There is need for popularization of these machineries among the cane growers to address the problem of labour availability and to bring cost efficiency in sugarcane cultivation.

Reference:

Anon, 2006. Development of a tractor operated mounted type two row ratoon management device. Annual Report (2005-06), Indian Institute of Sugarcane Research, Lucknow, India: 47-48.

Sharma, M.P. and N.S.L. Srivastava. 1979. Report on ratoon shaving. Annual Report(1978-1979), Indian Institute of Sugarcane Research, Lucknow, India: 125.

Sharma, M.P. and Kishan Singh, 1984. The New IISR tractor mounted stubble shaver for sugarcane ratoon culture. *Journal of Agricultural Engineering*, Vol. XXI (342): 167-171.

Singh, J., A.K. Singh, M.P. Sharma, P.R. Singh, and A.C. Srivastava. 2011. Mechanisation of sugarcane cultivation in India. *Sugar Tech* 13(4): 310-314.

Singh, P.R. and M.P. Sharma. 1986. Prototype feasibility testing of stubble shaver-cum-fertiliser applicator.Annual Report of AICRP on Farm Implements and Machinery, I.I.S.R. Lucknow, India: 10-16.

Singh, S.N., A.K. Singh, J.P.S. Malik, R. Kumar, Sunderpal and M.L. Sharma. 2012. Cultural practice packages and trash management effects on sugarcane ratoons under sub-tropical climatic conditions of India. *Journal of Agricultural Science* 150: 237-247.

Srivastava, A.C. 2000.Mechanisation in sugarcane. In *50 years of Sugarcane Research in India*, *ed*. H.N. Shahi, A.K. Srivastava and O.K. Sinha. Indian Institute of Sugarcane Research, Lucknow, India.

Srivastava, N.S.L. 1977. The IISR tractor drawn stubble shaver for ratooning of sugarcane. *The Indian Sugar Crops Journal* 1-4, Oct.-Dec: 29-31.

Singh, A.K., Singh, P.R. and S. Solomon. 2017. Design and development of a tractor operated disc type sugarcane ratoon management device. *Sugar Tech*, 19(5): 501-509.

Singh, A.K. 2017. Advances in sugarcane mechanisation research in India. Compendium of Research Papers, National Symposium on Sugarcane Mechanisation: Challenges and Opportunities, BAIT Sathyamangalam, Mar 17-18: 8-13.

Singh, A.K., Sharma, MP. and Gupta, R. 2017. Development of tractor operated double bottom pit digger for mechanizing ring pit method of sugarcane planting. *Sugar Tech*, 19(5): 510-516.

Singh, A.K. and Singh, P.R. 2017. Development of a tractor operated sugarcane cutter planter for mechanisation of sugarcane planting in deep furrows. *Sugar Tech*, 19(4): 416-423.

Singh, A.K., Gupta, R., Singh, S. and Singh, R.D. 2016. Mechanization of sugarcane for sustainable sugarcane production. Souvenir, National Symposium on Challenges, Opportunities and Innovative Approaches in Sugarcane: Agriculture, Bio energy and Climate Change, UPCSR Shahjahanpur, Dec 21-23: 65-66.

Singh, A.K. 2016. Recent developments in mechanization of sugarcane planting at IISR. Proceedings, 74^{th} Annual Convention of STAI held at Delhi during 28-30 July: 123-129.

Sharma, M.P. and Singh, K. 1989. Tractor mounted pit digger for ring method of sugarcane planting. *Indian Journal of Sugarcane Technology* 4:1-6.

Sharma, M.P. and A.K. Singh. 2007. Mechanization of ring-pit system of sugarcane planting. In: *Sugarcane Planting Techniques and Crop Management*, *Eds* R.L. Yadav and D.V. Yadav IISR, Lucknow, 21-23.

Chapter No. 50: Small farm tools in sugarcane culture

Sukhbir Singh and AK Singh
Principal Scientist, Division of Agricultural Engineering
ICAR-IISR, Lucknow-226 002

Sugarcane is an important commercial crop of India which plays a decisive role in social and economic upliftment of rural population.It is grown in 4.85 million hectare area with production of 397.6 million tonnes and productivity of 81.98 tonnes/ha (Table 1).Uttar Pradesh state is the largest producer of sugarcane in the country as it contributes 44.94 % of the total area and 44.58% of the total production in the country but have the average yield (81.31 tonnes/ha) slightly less than the national average(Table 2).In India, the majority of the farm holdings fall under small and marginal category (86%) and the average size of land holding is about 1.08 ha(Table 3). Table also revealed that number of land holdings having less than 2.0 ha farm size has increased in 2015-16 as compared to 2010-11. The density of agricultural workers per thousand hectares is about 2218.The sugarcane cultivation involves different operations such as seed bed preparation, planting (seed setts cutting, furrow making, placement of seed setts in furrows, fertilizer and chemicals application, soil covering over setts), weeding/inter-culturing, spraying, harvesting including de-trashing and transportation. Most of these operations are being done manually with conventional tools and equipment which are very time, labour consuming (more than 500 man-days/ha) and involve lot of drudgery which ultimately increases the cost of operation and reduces the net profit to the growers (Singh and Gupta, 2015; Singh *et al* 2016). The participation of women farmers are there in carrying out most of these operations such as seed sett cutting, seed sett placement, weeding, harvesting and de-trashing with traditional tools(Table 4). The use of small farm tools and equipment in Indian agriculture is evitablebecause these are easily available and manufactured by the local artisan without considering the anthropometric data of the user's population. With the use of traditional tools, work efficiency of the operation reduces and drudgery involved in performing the operations resulted in physical stress on the worker. So, there is a need to ergonomically study the various traditional tools used for different operations in sugarcane cultivation critically.The design modification of the existing one and development of improved tools based on the anthropometric data of the user's population is urgently needed to reduce the drudgery. Many improved hands tools have been ergonomically designed/modified by different R& D Institutes to minimize drudgery with enhanced efficiency.Indian Institute of Sugarcane Research, Lucknow has also developed many small tools suitable for the sugarcane growers.

Table 1.Area and production of sugarcane in India

Year	Area (1000 ha)	Production (1000 tonnes)	Yield (tonnes/ha)
2010-11	4,886	3,42,382	70.1
2011-12	5,038	3,61,037	71.7
2012-13	4,998	3,41,198	68.3
2013-14	4,993	3,52,141	70.5
2014-15	5,067	3,62,333	71.5
2015-16	4,927	3,48,448	70.7
2016-17	4,436	3,06,070	69
2017-18	4,732	3,76,905	79.6
2018-19	5,114	4,00,157	78.25
2019-20	4,603	3,70,500	80.5
2020-21	4,851	3,97,657	81.98

Source: NFCSFL, 2022

Table2. Major Sugarcane producing states in India

State	Area (1000 ha)	% to All India	Production (1000 tonnes)	% to All India	Yield (tonnes/ha)
Uttar Pradesh	2180	44.94	177262	44.58	81.31
Maharashtra	1142	23.54	97070	24.41	85
Karnataka	428	8.82	41088	10.33	96
Bihar	219	4.51	15005	3.77	68.43
Tamil Nadu	139	2.87	13944	3.51	100
Gujarat	183	3.77	13621	3.43	74.53
Andhra Pradesh	55	1.13	4295	1.08	78.08
Telangana	20	0.41	1536	0.39	76.82
Madhya Pradesh	106	2.19	5666	1.42	53.45
Chattisgarh	32	0.66	1750	0.44	55.5
Haryana	93	1.92	7567	1.90	81.19
Uttarakhand	84	1.73	6913	1.74	82.3
Punjab	95	1.96	7855	1.98	82.6
Odisha	7	0.14	389	0.10	56.14
All India	4851	100.00	397657	100	81.98

Source: NFCSFL, 2022

Table3. Number and size of operational holding by size group

Category of holdings	No. of holdings ('000 no.)		Area ('000 ha)		Average size of holdings (ha)	
	2010-11	2015-16	2010-11	2015-16	2010-11	2015-16
Marginal (<1 ha)	92826 (67.0)	100251 (68.45)	35908 (22.5)	37923 (24.0)	0.39	0.38
Small (1.0-2.0 ha)	24779 (17.9)	25809 (17.6)	35244 (22.08)	36151 (22.9)	1.42	1.40
Semi-medium (2.0-4.0 ha)	13896 (10.0)	13993 (9.55)	37705 (23.6)	37619 (23.8)	2.71	2.69
Medium (4.0-10.0 ha)	5875 (4.2)	5561 (3.79)	33828 (21.2)	31810 (20.15)	5.76	5.72
Large (10.0 ha & above)	973 (0.7)	838 (0.57)	16907 (10.6)	14314 (9.06)	17.38	17.07
All Holdings	**138348 (100.0)**	**146454 (100.0)**	**159592 (100.0)**	**157817 (100.0)**	**1.15**	**1.08**

Source: Agriculture Census 2015-16 (Phase I), Agriculture census Division, Department of Agriculture, Co-operation & Farmers Welfare, Ministry of Agriculture & Farmers Welfare, Government of India, 2019.

Table 4. Gender participation &Labour requirement per hectare in sugarcane cultivation

S.No.	**Operations performed**	**Gender Involvement**	**Equipment/ method used**	**Man-h/ ha**	**Man-days/ ha**
1.	**Land preparation**				
a.	Ploughing & harrowing	Male	Bullock plough/tractor cultivator	126	21
b.	Removal of grass	Male & female	Manually by sickle	296	50
2.	**Planting of cane**				
a.	Sett cutting	Male & female	Manually by sickle	90	15

b.	Furrow opening	Male	By bullock plough/tractor cultivator/ridger	55	9
c.	Dropping of setts	Male & female	Manually	5	1
d.	Dropping of fertilizer	Male & female	Manually	5	1
e.	Dropping of insecticides	Male	Manually	5	1
f.	Closing of furrow	Male	Bullock plough	7	1
g.	Planking	Male	Manually Bullock/Tractor Planker	8	1
3.	**Interculture**				
a.	Hoeing (2 times)	Male	Desi plough	100	16
b.	Hoeing (4 times)	Male	Kudal	1018	166
c.	Weed picking (2 times)	Male & female	By hand sickle	447	74
4.	**Top Dressing (1time)**	Male & female	By hand	15	3
5.	**Earthing-up (1 time)**	Male	Spade	667	111
6.	**Stubble Shaving (1time)**	Male	Spade/kudal	144	24
7.	**Harvesting**	Male & Female	Gandasa/different types of knives	600	100
Total				**3588**	**594**

Improved Manual Tools and Equipment

IISR manual Sugarcane Bud Chipper

Manual sugarcane bud chipper has been developed to remove buds from the sugarcane stalk for raising seedling for transplanting (Fig1). The device consists of a platform with a fixed frame supporting spring loaded shaft, a handle and a semi-circular chipping device/blade. Cane stalk is put transversely on the platform manually to cut the eyes by pressing the handle. An output of 1000 buds/h can be achieved with this tool.

Fig1. IISR Manual Sugarcane Bud Chipper

IISR cane juice sampler

This sampler is used to draw composite juice samples from standing crop of cane for assessment of maturity of the crop. The sampler consists of an aluminium handle, machined to take a stainless steel needle and glass capsule (Srivastava, 2000). The needle is locked in position on the handle with a grub screw. It has a cutting edge which neatly severe the fibres when pushed into a cane stalk. The juice from the puncture runs down the groove in the middle of the needle and collects in the capsule. A rubber seal provides a leak proof seat for the capsule which is held in position by a cap made of polyethylene (Fig.2).

Fig.2. IISR Cane Juice sampler

IISR manual harvesting knife

Manual harvesting knife is used to cut the cane stalks closed to ground surface during harvesting. It consists of chaff cutter knife mounted on an angle of 120^0 with the handle. While working with this tool there is no need to bend for cutting the standing canes. Use of this tool facilitates the cutting of cane closed to the ground surface (Srivastava, 2000).

IISR Manual detrasher

Manual detrasher is used to remove dry trash from standing as well as harvested cane crop (Fig.3). It has three fingers (20-30 cm long) mounted at an angle of $15\text{-}20^0$ with the handle (Srivastava, 2000).While working in the standing crop long handle is removed. With the help of this tool 13 persons can cover 1 ha of field in a day.

Fig.3.IISR Manual detrasher

IISR Sugarcane detrasher cum detopper

For detrashing and detopping,IISR Lucknow has developed a hand toolwhich does the job of stripping ofdry leaves and cutting the green topsatisfactorily (Fig.4). It consists of a pairtongs, the jaws of which close toform a square and extend beyondthe square to form a "V" in front(Srivastava, 2000).One of the two limbs is bent downand provided with a wooden handle. A light tension spring holdsthe jaws closed. A knife is weldedon the stem of the detrasher fordetopping the cane after harvest.The cane is gripped between thejaws of the tool and drawn downwardin one or two sweeps. Thestripper removes the dry/greenleaves by separating them and pushingthem away from cane stalk. The green top is then cut with a knife provided for this purpose on the stem of the stripper.

Fig.4. IISR Sugarcane detrasher cum detopper

OUAT Sugarcane Detrasher

The sugarcane detrasher developedat OUAT Bhubaneswar hassimilar configurations to that of theIISR model(Kathirvel*et al* 2010). The knife isabsent in this model. The sugarcanestem is held between the two jawsand the detrasher is forced verticallyfor detrashing the dry leaves fromthe sugarcane.

TNAU Sugarcane Detrasher

This is the tool for detrashing thegreen/dry leaves from the standingcrop of the sugarcane(Kathirvel*et al* 2010). It consists oftwo curved knives welded to twoends of the U shaped stem. Thestem is attached to a hollow metalpipe (Fig.5). An adjustable ovalshaped loop is provided to increaseor decrease the gap between twoknives depending on the diameterof sugarcane stalk. The knives areinserted between the internodes atthe top and pulled vertically downfor removing the dry and unwantedleaves.

Fig.5. IISR Manual Sugarcane Bud Chipper

IISR manual cane node/bud chip/sett cutting tool (3 in 1)

A manual tool was developed for doing three operations separately viz. cutting cane node, bud chip scooping and seed sett cutting of sugarcane as seed material required for sugarcane planting by various methods (Fig.6). The machine has a handle, high carbon steel blade, a scoop and platform to fix the machine. One person can easily operate by holding cane in one hand and pressing handle with other hand for the required operation. The average number of cane node, bud chip and sett cut in one hour were 665, 680and 1175 respectively. The damage of 6-8% was observed during cane node cutting while it was 1-2% in bud chip cutting and no damage during sett cutting.

Fig.6.IISR manual cane node/bud chip/sett cutting machine

IISR manual cane stripper cum detopper (new model)

The weight of earlier designed model ofmanual stripper cum detopper was slightly heavy to use for a longer duration. So, anew model of sugarcane stripper cum detopper was designed and developed (Fig.7). The technical specifications of this model is given in Table 5. It was tested at Institute farm. Two individuals male and female were selected for operating the tool that have the experience of sugarcane harvesting for more than five years. After harvesting of cane, data of cane stripping and de-topping was taken and analysed(Table 6).It was observed that a person can clean 135-150 kg of cane easily in one hour.

Fig.7. Developed sugarcane stripper cum de-topper

Table 5. Technical specifications of the sugarcane stripper cum detopper

Parameters	**Sugarcane stripper cum detopper**
Weight, g	225
Material of blade	High carbon steel
Thickness of blade, mm	2.0
Thickness of cutting edge, mm	0.5
Dia. of hand grip, mm	30
Cutting length of the blade, mm	85
Material of handle	PVC
Overall dimensions (LxB), mm	310x55

Table 6. Test results of sugarcane stripper cum de-topper (Variety: CoPK 5191)

Parameters	**Model III**	
	Male	**Female**
No. of cane stripped & de-topped/h	348	297
Weight of the clean cane, kg	150	135
Green top weight, kg	45	30
Dry trash, kg	27.2	16.5

IISR Manual multi crop planter

A single row manual multicrop planter was designed and developed for sowing intercrops in sugarcane (Fig. 8). PVC rotor with vertical grooves on periphery was used for metering the seed. There is a provision to change the rotors as per the seed size of the crop to be sown. The drive to the seed metering shaft was from ground wheel through chain and sprocket. Two persons were used to operate the machine.

Machine can be used for line sowing of black gram,lady finger, wheat, peas, maize, coriander and mustard as intercrop in sugarcane. The effective field capacity of the machine was in the range of 0.07-0.10 ha/h.

Fig.8. Manual multicrop planter for sowing intercrop in sugarcane

A two rows manual multicrop planter was also developed at ICAR-IISR, Lucknow for sowing of intercrops in sugarcane (Fig.9). The row to row spacing could be adjusted between 20-30 cm as per the need. The seed box has the capacity of 2.5 kg of seed each. The weight of the machine is 17.3 kg. Two person are required to operte the machine.

Fig.9. Two rows manual multicrop planter

Fig.10. Manual light weight weed cleaner

Manual weed cleaner for weed management

A manual light weight weed cleaner was developed based on the principle of wiping (or brushing) for weed control in between crop rows by using non-selective herbicides to the targets (weeds) by direct contact without damaging the crops (Fig.10). The herbicide solution is supplied to an absorbent surface i.e. spongy roller in weed cleaner. The weed cleaner was calibrated for herbicide dose and volume of water. Testing of weed cleaner was carried out at Institute farm.Weed cleaner was tested at the farm in sugarcane field planted at 75 cm row spacing. One person is required to operated the cleaner. The capacity of the cleaner was 0.04 ha/h at operating speed of 2.0 km/h. The discharge rate was observed 470 l/ha.

Modified weed cleaner for weed management

The developed prototype of manual weed cleaner was modified by changing its main pipe which acts a reservoir for herbicide solution (5 litre) with a CPVC pipe of 150 cm length and diameter of 3.3 cm with no reservoir (Fig.11). In new prototype, the cleaner was attached with a separate tank of 15 litre capacity which will act as a reservoir for herbicide solution and it was kept on the back of the operator while in operation. The herbicide solution was supplied from this tank to the spongy roller with a pvc pipe of 8 mm through a ball valve.The ball valve was attached for controlling the flow of herbicide solution to the spongy roller.

Fig.11. Modified weed cleaner for weed management   **Fig.12. Protective shield for weed management**

This model was further modified. To prevent the air drifting during spraying, a protective cover (shield) made of PVC was fabricated and installed on the flat fan nozzle of the sprayer (Fig.12). The width of the cover is 50 cm. Weight of the (shield)cover is 300 g.

Solar powered manual sprayer

A solar powered manual sprayer was developed for spraying herbicide/fungicide in different crops (Fig.13).The technical specification of the sprayer has been given in Table 7. The height of the spraying can be adjusted from 300 mm to 1000 mm. Preliminary testing of this sprayer has been carried out at Institute farm for spraying pre-emergence herbicide in sugarcane.

Fig.13. Solar powered manual sprayer

Table 7. Technical specifications of the solar powered manual sprayer

Overall dimensions(LxWxH), mm	1830x2930x1550
Minimum base height, mm	300
Maximum height, mm	1000
Type & No. of nozzles	Flat fan nozzles, 7
Nos. of wheels & dia., mm	3, 670
Nos. of battery & pump used	2 each
Battery voltage & capacity	12 V, 8Ah
Pump voltage, press., flow rate	12V, 5.09 kgf/cm^2, 3.1 l/min
Pipe length, dia. & capacity	1900 mm, 200 mm, 65 litre
Power of solar panel used	20 W
Another drum capacity & separate pipe used	220 litre, 30 m

The effective field capacity of the sprayer was observed 0.52 ha/h with field efficiency 80% at average speed of 1.8 km/h (Table 7). The effective width of spraying was 3.6 m. The average discharge of all nozzle was 4.3 l/min and force required to pull the sprayer was 18 kgf. The sprayer takes about 71% less time as compared to knapsack sprayer to cover one hectare area.

Conclusion

The improved manual tools and equipment enhances the capacity and efficiency of the operation with less time, cost and drudgery as compared to conventional practices. So, these manual tools need to be popularized for wide adoption among the farmers.

References

Anonymous 2018-19. Annual Report. ICAR-IISR, Lucknow.

Anonymous. 2019. Agriculture Census 2015-16 (Phase I), Agriculture census Division, Department of Agriculture, Co-operation & Farmers Welfare, Ministry of Agriculture & Farmers Welfare, Government of India, 2019.

National Federation of Cooperative Sugar Factories Limited (NFCSF) 2022. *In*: Cooperative Sugar. January 2022: 42-44.

D. Ramesh, D. ManoharJesuda
D. Ramesh, D. ManoharJesuda
D. Ramesh, D. ManoharJesudas
K. Kathirvel, R. Thiyagarajan
K. Kathirvel, R. Thiyagarajan
K. Kathirvel, R. Thiyagarajan

Kathirvel K.,ThiyagarajanR., Ramesh D.JesudasM. 2010. Ergonomic intervention in sugarcane detrashing. Agricultural Mechanization in Asia Africa and Latin America (AMA),41(2):9-14.

Singh PR and Gupta R. 2015. Role of women in mechanized sugarcane cultivation. Agricultural Engineering Today. Vol. 39(3): 22-29.

Singh S, Singh P R, Singh AK and Gupta R. 2016. Present status and future need of mechanizing sugarcane cultivation in India. Agricultural Mechanization in Asia Africa and Latin America (AMA), Vol. 47 (1): 75-81.

Srivastava, A.C. 2000. Mechanisation in sugarcane. *In*: *50 years of Sugarcane Research in India*, *ed*. H.N. Shahi, A.K. Srivastava and O.K. Sinha. Indian Institute of Sugarcane Research, Lucknow, India.

Chapter No. 51: Recent development in sugarcane harvesting machinery

A.K. Singh
Principal Scientist, Division of Agricultural Engineering
Indian Institute of Sugarcane Research, Lucknow

SUGARCANE HARVESTING

Sugarcane is an important industrial crop of India. Harvesting of sugarcane and its transportation to sugar mills is an energy and labour intensive operation. Sugarcane harvesting is an energy intensive operation and involves human drudgery when performed manually. Harvesting of cane involves cutting of cane stalks, detopping and detrshing of cane stalks, making bundles of 10 to 12 stalks and finally loading of clean cane bundles into transport vehicles. In India, harvesting is performed manually using different types of knives. The harvested cane is transported to sugar mills for its processing using different modes of transportation viz., bullock carts, tractor operated trailers and trucks. Basically, two types of harvesting systems are prevalent worldwide i.e. green cane harvesting and burnt cane harvesting. The green cane harvesting is performed without burning the standing crop. The green cane harvesting is preferred due to superior quality of juice. Also, this method allows green top to be used as fodder and incorporation of trash into the soil. In case of burnt cane harvesting the cane field is first burned. The cane is harvested once temperature goes down to the operating comfortable level. In India, generally green cane harvesting is practiced. As the availability of labours is precarious and varies with the season, the availability of cane to the mills become uncertain. This necessitates the adoptability of mechanization of harvesting operation of sugarcane along with suitable transportation system.

Present scenario

Presently harvesting of sugarcane is done manually using different types of knives. The mechanization efforts in the country have been basically limited to the development of whole stalk harvesters for the partial mechanization of sugarcane. These harvesters were basically designed to cut the cane and in some cases to detop the green top also. The remaining operations such as detrashing, bundle making and loading were to be performed manually. At few places such as in Andhra Pradesh and Maharashtra whole stalk harvesters were imported and evaluated for partial mechanization of sugarcane (Singh et al 2010). So far these harvesters are still under development and evaluation stage. Of late, combine chopper harvesters have been imported at few places in Tamilnadu and Maharashtra. These harvesters are intended to mechanize the whole operation of sugarcane and found acceptability at few places at limited scale. Combine chopper harvesters are capable of harvesting green as well as burnt crops and also heavy yielding and lodged crops unlike whole stalk harvesters. Whole stalk harvesters are suitable for harvesting of erect and medium tonnage crops.

The available sugarcane harvesting options can be grouped into

A. Manual harvesting

B. Mechanical harvesting
   (i) Whole stalk harvesters -linear windrowing, transverse windrowing
   (ii) Self propelled whole stalk harvesters
   (iii) Self propelled chopper harvesters

A. Manual harvesting

In India, harvesting of sugarcane is done manually using conventional harvesting tools. The productivity of manual cutters can be improved by giving them proper training, the use of correct cane knife, balance diet, etc. On an average an out put of 0.8 to 1.0 tonne per man-day is obtained. Human drudgery involved in cane cutting, detrashing, detopping and carrying head loads to the transport wagon together with shortage of labour during harvest season, is compelling the cane growers to look for alternate viable options for mechanizing of harvesting operation.

Fig. 1 Different types of sugarcane harvesting knives

B. Mechanical harvesting

Attempts have been made at different places to develop and adopt mechanical harvesters for sugarcane. Mechanical harvesters can be grouped into (i) whole cane and (ii) combine chopper harvester.

(i) Whole cane harvester

A tractor operated side mounted whole harvester was developed for cutting of single row of cane. Power to the cutting blade was provided from P.T. O. of the tractor through chain sprocket and P. T. O. pulley. Stationery guider was provided to guide the cut cane stalks for the windrowing. The equipments needed for space for the tractor and could be operated only in one direction. The harvested cane needed to be lifted prior to cutting of next row of the cane. Due to this the equipment could not be taken for futher trial.

A tractor front mounted sugarcane windrower harvester at Indian Institute of Sugarcane Research, Lucknow (Sharma and Singh, 1992). It was reported that with the help of this harvester two rows of sugarcane was cut simultaneously and windrowed at the centre of the rows. Removal of green tops and dry trash, bundle making and loading into transport vehicles, were performed manually. The major components of the harvester were main frame, drive system, base cutters and rotating crop dividers and front reels. The drive from tractor pto was through double chain and sprockets. Base cutters consisted of a disc carrying three cutting blades. Crop dividers having spirals, rotating in opposite directions were provided to facilitate harvesting of lodged crop and proper windrowing.

Performance of imported sugarcane harvesters, viz Bonnel, Carib, Cameco and indigenous model VSI-Merado were also reported (Devnani and Prasad 1994). Bonnel sugarcane harvester consisted of a front mounted and three point link mounted, side harvesting cum windrowing unit on a standard tractor chassis. The detopped cane were cut at the base by twin disc blades and windrowed with the help of a conveyor along the direction of travel. Carib whole stalk harvester is a single row harvester on a standard tractor base, having two spiral scrolls to separate standing canes which are either lodged or bent and for gathering canes towards the centre of the cutting row for base cutting. The base cutter is a twin blade cutter having adjustable depth wheels to take care of field undulation to maintain a constant height of cut. The cut cane stalks are windrowed beneath harvester along the travel direction thereby overlaying harvester canes over each other. Cameco whole cane harvester is a single row machine having a single spiral scroll at the left to separate entangled and lodged cane stalks from the adjoining rows of standing crops. It has upper and lower conveyors to gather and convey standing cane stalks for base cutting along row. Height of these conveyors can be adjusted independently. Base cutter height can be adjusted by hydraulic power and is always inclined to the ground. Windrowing unit has a conveyor which can discharge detopped and base cut canes at any angle, to a maximum, perpendicular to the direction of travel. The topper detops and shreds immature green tops and leaves. All the functional components and sub systems are hydraulically powered. The VSI- Merado prototype is similar to Carib model having a detopper at the front to detop immature green tops. It has twin base cutter powered by tractor power take off. A front detrashing roller is mounted to remove dried and loose leaves adhered to the cane stalks. The base cut canes are windrowed underneath the harvesting machine along forward travel. It has twin spiral scrolls to separate entangled stalks and for gathering lodged or bent cane stalks towards base cutter.

A tractor front mounted sugarcane harvester was developed for cutting and windrowing of two rows of cane. Windrowing of one row is in transverse direction while the other row is windrowed linearly to the direction of travel of the tractor (Singh et al, 2009). Attachments, consisting of a M.S. frame and hydraulically controlled arms through hydraulic cylinders, were developed for raising and lowering of harvester during transportation as well as field operation. Power to the cutting blades was provided through tractor PTO. Attachments were also provided with the main frame for windrowing of harvested cane by guiding the cane towards cutting blades during harvesting operation and up to some extent for raising the partially lodged canes. The harvester was tested at IISR farm at different speeds of cutting blades (300-350, 450-500 and 600-650 rpm). The cutting was clean without any splitting and rupture of cane stubbles at cutting blade speed of 450-500 rpm. The cutting and windrowing was satisfactory for crops which were not lodged and where the canopy was not intermingled with the other rows. Equipment needed free space towards right hand side to facilitate transverse windrowing of cut cane stalks. Due to this it could be operated in one direction only. During return equipment is not engaged in cutting. Due to these limitations, the equipment was not taken for commercial exploitation.

For removal of green top as well as dry trash from the harvested sugarcane a power operated detrasher was developed (Srivastava and Singh, 1990, Shukla et al., 1991, Singh and Sharma, 2009 and Singh and Solomon, 2015). Equipment consisted of mechanisms for cane feeding, detrashing and delivery. It separates the top from the cane by breaking it from the natural weak point at the joint of immature top with mature cane stalks. It can be transported on three point linkage of the tractor and operated by a electric motor, diesel engine or tractor PTO. Performance of the equipment was evaluated by feeding different varieties of harvested canes, with their tops first, to the detrashing rollers through the feeding chute. The trash left on the cane after passing through the detrasher varied from 1.5 to 6.6%. Trash removal efficiency varied from 77.5 to 94.5% depending upon the variety. The output of the detrasher was 2.4 t/h for feeding of 2-3 cane stalks at a time. There was a saving of about 17% in cost of operation and 84% in labour requirement using the detrasher as compared to manual method.

Fig. 2 IISR tractor operated front mounted sugarcane harvester

Fig. 3 IISR sugarcane detrasher in operation

(ii) Self propelled whole stalk harvester

Self propelled whole stalk harvesters were imported in Tamilnadu from China. It was a Hansen make whole stalk harvester. It performs cutting and detrashing. The cut and detrashed cane stalks were delivered to the rear side of the harvester which is needed to be collected manually or could be collected in a bin attached with the rear of the harvester in the later models. The field testing of these harvesters are conducted in Sathy sugar mill area in Tamilnadu. The manufacturers are trying to modify the harvester in collaboration with local manufacturer from Coimbatore (M/s LCT) to make it more suitable to the local conditions of Tamilnadu.

Fig. 4 Self propelled whole stalk cane harvester imported from China in field operation at Sathy (Tamilnadu)

Fig. 5 Self propelled whole stalk Japanese (Bunmai make) sugarcane harvester

(iii) Self propelled chopper harvester

Austoft 7000 sugarcane harvesters were imported from Australia at Sakthi Sugars Limited, Sakthinagar (Tamilnadu). These were combine chopper harvesters. With the help of this harvester cane is cut, cleaned and loaded into an articulated infield transporter. The harvested cane was transported to the mill using trucks. It has been reported that the harvester is commercially used. The average quantity of sugarcane harvested in a day was reported as 200 tons per day. The maximum quantity harvested in a day was 405 tons (Nagendran, 1999 and Vachaparampil, 1999).

Fig. 6 Self propelled imported sugarcane copper harvester

Under NATP different types of combine chopper and whole cane harvesters were evaluated. The net cane output of combine chopper harvester (Austoft 7000) was found to be 24 to 30 tonnes per hour (Anon 2002). The minimum working row space for this harvester was 150 cm. The cost of harvesting varied from Rs 157 to 200 per tonne in case of mechanical harvesters, which could be lowered by increasing the total tonnes of cane harvested per day by operating the harvester for longer hours per day.

Presently few firms in India (New Holland, John Deere, Shaktiman) are manufacturing the self propelled chopper harvesters. These harvesters are suitable under row spacing of more than 120 cm. CNH

8000 harvesters are suitable for more than 150 cm spacing but there output is also high. Wider row spacing could be achieved by adopting paired row planting of 30:120 cm row geometry without sacrificing the plant population per unit area.

Constraints in adoption of mechanical billet harvesters

Following are the major constraints in adoption of mechanical harvesters particularly billet harvesters;

i) High initial cost of the harvester
ii) Wider row spacing (1.2 m and above) requirement
iii) Piecemeal harvesting system prevalent in the country
iv) Sucrose losses due to delay in supplying billets to the mill
v) Higher trash content (7-8%)
vi) Higher non operating time due to small size of fields resulting into low output

Future Strategy

It can be observed that no single tailor made solution is available because of the different cane growing practices and cane supply management. Multi pronged approach can be adopted keeping in view the present scenario in India. Billet harvesters can handle difficult and heavily lodged crop but the situation in India is not yet congenial for large scale adoption of such highly sophisticated equipment.

Developing country like India need time to shift to billet harvesting by making requisite changes and preparations in sugarcane production and supply system suiting to the combine billet harvesters. As such, adoption of these machines may be un-economical and practically not possible because of agronomical and other constraints. It needs the formulation of proper strategy where cane growers, sugar industry, Govt. organizations and private entrepreneurs all work together as a team.

References

Anon. 2002. Performance evaluation of sugarcane harvesters. Technical Report. CIAE/AMD/NATP/2002/272, CIAE, Bhopal.

Devnani, R. S. and Prasad, J. 1994. Status of development and evaluation of sugarcane harvesters in India. *Paper presented at the XXIX Annual Convention of ISAE* held at Junagarh. Feb. 10-12.

Kamthe, S. D. and Jadhav, S. B. 1999. The mechanization in sugarcane. *Souvenir, National Workshop on Mechanization of Sugarcane*, Sakthinagar. April 25 : 31-34.

Nagendran, K. 1999. Mechanization programme in Sakthi Sugars. *Souvenir, National Workshop on Mechanization of Sugarcane*, Sakthinagar. April 25 : 45-51.

Sharma, M. P. and Singh, P. R. 1992. Development of tractor front mounted double row sugarcane windrower harvester. *Indian Journal of Agricultural Engineering*. 2(2) : 102-105.

Shukla, L N; Singh, I. and Sandhar, N S. 1991. Design development and testing of sugarcane cleaner. *Agricultural Mechanization in Asia, Africa and Latin America* 22(3): 55-58.

Singh, A.K. and Sharma, M.P. 2009. Development of an equipment to remove trash from harvested cane stalks for cleaning. In, Souvenir of 43rd Annual Convention & Symposium organized at Birsa Agricultural University during Feb. 15-17, pp 123.

Singh, A.K., Sharma, M.P. and Singh, J. 2009. Development of sugarcane harvester. Annual Report, 2008-2009, Indian Institute of Sugarcane Research, Lucknow: 40.

Singh, A.K., Sharma, M.P. and Singh, J. 2010. Sugarcane harvesters and their utility in Indian conditions. Souvenir : National Seminar on Mechanization of Sugarcane Cultivation organized at IISR, Lucknow, p. 13-20.

Singh, A.K. and Solomon, S. 2015. Development of a sugarcane detrasher. Sugar Tech, 17(2): 189-194

Srivastava, A C and Singh, K. 1990. Development of a power driven sugarcane detrasher. *Agricultural* Mechanization *in Asia, Africa and Latin America* 21(2): 49-52.

Vachaparampil, M. M. 1999. Case Austoft harvesters in India. *Souvenir, National Workshop on Mechanization of Sugarcane*, Sakthinagar. April 25: 52-59.

Chapter No. 52: Nutrient deficiency symptoms in sugarcane and their ameliorative measures

S.P. Singh
Principal Scientist (Plant Physiology)
ICAR-Indian Institute of Sugarane Research, Lucknow

There are several methods for diagnosing nutrient deficiencies but under field conditions visual symptoms serve as a potential tool. It does not involve sophisticated equipments and chemical inputs as required in other techniques. The visual diagnosis is based on the principle that deficiency of a particular element in soil induces a specific and readily recognizable symptom in the external appearance of the plant which is distinct from deficiency symptoms of other elements. The deficiency symptoms of various nutrients in sugarcane are described as below:

1. Nitrogen

Deficiency Symptoms:

- Stunted growth, chlorosis (uniform light green to yellow in colour) of older leaves and leaf blades, reduced internode growth.
- In severe cases, the tips and margins of leaves become necrotic and dries off prematurely.

Correction Measure :

- Soil application of N fertilizer or Foliar spray of Urea 1-2% twice at weekly interval.

2. Phosphorus

Deficiency Symptoms:

- Growth depression, reduced length and width of leaves, short stalks and reduced tillering.
- Generally, the symptoms of P deficiency appear in the older leaves which becomes dark green in color with blue tings. As the deficiency progress the blue coloration uniformly appears on mid rib and leaf lamina.
- In acute deficiency the leaf show reddish violet coloration covering the entire leaf lamina. Finally, lower leaves dries and withers completely and next upper leaf is affected in similar way.

Corrective Measure:

- Foliar spray of DAP 2% twice at fortnight interval
- Applying large amounts upto 1 tonne/ha of rock phosphate
- Application of triple super phosphate @ 0.5 to 0.75 kg /ha

3. Potassium

Deficiency Symptoms:

- The symptoms of K deficiency generally begin in older leaves. However under extreme deficiency, the symptoms may occur on the younger leaves.
- The plant show stunted growth with shortened internodes. The leaves become small, thick, fleshy and deformed with downward curling.
- The chlorosis appears on the margins of lower leaves first and then progress to the middle and upper leaves which becomes necrotic and ultimately dries off. The chlorosis and necrosis spread from margin to inner side of the leaves however, midrib remains green.

Correction Measure :

- Foliar spray of KCl 1% twice at fortnightly interval

4. Calcium

Deficiency Symptoms :

- Chlorosis of young leaves which develops necrotic spots with dead centre.
- The meristematic growth almost gets completely ceased and lateral branches emerged resulting in bunchy top. Stalks become thin, tough and woody and characterized by soft rind.

Correction Measure :

- Soil application of 100kg/ha of Gypsum.

5. Sulphur

Deficiency Symptoms :

- Plants have an off-color or yellowish-green appearance like N deficiency the youngest leaves are more chlorotic.
- Stalks short thin and leaf area reduced.

Correction Measure :

- Foliar spray of K_2SO_4 1% twice at fortnight interval

6. Magnesium

Deficiency Symptoms :

- Magnesium deficiency is first evident on older leaves. Red necrotic lesions result in a "rusty" appearance.
- The "rusty" appearance can spread across all leaves and may also result in premature dropping of older leaves.
- Stalks show internal browning.

Correction Measure :

- Soil application of $MgSO_4$ 25kg/ha or Foliar spray of $MgSO_4$ 2% twice at fortnight interval.

7. Iron

Deficiency Symptoms :

- Interveinal chlorosis in young leaves; in acute cases, chlorotic leaves bleached and turned to whitish.
- Older leaves remain green; root system is less developed**.**

Corrective Measure :

- Foliar spraying of 250-500g of ferrous sulphate dissolved in 100 lit of water or Soil application of 25kg/ha of ferrous sulphate or
- Alternatively foliar spraying of 5 kg of ferrous sulphate with 2.5 kg of urea in 500 litres of water for one hectare should be done.
- The foliar spraying may be repeated at an interval of 7-10 days depending upon on the severity of the disorder.

8. Manganese

Deficiency Symptoms :

- Interveinal chlorosis in middle part of middle leaves which later develops necrotic spots; these spots enlarge and coalesce to form necrotic streaks.
- Under severe Mn deficiency, the entire leaf becomes bleached

Correction Measure :

- Foliar spray of $MnSO_4$@1-2%

9. Copper

Deficiency Symptoms :

- Copper deficiency generally appears first in young leaves.
- Green splotches are an early symptom
- Apical meristems remain alive, but internode elongation will be greatly reduced when Cu deficiency is severe.

Correction Measure:

- Foliar spray of $CuSO_4$@2%

10. Zinc

Deficiency Symptoms :

- Zinc deficiency is first evident on the younger leaves. A broad band of yellowing in the leaf margin occurs.
- Red lesions are often noticed. The lesions may be associated with a fungus that prefers to grow in Zn-deficient tissues.

Correction Measure :

- Foliar spray of $ZnSO_4$@0.5%

11. Boron

Deficiency Symptoms :

- Short chlorotic streaks confined to young leaf laminae; which gets pronounced and develops interrupted translucent areas. Minute elongated watery spots could be seen on young leaves parallel to veins which give ladder like appearance.
- Boron-deficient plants have distorted leaves, particularly along the leaf margins on immature leaves. Immature leaves may not unfurl from the whorl when B deficiency is severe

Correction Measure:

- Foliar spray of borax@0.2-0.5%

12. Molybdenum

Deficiency Symptoms :

- Molybdenum deficiency is seen on older leaves.
- Short yellow streaks, especially near the tip of the old leaves; may turn reddish in acute cases. Pitting develops along the veins.

Correction Measure :

- Foliar spray of sodium molybdate@2mg/litre

Sugarcane leaf nutrient critical values and optimum ranges

Nutrient	Critical Value	Optimum Range
	%	%
Nitrogen	1.80	2.00–2.60
Phosphorus	0.19	0.22–0.30
Potassium	0.90	1.00–1.60
Calcium	0.20	0.20–0.45
Magnesium	0.13	0.15–0.32
Sulfur	0.13	0.13–0.18
Silicon	0.50	≥0.60
	mg/kg	mg/kg
Iron	50	55–105
Manganese	16	20–100
Zinc	15	17–32
Copper	3	4–8
Boron	4	15–20
Molybednum	0.05	--

From Anderson and Bowen (1990) and McCray and Mylavarapu (2010). All values are from Florida except S and Mo, which are from Louisiana

Chapter No. 53: Post harvest management to sustain sugar recovery

Radha Jain
Plant Physiology and Biochemistry Division
ICAR- Indian Institute of Sugarcane Research, Lucknow
Email: Radha_dinesh@yahoo.co.in

Sugarcane is one of the most important sugar crops, accounting for 78% of sugar produced worldwide. Being a C_4 crop, it is capable of accumulating up to 25% (w/w) of sucrose in cane stalk. The quality of sugarcane juice is determined by the high concentration of sucrose and low concentration of non-sucrose components. Sugarcane being a perishable commodity must be processed at the earliest. A well ripened crop tends to lose its sugar within a few days after harvest and aggravated by many intrinsic and extrinsic factors such as ambient temperature, humidity, cane variety, period of storage, microbial population, activity of invertases, maturity status, causing enormous losses in cane tonnage and sucrose recovery. In sub-tropical India, sucrose losses after sugarcane harvesting and subsequent milling operation are some of the most vexing problems of sugar industry. Staling beyond 72 hours results in considerable loss in cane weight due to moisture loss and reduction in sucrose content due to inversion. Efforts have been made to reduce loss in cane weight and sucrose using physic-chemical methods *viz*., spraying of water, biocide, anti-inversion chemical formulations and pre-harvest foliar application of zinc and manganous compounds. An integrated mill sanitation program and simultaneous use of dextranase could further improve sugar recovery and minimize problems caused by dextran. The possibility of electrolyzed water (EW) fogging to reduce post harvest deterioration in field and mill yard has also been explored.

Definition of Post -harvest losses

Post harvest deterioration means any quantitative and qualitative changes occured in sugarcane composition from the time of harvest to its crushing. Loss in cane weight ranges between 7-15% due to drying after harvest. After harvest of cane, percent loss in moisture and reducing sugars increases which finally declines sucrose content. Certain microorganisms also develop that make the cane sour due to formation of organic acids. Reduction in sucrose recovery and increase in gum content leading to higher viscosity of cane juice. Hence, physical, biochemical and microbial aberrations are responsible for the deterioration of harvested canes and therefore proper management of these canes are essential to improve sugar recovery and fables better return to both farmers and millers.

At farmers and factory level, following constraints operate which considerably delay the milling operations and affect the sugar recovery:

- Absence of a proper varietal balance and scientific harvesting and crushing schedule based on crop/varietal maturity
- Extension of milling period during summer months when ambient temperature is high (> 40^{o}C)
- Practice of harvesting canes 3 to 5 days in advance before supply to mills, in some areas this delays is 7-10 days
- Limited crushing capacity of the mills resulting into staling of cane at mill yard/ cane centres
- Inordinate delay in transport of harvested cane from farmers field/cane centers to the sugar mills and lack of an efficient communication network
- Complete absence of cleaning system, practice of uprooting, burning and detopping of cane in certain areas
- Labor scarcity and power interruption
- Lack of understanding regarding cane and mill sanitation program and use of low quality biocides during milling process
- Mechanical harvesting of sugarcane / burnt crop without proper and timely supply arrangements

At two levels post harvest quality losses occur leading to low sugar recovery:

(i) Primary losses- Sucrose inversion process following harvesting of sugarcane (also in over-stand) and subsequent delays in delivery of cane to the sugar factory (ii) Secondary losses- Losses due to inversion and formation of dextran, alcohol, acid in extracted juice mainly due to inefficient and unhygienic processing of cane juice.

Harvesting Transport At Mill Milling

Fig.1: Cane quality loss after harvest

Major causes of post- harvest losses

- Nature of varieties and their inversion behavior
- Moisture and original condition of cane
- Maturity status of the crop
- Pre-harvest practices such as burning and detopping
- Weather conditions at the time of harvest and storage
- Methods of harvesting
- Green or burnt cane harvesting and size of billets if harvested mechanically
- Storage methods and duration
- Time lag between harvesting to milling
- Sanitary conditions outside and inside the mill as well as processing efficiency
- Crop history *viz*., incidence of pests and diseases
- Abiotic factors saline/alkaline/drought/waterlogged/frost and stand over cane. affecting growth and quality of crop

Magnitude of post harvest sucrose losses

The cut- to crush delay and external temperature are the major factors determine the rate of sucrose loss through inversion, respiration and formation of organic acids, dextran and polysaccharides. Quality losses from stale crushing of sugarcane crop varied from a minimum of 12% to as high as 50% of recoverable sugar if it was held for 14 days. Rao (1989) have shown 2% loss in sugar recovery when cut-to-crush period exceeds 72 h. Solomon (2008) reported 1.0 unit loss in pol% cane from harvest to milling stage. On an average Indian sugar mills suffer and a loss of ~ 5 to 10 kg sugar per tonne of cane crushed. These losses further shoot up when crushing is extended in summer months.

Economic implications of cane staling

The cane deterioration after harvest has serious socio-economic consequences affecting farmers, millers, refiners, exporters and consumers. The post-harvest deterioration of sugarcane mainly affects cane growers and millers. A moisture loss from the harvested canes affects the growers due to reduction in cane weight and sugar industry loses money due to low sucrose recovery. Besides, many undesirable compounds are formed as a result of bacterial invasion, and chemical reactions which hamper milling process. The low quality sugar produced from staled cane affects consumers and exporters.

Cane growers: Loss of moisture from the harvested cane affects the growers due to reduction in cane weight, as payment is made on weight basis. Solomon (2009) observed weight loss between 7 to 10 percent within 72 hrs after harvest under subtropical conditions. This delay in supply of harvested cane to sugar factory could lead to major economical loss to cane growers. As per the prevailing State Advised Prices (SAP) in north India, loss to growers may exceed Rs 200/- per ton cane.

Sugar industry: The sugar industry loses money due to low recovery from deteriorated cane. A sugar mill (5000 TCD) crushing >72 h stale cane may lose around Rs 3-5 lakh per day on account of low sucrose recovery. These losses may further accelerate depending upon the variety, cut-to crush delay and ambient temperature. In addition, many undesirable compounds formed during cane deterioration due to chemical and microbial activity entail sugar processing difficult and also render sugar manufacturing uneconomical.

Biochemical constituents affecting post- harvest sucrose loss

The deterioration of harvested cane is primarily a biochemical process which aggravates with the passage of time. After harvesting, endogenous invertases get activated due to lack of any internal physiological and biochemical control mechanism. There are two types of invertase (s) namely acid invertase (A) (pH 4.8) and neutral invertase (N) (pH 7.0) in cane stalk and behavior of both these invertases strongly influenced by variety, pre-harvest burning and storage duration. The activity of soluble invertase in harvested cane juice is mainly associated with the decline in cane quality. The varietal response difference in A/N ratio seems to be important criteria for varietal selection programme. Batta and Singh (1991) observed 0.8 units decline in sucrose recovery during 24 hrs storage at high ambient temperature. They have reported drop in recovery from 13.7% to 7.9% on fresh weight basis in 12 days of cane storage. During staling, enzymatic hydrolysis of starch causes formation of dextran and reducing sugars and as a result specific gravity of the juice increases and sucrose recovery decreases (Gupta 1981). Das and Praphu (1988) reported the presence of amylase, acid phosphatase carboxyl-methyl cellulose and fructose 1-6 di phosphatase in the stale cane. Presence of cellulolytic enzymes in cane juice was also reported by Solomon and Kumar (1983). Eggleston and Legendre (2003) emphasized that the enhanced activity of acid invertase could be due to possible synthesis of cut induced invertase and decreased activity of sucrose synthesizing enzymes due to change in pH of cell sap. It has also been noted that the acid invertase activity enhanced the dextran formation (Solomon, 2009).

Microbiological aspects of cane deterioration

At later stage of staling besides enzymatic, chemical and respiratory losses, growth of microbes (dextran, alcohol, acid producing) is responsible for huge losses in recoverable sugar. Microorganisms such as yeast (*Saccharomyces*, *Torula, Pichia), Leuconostoc, Xanthomonas, Aerobacter,* acid producing *Streptomyces* are found at the cut ends or damaged sites of the canes. Bio-deterioration is caused mainly by *Leuconostoc mesenteroides.* These bacteria enter into sugarcane stalk from the soil through the cut ends of damaged sites of stalks and multiply in the mill corners, gutters, pipe lines and the mixed juice tank. These microorganisms convert sucrose into polysacharides such as dextran catalysed by enzyme dextransucrase or exogenous invertase. The presence of dextran even in very small amount creates problems of filtration, clarification, crystallization and alters the shape of sugar crystals thereby affecting the quality of sugar. In addition to the many external microbes, sugarcane stalks contain an endophytic flora viz., *Acetobacter, Pseudomonas, Aeromonas, Vibrio, Bacillus* and lactic acid producing bacteria and these have been reported to increase several folds during staling and significantly responsible for deterioration of juice quality.

Detrimental effect of organic metabolites formed in stale cane on sugar processing

- Reduction in sucrose recovery
- Formation of more reducing sugars

- Increased dextran formation leading to processing and sanitation problems
- Slow crystallization, poor clarification and slow mud settling rate
- Formation of elongated crystals of sucrose which affects its marketability
- Increase in gum content leading to high juice viscosity
- Increase in organic acids leads to scaling problems requiring more heating time
- To cane growers due to reduction in cane weight
- The stale cane undergo further deterioration in quality during subsequent milling operation i.e. cane preparation, juice extraction and clarification
- Poor mill sanitation and lack of effective biocide hampers the processing efficiency and reduces sucrose recovery in the following ways: Direct loss of sucrose by native invertase (13%) and sucrose loss by metabolic products formation like dextran, ethanol, polysaccharides, acid, *etc*. (25%)
- Microorganisms growing in the cane juice consume sucrose present in it (62%).

Parameters of quality assessment of harvested cane

- External indicators: sourish odor, vinegar smell, yellowish brown juice
- Juice viscosity
- Purity drop and Pol deviation= Juice pol-(1.25 Brix-7.32)
- Dextran content
- Oligosaccharides
- Reducing sugars
- Organic acids
- Analysis of split canes
- Ethanol formation
- Titrable acidity and gum content
- Increase in acid invertase activity

Management of post- harvest sucrose losses:

Based on these indicators, quality of cane supplied to the mills could be assessed, however, sucrose loss in the harvested cane could be minimized by using methods described below:

(1) There is no substitute for better communication, quick and efficient transport to minimize post-harvest losses. The harvested cane must be brought to mill and processed as quickly as possible. The factory management must ensure that fresh cane is supplied regularly and all indents should be placed accordingly. Solomon *et al.* (2004) have advocated following milling schedule for harvested cane/billets for Indian sugar factories:

- Full green cane: Milled within 48 h (early season)
- Milled within 24 h(late-season)
- Burnt full cane Milled within 24 h
- Billets (green/burnt) Milled within 12 h

(2) The harvested cane before crushing should be made free from trash, leaves and roots etc. For late-milling season (high ambient temperature), varieties with high rind hardness/ fiber along with high wax content should be preferred. This will reduce considerable moisture and sugar loss from cane.

(3) Soil content of cane is also one of the factors influencing not only cane deterioration but also causes process difficulties, such as cane preparation, milling, clarification and is a source of millions of microbes that can grow in juice. Soil particles are directly responsible for damage of hammer, knives, conveyer, juice screens, pipes and many other parts of the processing unit. It is therefore, important that processing of muddy cane should be avoided.

(4) It has been observed that topped cane deteriorates faster than cane with the crown of leaves attached. In case of any anticipated delay in crushing, topping should be avoided.

(5) Maturity of cane is a major factor in the inversion and subsequent reduction of stored sucrose. As maturation level increases the extent of sucrose loss is minimized. Harvestingof immature or over mature cane should be avoided to cut down post-harvest sugar losses. It is necessary that maturity-wise harvesting should be implemented, especially in the low recovery areas.

(6) In order to cut down post-harvest sugar losses, it is important to identify sugarcane varieties with high sucrose content and less inclined to post-harvest inversion (both biochemical and microbiological). These varieties should also be screened for rind hardness, wax content, etc.

(7) The transport and storage of cane also affect the process of dextran formation i.e. degree of damage from loading equipments, size and shape of container, etc. Excessive mechanization viz., grab loader, chains and slings tend to bruise cane.

(8) In case of unavoidable delay in crushing, the harvested cane should be stored in small heaps with minimum ground contact and sprinkled with a solution of bactericide and covered with a thick layer of trash. This method has been found to suppress the activation of invertases. The cane piles should be stacked in such a way so as to facilitate proper ventilation.

(9) The cleanliness in the cane yard is of utmost importance.

(10) Pre-harvest application of chemicals: Many preventive methods developed earlier could not be scaled up into commercial venture due to poor efficacy of chemicals and operational difficulties under field conditions. These methods include treatment of cane with bactericidal chemicals, gamma irradiation from ^{60}Co and pre-harvest spray of divalent cations such as Zn++, Cu++, Co++ and Ba++. Pre-harvest foliar application of Zn++ (@ 1000 mg/l) showed appreciable improvement in juice quality in stale cane. Inhibitory effect of Mn++ on cane invertases has also been reported(Solomon *et al*.,1990; Batta *et al*.,2007) .

(11) A study conducted by Tomar and Malik (2004) has indicated that basal application of zinc sulphate (25 kgha-1) reduced the pace of post harvest deterioration of sugarcane.

Recent studies conducted at the Indian Institute of Sugarcane Research, Lucknow have shown that pre-harvest soil application of zinc sulphate and manganous sulphate @ 25 kg/ha six weeks prior to harvest improved sucrose content in sugarcane and minimized post-harvest sucrose losses.

Post-harvest application of chemicals

(i) At field/ harvest level:

(A) Combined application of solution containing potassium permanganate (0.1%) and 1% sodium metasilicate 3 days prior to harvest prevented post harvest losses by minimizing invertase activity and retaining the juice quality. Spraying of QUAT based formulation and anti-inversion chemical (sodium metasilicate) on billets followed by covering with trash saved 1.37, 2.90 and 2.62 units of CCS.

(B) Application of anti-bacterial and anti inversion chemicals (BKC+ SMS) on harvested cane has improved sugar recovery. Solomon et al (2006) demonstrated efficacy of few chemical formulations containing antibacterial (quaternary ammonium compounds/thiocarbamates), anti inversion chemicals (sodium metasilicate/sodium lauryl sulphate) in minimizing post harvest sucrose losses in sugarcane. The aqueous formulation(s) are sprayed over freshly harvested cane (whole stalk and billets) followed by covering the treated cane with a thick layer of dried cane leaves (trash). Formulation containing benzalkonium chloride (BKC) + sodium meta silicate (SMS) was found to be most effective and improved sugar recovery over 0.5 units. This method reduces the loss of sucrose from harvested cane up to a period of one week, irrespective of temperature and variety.

(C) Use of electrolyzed water (EW) : The concept of electrolyzing saline to create a disinfectant is appealing because the basic materials, saline and electricity, are cheap and the end product (water) is not damaging to the environment Solomon . EW appears to work as an anti-infective agent by denaturing proteins in the membrane of single-cell organisms. The solution has been shown to be non-toxic to biological tissues. The antimicrobial activity of EW has been tested against bacteria, mycobacterium, viruses, fungi, and spores. Use of EW in sugar beet processing has been reported. For sugarcane it showed relatively lesser reduction in quality as compared to untreated cane.

(ii) At mill/ processing level:

- Mill sanitation: Regular thorough washing and steaming with hot water
- Biocides application (KilbactTM) (20 ppm),
- Some important biocidal agents which are used in sugar industry are halogen compounds, ammonium bifluoride, formaldehyde, quaternary ammonium compounds(QUAT) and thiocarbamates.
- Treatment with dextranase enzymes to remove dextran

Chapter No. 54: Physiological approaches for enhancing germination, tillering and sugarcane yield

Pushpa Singh[1]*, Anam1, Nidhi Tripathi[2]
[1]ICAR-Indian Institute of Sugarcane Research, Lucknow
[2]Anurag Memorial College, Magadh University, Bodh Gaya, Gaya, Bihar

Abstract

Sugarcane is one of the most efficient quantum converters, endowed with vast tillering, ratooning and biomass potential. Vast tillering potential, innumerable root primordia, two types of roots and emergence of leaves constitute a "*Compensatory Physiologic Continuum"* which imparts this plant a unique ability to tide over abiotic stress conditions, gaps in the field and agro-physiological disorders arising in its 12-18 months long cycle. Despite this, the recorded yields of sugarcane are about 168 MT $ha^{-1}yr^{-1}$ that is just about 36 % of the theoretical maximum of 470 MT ha^{-1} yr^{-1}, which however, in India is only 28.6 % of the theoretical maximum. As the inputs of CO_2, water and light can be limiting to yields, more economical yields can be obtained by increasing the photosynthesis, nutrient use and transpiration efficiency. So, despite the fact that each of these process possess the potential for improvement of yield, the interrelationships between them show great difficulty in identifying an ideal ideotype that can result in yield increases under all the circumstances. The present chapter attempts to illuminate the strategies for improving the productivity of sugarcane under Indian subtropics by utilizing knowledge on interactions of various plant processes. The processes involving high photosynthetic efficiency, increasing light absorption by increasing the leaf size, number of leaves per stalk and number of stalks per unit area, increasing the CO_2 uptake through increase in stomatal conductance and decrease in boundary layer resistance to CO_2 by decreasing leaf width, increasing the efficiency of partitioning of photosynthates and reducing the yields losses for enhancing tillering and sugarcane yield have been broadly elaborated.

Introduction

Commercially grown sugarcane varieties are complex hybrids that involve more than two *Saccharum* species. The genus belongs to the tribe Andropogoneae of the family Gramineae. The crop is endowed with certain unique features. It has a vast tillering and ratooning potential. Sugarcane crop cycle is divided into four growth stages; germination, tillering, grand growth, ripening. In a subtropical February planted crop, duration of these stages is; germination (0–45 DAP; tillering (45–120 DAP); grand growth phase (120–270 DAP) and ripening phase (270–365 DAP). Depending upon the ripening behaviour, varieties have been grouped as early, mid-late and late ripening varieties. Dry matter production and partitioning in this crop, like other crops, is a dynamic process and it varies as a function of time, varieties, crop stands, ratooning, etc. Being a long duration crop, its water requirement varies from 1,400-3,000 mm depending upon climatic conditions, soil type and crop duration. Sugarcane requires large amount of nutrients and for production of 100 Tonnes cane ha^{-1}, it removes 67–307 kg nitrogen (N), 12–58 kg phosphorus (P_2O_5), 111-257 kg K_2O, 53–128 kg CaO, 20-30 kg MgO, 20–50 kg S, 0.18-0.24 kg Fe, 1.12-1.33 kg Mn, 0.14-0.21 kg Cu and 0.39-0.49 kg Zn ha^{-1}. By and large the ratoon crops are given 25 % extra nitrogen. Subterranean buds on stubble-the part of cane left underground after harvesting plant cane, gives rise to succeeding crop stand which is usually referred to as 'ratoon' or the 'stubble crop'.

Physiological Interventions for Enhancing Germination, Tillering and Sugarcane Yield

The crop is planted from culm pieces containing axillary buds positioned above each node. The phytomers originating from buds pass through four growth stages, that is, germination, tillering, grand growth and maturity, before the commercial component is harvested (Moore and Botha, 2014). The yield is dependent upon higher germination rate and %, which governs the initial shoot population, Tillering numbers, T_{max} and NMC. When the culms are cut from the plant, initiation of sprouting of axillary buds is not automatic. Sprouting of buds requires both the correct temperature (20–30°C) and a moist environment (Donaldson, 2009). The germination stage in often coincides with adverse temperature, exposing buds to temperature ranging from about 10-13 °C higher and lower than their optimal growing conditions. This causes severe losses in soil and sett moisture contents (Yadav et al., 1997). Plants exposed to temperatures ± 5 °C above their optimal growing conditions exhibit a characteristic set of cellular and metabolic responses required for the plants to survive under high- temperature conditions (Guy, 1999). These effects include rapid and excessive accumulation of reactive oxygen species and abscisic acid (Maestri et al., 2002), accompanied by a decrease in synthesis of normal proteins and accelerated transcription and translation of heat-shock proteins (Bray et al., 2000). The overproduced reactive oxygen species (ROS) react directly with lipids, proteins and nucleic acids and cause lipid peroxidation-mediated membrane injury, protein degradation, enzyme inactivation, deoxyribonucleic acid (DNA) strand disruption and moisture deficit in cells (Liu and Huang 2000; Maestri et al., 2002). The cellular and metabolic changes prevailing at germination stage impose severe limitations on the early germination pattern, subsequent settling establishment and restrict the crop growth period to 220 days (Yadav et al., 1997). The restricted crop growth period suppresses physiological growth of leaves and shoots at the tillering stage, stem elongation and dry matter accumulation during the grand growth stage and sucrose accumulation and yield at the harvest stage (Lingle, 1999).

Adverse temperatures reduce CO_2 influx for photosynthesis, net photosynthetic rate and dry matter partitioning and the ability to utilize photosynthates and restricts tiller formation (Oh-e et al., 2007). Under normal conditions, a synchronism exists between the mother shoot and tillers and further, between tillers themselves. Adverse temperature, however, imposes adverse impacts on synchronism and mobilization of assimilates and nutrients amongst tillers, causing a severe reduction in their numbers (Bita and Gerats, 2013). Decreased tiller numbers reduce productivity, as tillers per plant at an early stage determine the number of millable canes, which is the key component of cane yield (Bell and Garside 2005). Physiologically, adverse temperatures affect leaf development, leaf characteristics and internodal elongation at the tillering stage (Bonnett et al., 2006). The base temperature for stem elongation has been calculated as 16–18°C (Lingle, 1999). Adverse temperatures reduced moisture availability leading to shorter internodes and stalk length (Bonnett et al., 2006). A short grand growth period imposes adverse effects on canopy coverage, amount of light interception, cumulative growth rate and dry matter accumulation (Dhawan et al., 1997**;** Moore and Botha, 2014). The physiological causes for poor yield is given in **Figure 1.**

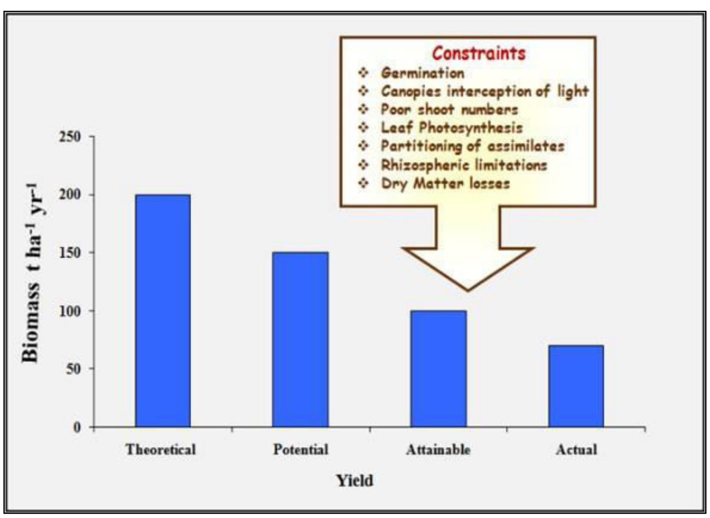


Figure 1: Physiological causes for low cane and sugar yield

Strategies for Improving Germination, Tiller Numbers, Growth For Synchronous Tillering and Reducing Tiller Mortality

For planting sugarcane, 6–8 tonnes of seed cane/ha is required. Several attempts have been made for improving germination, sprouting, shoot numbers and cane yield in sugarcane. Physiological interventions like, exploitation of potential of single buds setts (as in STP method of planting) (Srivastava et al., 1981), bud-chip nursery raised-plants (Narendranath, 1992) and reducing the internodal length by certain chemicals like paclobutrazol (Croft and Magnanini, 2007) have been useful in reducing the volume of the seed cane used for planting. Soaking bud-chips in $CaCl_2$ 0.1 % solution ensured higher germination (90 %) and used only 1 tonne seed caneha^{-1} as against 6-7 tonnes in conventional system (Anonymous, 2011–12). Soaking setts in 0.5 % Thiourea and Glycine/Betaine (250 ppm each) enhanced germination. Using these chemicals, reducing sugars, acid invertase and nitrate reductase activity *in vivo* increased and soluble proteins decreased. Reduction in moisture deficit in cane setts and buds due to adverse temperature has been attempted through irrigation between planting and the germination stage. However, irrigation causes crust formation in the upper layer of soil and blocks the emergence of young settlings (Srivastava and Mahindra, 2012; Yadav et al., 1991). Improvement in sprouting has also been addressed through increased seed rate and altered plant geometry. A narrow row to row spacing of 60 cm was adopted with a huge seed requirement (7–8 tha^{-1}), for accommodating increased seed rate, unlike row to row spacing of 75 cm in spring planting, where the seed requirement was 5–6 tha^{-1} (Singh, 2000; Bhullar et al., 2002**).** However, no significant improvement in germination, shoot numbers, cane harvest index or sugar productivity was obtained.

Strategies for Enhancing Germination

1. Spaced Transplanting Technique (STP)

Occurrence of higher mortality adversely affects stalk density and crop productivity. Besides, with the advent of new improved varieties, transportation of their bulk cane seed material and slow multiplication rate (ratio being 1:8 to 1: 10) is an important constraint to seed programme. Based on physiological understanding of germination (sprouting), tillering *vis-a-vis* inter-and intra-plant competition, a planting procedure, Spaced Transplanting Technique (STP), has been developed which saves the precious cane seed material, ensures higher stalk population (number of millable canes) with a uniform crop stand and higher average cane weight. It has also been a boon for rapid multiplication of seed cane. Seed Requirement is 2 tha^{-1} and seed multiplication ratio is 1: 40 (Srivastava et al., 1981; Kapur et al., 2011**).**

2. Bud Chip Technique

Bud chip technology reduces mass, quality and leads to quick multiplication of seed and optimizes initial shoot population. Scooped bud chips / single bud setts with a viable bud and root primordial is used as a planting material and raised their nursery under field conditions. The technique led to uniform crop stand, synchronized tillering, higher rate of tiller formation (>2.0 lakh) and their conversion into millable canes leading to higher population of millable canes (>1.2 lakh canes/ha), with higher average cane weight and finally higher cane yield (>100t/ha). Seed Requirement - 1 t ha^{-1}; Seed MultiplicationRatio - 1: 60 **(**Jain et al., 2015**)**

3. Sugarcane Sett Priming / exogenous application of *Ethrel*

Overnight sett soaking in 100 ppm *Ethrel improves* seed quality, induces early (20 days) and higher rateof bud germination (46 %**).**

4. Improving Stubble Sprouting in Winter-Initiated Ratoons

Early ripening varieties, autumn planted crops and ratoon crops are harvested during sub- optimal temperatures which affects sprouting of stubble buds and productivity of the succeeding ratoon crop. Therefore, ameliorative measures are needed for protection of stubble buds, stimulating their growth by using growth regulating substances and improving stubble sprouting. Pre-harvest application (spray normally 15 days before harvest of plant crop) of *Ethrel* (200 ppm)/ urea (4 %) (Sharma and Kanwar 1987), Muriate of potash with last irrigation (1 month before harvest) (Brown 1976), post-harvest application of Cycocel (@ 5 l/ha) (Peng and Twu, 1970; Chauhan et al., 1984) to the stubble of freshly harvested crop improved stubble sprouting and cane yield of ratoon crop. Spray of *Ethrel* (@100ppm) at 60 DAI rendered increase in sprouting of the rest of the underground quiescent buds. This led to about 82 % of sprouting and established an initial settling population of 90,000 settlings ha^{-1} against control (62,000 settlings ha^{-1}) at 90 days after planting (DAP).

Strategies for Enhancing Number of Tillers *vis-a-vis* Number of Millable Canes

Tillering is characteristic mode of branching in Gramineous plants. A tiller is structural and functional unit of a sugarcane plant. Practically it is a shoot that includes roots, stem, and leaves. It is initially dependent for its growth on mother-shoot; later on it becomes independent and may also produce tillers. Sugarcane has vast tillering potential; and as many as 144 millable canes from a single bud have been reported (Van Dillewijn, 1952). The shoot emerging from the planted bud (of sett) is called mother-shoot, shoot emerging from the buds in the lower part of mother shoots is a primary tiller, the one arising from the lower buds of a primary tiller is called secondary tiller and the ones from the lower buds of secondary tiller are designated as tertiary tillers. A tiller becomes independent of mother-shoot when it develops its own roots; but still continuity is maintained for movement of water, nutrients and assimilates. Several tillers attached to a sugarcane plant (and leaves and roots) make a ''physiologic compensatory continuum'' which imparts the sugarcane plant an ability to tide over many abiotic stress conditions, gaps in the field, varying nutrient levels, infestation of pests, etc. (Shrivastava, 2004). For sugarcane, tillering is critical as it determines number of millable canes (NMC)-the most important yield component of sugarcane yield. It is also the critical stage for irrigating the crop. Sugarcane productivity and quality depend on quantity, size and quality of millable canes. Cane yield is contributed approximately 70 % by NMC, 27 % by cane length and 3 % by the cane girth through foliar application at different growth stages.

1. Foliar application of PGRs at different crop growth stages in plant crop

Plant growth hormones (usage of *Ethrel* and GA3) have potentially improved the sett vigour, enhanced its ability to sprout and established uniform and robust settlings in spring planted crop. Their usage led to significant alteration in leaf orientation, cane length and root architecture. Architectural alterations caused faster heterotrophic to autotrophic transitions at planting stage (February). This induced high initial plant population (45 DAP), which was followed by induction of smart canopy with increased source activity, above and below ground sink development at 60 DAP. The formation of smart canopy was due to development of erectophiles against planophiles in control. Changes in leaf angle enabled added advantage of enhanced CO_2 utilization and radiation use efficiency. The GA3 induced leaf orientation formed a smart canopy and improved dry matter partitioning. Further, leaf erectness also reduced the shading effects amongst the leaf present on a stalk, rendering increase in radiation use by lower leaf laminae of the stalk. GA3 induced branched roots with steep angles, three-fold increase in root weights and root hair development, sustained the nutrient requirement of increased shoot population. At grand growth and harvest stage, a Tmax 5.37 lakhs shoots ha^{-1} with NMC of 3.01 lakhs ha^{-1} with *Ethrel* and GA3 was obtained against Tmax 2.13 lakh shoots ha^{-1} in untreated with NMC of **1.32 lakhs shoots ha^{-1}. Foliar application of GA3 rendered increased tiller numbers (Figure 2 & 3).**

Figure 2: Foliar application of GA3 at 90, 120 & 150 DAP for canopy development and tillering

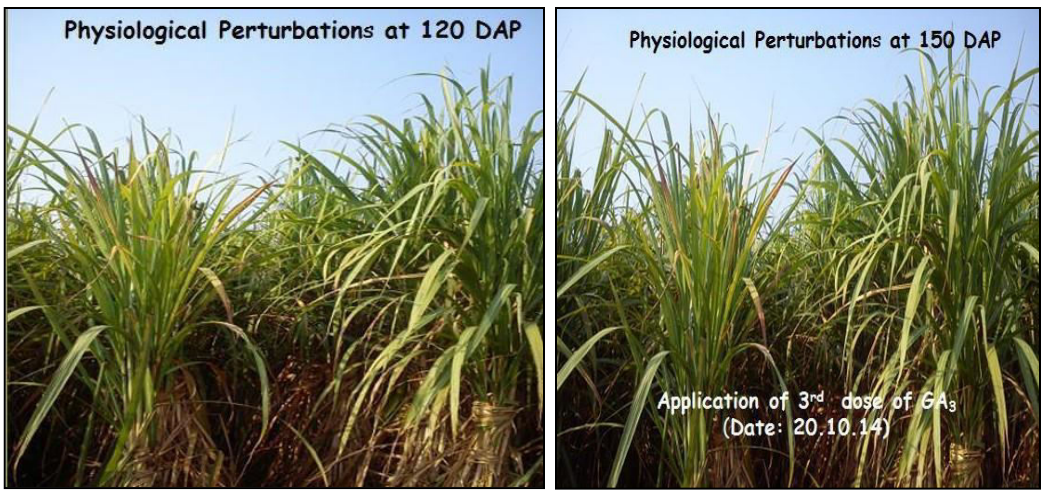


Figure 3: Foliar application of GA3 @ 35 ppm at 90, 120 & 150 DAP for changes in leaf angles, Internodal elongation and NMC.

2. Foliar application of PGRs at different crop growth stages in ratoon crop (Figure 4& 5)

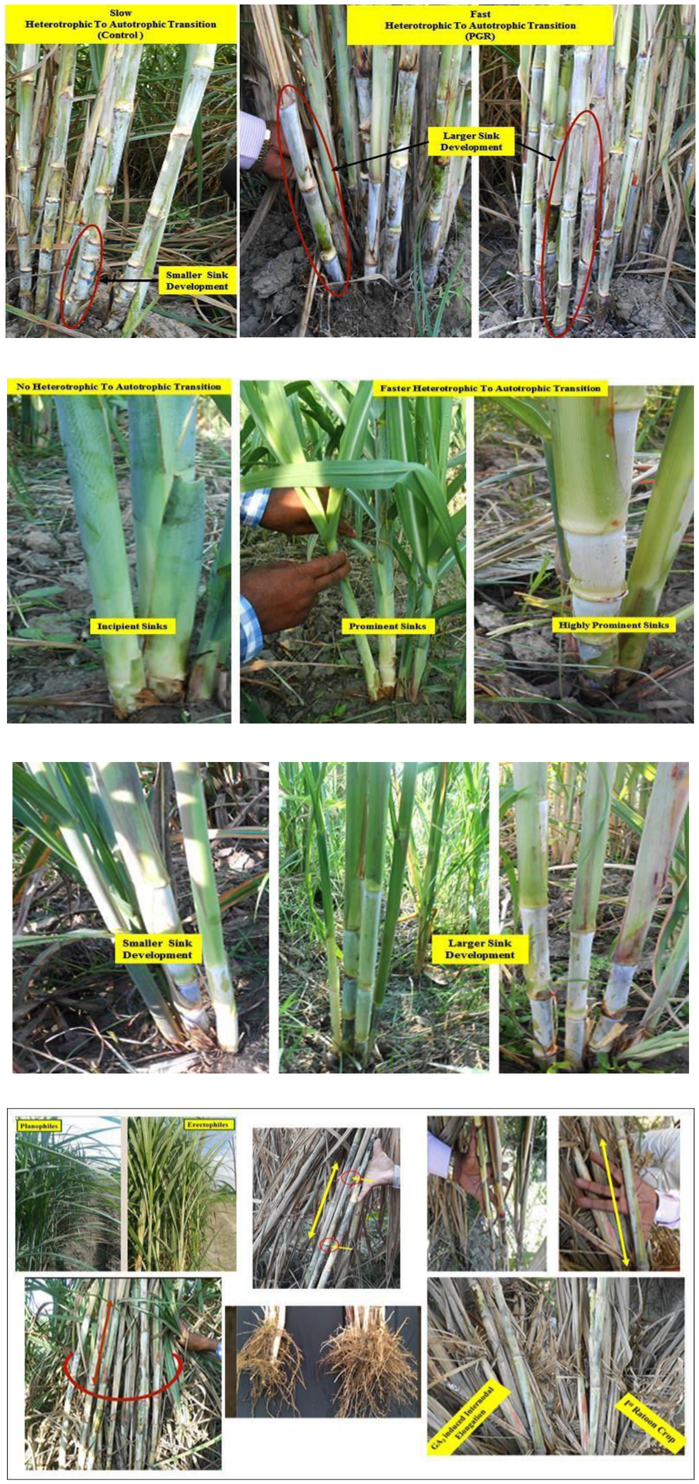


Figure 4: Effect of *Ethrel soaking* on tiller numbers, leaf and root architecture and Internodal elongation in plant and ratoon crops

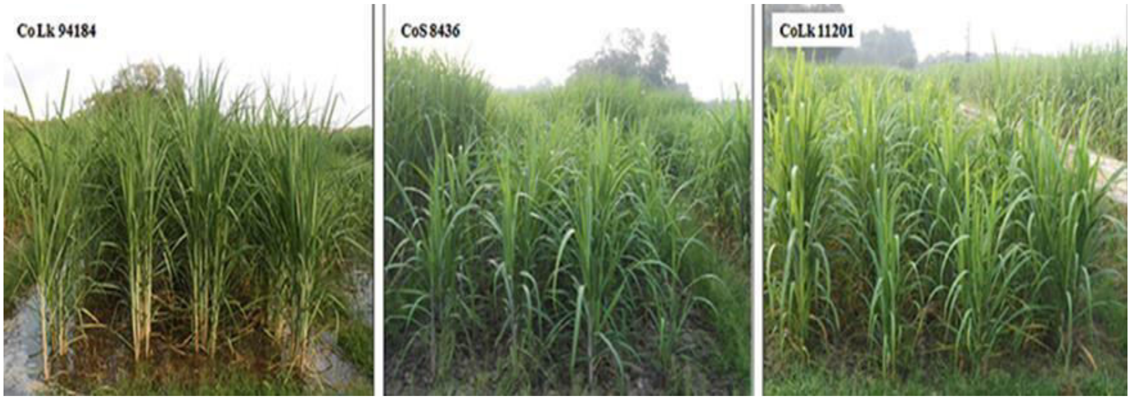


Figure 5: *Ethrel* induced faster heterotrophic to autotrophic transition a. CoLk 94184 b. CoS 8436 c. CoLk 11201

For Increasing Sugarcane Yield

1. Crop architectural changes

Exogenous hormonal interventions during the crop stages have led to increase in cane and sugar yield (CCS tha^{-1}). An increase in the Internodal length through hormonal interventions at grand growth stage increases sucrose content (CCS tha^{-1}) at harvest. PGR technology has been developed for addressing the yield barriers and sugar yield in sub-tropical India**.** The approach involved alterations in the crop architecture during the four primary growth phases in sugarcane. This involved faster and enhanced emergence of cane setts during germination phase, increased shoot numbers (horizontal growth) during the tillering phase and increased Internodal length *vis a vis* cane length (vertical growth) during the grand growth phase. Increase in Internodal length increased cane yield and sugar content (commercial cane sugar tha^{-1}). This was resultant of increased Internodal length, that led to change in leaf architecture, accommodation of larger number of cane stalks in lesser ground area, development of smart canopies that was supported by supported by a robust root system. The overall changes led to increased cane length, per cane weight, juice weight $cane^{-1}$ *vis a vis* number of millable canes per unit area. The gain in number of millable canes per unit area increased the sugar yield (CCS tha^{-1}). The architectural alterations are shown in Figure 6.

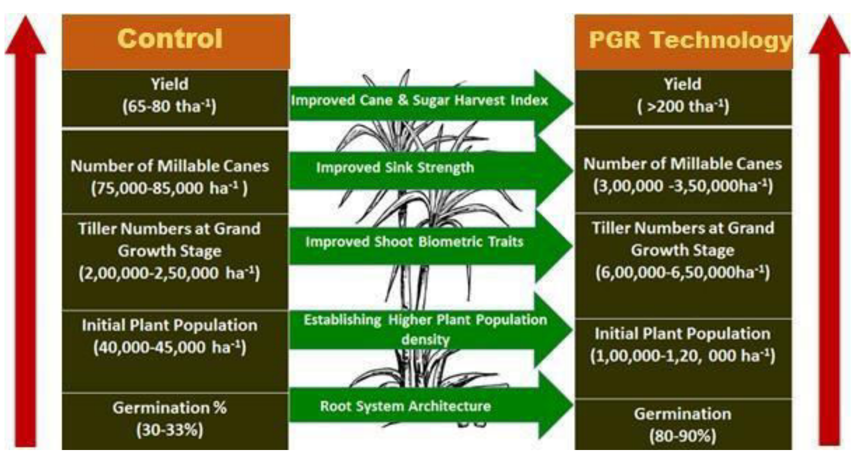


Figure 6: Architectural alterations in Sugarcane

2. Prevention of Flowering

Application of *Ethrel* (0.25 kg ai/ha; 250 ml in 250 l of water/ha) as a mist over the canopy before 3rd week of August reduced flowering by 72 % in a flowering variety Co 62175 in heavy flowering areas of Mandya and Mysore (in Karnataka). It led to an improvement of 0.25 kg in average cane weight, 1.2 units in °Brix and 0.31 units in purity coefficient. Improvement in cane yield was of the order of 8-10 tones/ha (Balasundram, 2004).

3. Nutrient Management for Improving Cane and Sugar Yield and Recovery

Crop logging (Clements 1984) is another useful intervention which is indeed a graphic record of the progress of the crop growth and contains a series of nutritional, moisture contents and crop growth data indicating general condition of crop growth. It is based on critical nutrient concentration (CNC) and critical nutrient ratio (CNR). It also suggests changes in the crop management necessary to attain maximum cane and sugar yields. Use of many nutrient ratio is an integral part of the DRIS (diagnosis and recommendation integrated system) developed by Beaufils at the University of Natal in South America. It is a comprehensive system which identifies all the nutritional factors limiting crop production and in doing so the chances of obtaining high crop yields by improving fertilizer recommendations are included.

REFERENCES

1. Anonymous, 2011–12. Improving physiological efficiency of sugarcane (1) Germination, **Annual Report IISR**, Lucknow, 37.
2. Balasundram, N. 2004. Control of flowering in sugarcane. In Physiological and molecular approaches for improving sugarcane productivity, (**Shrivastava, et al, eds**.), I.I.S.R., Lucknow 65–70.
3. Bell MJ, Garside AJ (2005) Shoot and stalk dynamics and yield of sugarcane crops in tropical and sub-tropical Queensland, Australia. **Field Crops Res** 92:231–248
4. Bhullar MS, Saini LK, Kapur ML, Singh S (2002) Effect of Method and Density of Planting on Growth and Yield of Late Planted Sugarcane. **Sugar Tech** 4(3–4):181–184
5. Bita CE, Gerats T (2013) Plant Tolerance to high temperature in a changing environment: Scientific fundamentals and production of heat stress -tolerant crops. **Front Plant Sci** 4:273. Doi:10.3389/fpls.2013.00273
6. Bonnett GD, Hewit ML, Glassop D (2006) Effects of high temperature on the growth and composition of sugarcane internodes. **Aust J Agric Res** 57:1087–1095
7. Bray EA, Bailey-Serres J, Weretilnyk E (2000) Responses to abiotic stresses. In: Gruissem W, Buchannan BB, **Jones RL (eds) Biochemistry and molecular biology of plants**. American Society of Plant Physiologists, Rockville, pp 1158–1203
8. Chauhan, R.S., R.S. Verma, and K.C. Pathak. 1984. Effect of CCC application in improving the stubble sprouting and yield of winter harvested rations. **Co-operative Sugar** 20(5): 315–317.
9. Croft, B.J., and A. Magnanini. 2007. Chemical control of sugarcane vertical growth to improve the quality of seed cane. **Sugar Cane International** 25(3): 8.
10. Dhawan AK, Sahtiya HL, Dendsay JPS (1997) Low germination of sugarcane setts in Indian sub-tropics: Constraints and their management. **Indian J SugTech** 12:17–21
11. Donaldson RA (2009) Seasons effect on the potential of biomass and sucrose accumulation of some commercial cultivars of sugarcane. PhD Thesis, University of Kwazulu Natal South Africa pp 173
12. Guy C (1999) Molecular response of plants to cold shock and cold acclimation. **J Mol Microbial Biotechnol** 1:231–242
13. Jain, R., Chandra, A., Shrivastava, A. K., & Solomon, S. (2015). Bud chip technology for rapid seed multiplication and improving cane yield.
14. Kapur, R., Duttamajumder, S. K., & Rao, K. K. (2011). A breeder's perspective on the tiller

dynamics in sugarcane. **Current science**, 183-189.
15. Lingle SE (1999) Sugar metabolism during growth and development in sugarcane internodes. **Crop Sci** 39:480–486
16. Liu X, Huang B (2000) Heat stress injury in relation to membrane lipid peroxidation in creeping bentgrass. **Crop Sci** 40:503–510
17. Maestri E, Klueva N, Perrotta C, Gulli M, Nguyen HT, Marmiroli N (2002) Molecular genetics of heat tolerance and heat shock proteins in cereals. **Plant Mol Biol** 48:667–681
18. Moore PH, Botha FC (2014) Sugarcane: physiology, biochemistry and functional biology. **Wiley-Blackwell**, New Jersey, pp 716
19. Narendranath, M. 1992. Cost-effectiveness of transplanting nursery raised sugarcane bud chip plants on commercial sugar plantations. **Proceedings International Society for Sugar cane Technologist** 11: 125.
20. Oh-e I, Saitoh K, Kuroda T (2007) Effects of high temperature on growth, yield and dry-matter production of rice grown in the paddy field. **Plant Prod Sci** 10:412–422
21. Peng, S.Y., and L.T. Twu. 1970. Application of plant growth regulating substances to improve germination and yield of ratoon cane**. Taiwan Sugar** 25: 8–17.
22. Sharma, H.K., Singh, O., and R.S. Kanwar. 1987. Effects of nitrogen in combination with growth regulators on ratoons of low temperature harvested sugarcane. **Proceedings Annual Convention Sugar Technologists Association of India** 50: 81–86.
23. Shrivastava, A.K. 2004. Yield decline and its management in sugarcane. **Management and agro-industrial imperatives** (eds. Solomon, S., S.S. Grewal, Yang-rui Li, R.C. Magarey and G.P. Rao) International Book Distributing Co., India 321–345.
24. Singh A (2000) Influence of seed rates and row spacing's on growth and yield of late planted cane. **Sugar Tech** 2(3):49–50
25. Srivastava AK, Mahindra RK (2012) Sugarcane production: impact of climate change and its mitigation**. Biodiversitas** 13(4):214–227
26. Srivastava, K.K., R. Narasimhan, and R.K. Shukla. 1981. A new technique for sugarcane planting. **Indian Farming** 31(3): 15–17.
27. Van Dillewijn, C. 1952. Botany of sugarcane, 352. Waltham, Mass: The Chronica Botanica Press.
28. Yadav RL, Kumar R, Verma RS (1991) Effect of planting technique and planting density on yield of late planted sugarcane in North Central India. **Exp Agric** 27(03):281–286
29. Yadav RL, Singh RV, Singh R, Srivastava VK (1997) Effect of planting geometry and fertilizer N on nitrate leaching, NUE and sugarcane yield. **Trop Agric** 74:115–120

Chapter No. 55: Impact of IISR Technology on Sugarcane field and farm Income

A K Sharma
Principal Scientist (Ag. Econ.)
ICAR-Indian Institute of Sugarcane Research, Lucknow

There are three main sources of funding to agricultural research: the Union Government, State Governments, and the private sector in India. The estimates of private expenditure on research are not readily available. Moreover, the research in the private sector is limited, and mostly confined to research foundations and in-house R&D in a few input industries such as the seed sector. Hence, agricultural research in India is largely in the public sector domain. Unlike in other countries and international organizations, public expenditure on agricultural research (including education) in India in real terms has steadily increased. Research intensity measured as research expenditure as percentage of agricultural gross domestic product (AgGDP), has shown appreciable growth till nineties but has been reduced in the last 20 years. The intensity increased from 0.31% during the 1974-79 period, to 0.42% during 1980-85 period, to 0.48% during 1985-90 period, and to 0.49% during 1992-97 period. At present, the research intensity has been reduced again to 0.37% of gross value added in agriculture (GVA) during 2021-22 (2011-12 constant prices). It is thus evident that the research intensity is much lower in India than in developed countries (2.5%). Further, about half the total research expenditure in developed countries comes from the private sector, whereas in India most of it comes from governments, with private research expenditure being marginal (15% of the total) (Pal and Singh 1997). Although private research expenditure is rising rapidly in India, it is unlikely to bridge the gap in the near future.

Trends in plan allocation reveal the government's priority for agricultural research, which unfortunately seems to be declining. The share of agriculture in the total plan outlays varied from 12 to 15% in early 1970s to quite low level of 3.36% during 2022-23. The share of research expenditure in total outlays for agriculture decreased drastically from 7.2% in early seventies to 2.6% by nineties. However, it improved and was 7.86% in 2022-23 budget allocation. Research investment in Indian agriculture is channeled through ICAR, the apex organization, which allocates resources for agricultural research, education, and frontline extension through a vast network of research institutes and SAUs. The Department of Agricultural Research and Education has been allocated Rs 8,514 Crore in 2022-23 (Table 1 & 2). The allocation to the Indian Council of Agricultural Research (ICAR) accounts for 69% of the Department's allocation in 2022-23. Hence, ICAR provides funds for most of the agricultural research in India.

Table 1: Allocation to Allocation Ministry (in Rs Crore)

Department	**2020-21 Actuals**	**2021-22 Revised**	**2022-23 Budget**
Agriculture, Cooperation and Farmers' Welfare	1,08,273	1,18,294	1,24,000
Agricultural Research and Education	7,554	8,514	8,514
Ministry	**1,15,827**	**1,26,808**	**1,32,514**

Sources: Expenditure Budget, Union Budget 2022-23; PRS.

Table 2: Allocation under the Department of Agricultural Research and Education (Rs. Crore)

Item	**2020-21 Actuals**	**2021-22 Revised**	**2022-23 Budgeted**
ICAR headquarters	4,985	5,561	5,877
Crop sciences	805	840	719

Agricultural education	526	553	455
Central agricultural universities	428	563	599
Animal and Fisheries sciences	400	400	343
Department	**7,554**	**8,514**	**8,514**

Sources: Demand no. 2, Expenditure Budget, Union Budget 2022-23; PRS.

Impact of Agricultural Research in India and Development of Technologies

Agricultural research under the ambit of ICAR has made significant contribution in the agricultural as well as non-agricultural sectors in India. The impact of research is discernible in many areas which may be broadly grouped as research in genetic enhancement, natural resource management (NRM), livestock and farm machinery, and on integrated pest management (IPM).

The genetic enhancement of a majority of agricultural crops received highest priority amongst different disciplines. The research efforts yielded positive dividends. Several improved varieties of almost all crops were developed and widely adopted by farmers. Their contribution to Indian agriculture is enormous. At the aggregate level, two important impact indicators were addressed: Total Factor Productivity (TFP) and poverty alleviation. Studies indicated that the TFP index for crops and livestock reached 290% in early nineties from the base year (1964-65 = 100). Research contributed significantly to the TFP growth. The Internal Rate of Return (IRR) on research investment was 53% during this period. Another indicator of the impact of agricultural research is related to poverty alleviation. The poverty ratio declined from 55% in 1973-74 to 21.9% in 2011-12. A strong and positive association between research outputs and poverty alleviation was noted. The better endowed (i.e., irrigated) regions produced a large number of successful technologies, which significantly contributed to enhancing the food security of those regions as well as that of the fragile environments (e.g., rainfed regions and hilly and mountainous terrains which yielded few acceptable research outputs).

Cereal production has increased substantially during the past five decades. Most of the growth in production was driven by yield growth. Rice research in India has been highly rewarding, with IRR in the range of 30-50%. There has been a reduction in the unit cost of production and real price of rice. Similarly, technical change contributed to an increase in wheat productivity ranging between 34 and 51%. About 98% of the area under wheat in the Indo-Gangetic irrigated regions is now covered by varieties having the dwarf gene, yields from which increased annually by about 43 kg ha^{-1} between1970-71 and 2019-20. With yields stagnating in the Green Revolution belt, new research opportunities were explored. Among others, hybrid rice was found to break the yield barrier. The average yield gain of hybrids over that of popular inbred varieties was 16%. All other crops such as coarse cereals, pulses, oilseeds, cotton, sugarcane and horticultural crops have also been benefitted by research efforts in one way or the other.

Towards Natural Resource Management Research, the Indian research program alsofocussed its efforts on improvingresource-use efficiency, conserving natural resources, particularly soil andwater, and rehabilitating degraded soils. Research efforts were made in the country to overcome land degradation in the form of soil erosion, salinity/alkalinity, and waterlogging, which were posing serious threats to sustainable agricultural development in the country. The impacts of various technologies (e.g., watershed research, reclamation of salt-affected soils, and vertisol technology) are well known. The watershed programs have shown severalbenefits in various target domains, documented in the form of higher incomes,crop diversification, increase in irrigated area and fodder availability, soiland water conservation, and women out-migration. Controlling soil erosion was found to benefit sustainable agricultural production in rainfed areas. Vertisol technology was developed to overcome the problem of about 12 million hectares of rainfed area. It increased agricultural production and prevented the degradation of soil and water resources. Several technological and policy options were developed and widely adopted in the trans-Gangetic region to solve the problem of soil salinity/ alkalinity and waterlogging. Chemical amelioration of alkaline soils has led to numerous benefits which include higherincome, employment generation, stronger inter-sectoral linkages, reduced income disparities, more effective and efficient conservation of rain water, etc.Farming System Models, more suited to medium and large farmers, were also developed to increase the resource-use efficiency of horticultural, plantation and perennial crops.

The Impact of Livestock and Farm Machinery Research could be seen from success story in respect of crossbreeding technology andmilkproduction increase in India. Milk production increased from from 20 Mt in 1960-61 to 198.4 Mt in 2019-20.Crossbreeding technology contributed significantly (11-57%) in the increase in milk production across states. Theaverage milk yield of crossbred lactating cows and graded Murrah buffaloeswas significantly higher than that of lactating non-descript cows and localbuffaloes. National-level evidence shows that output as well as TFP growth ofthe livestock sector picked up in the eighties when output growth touchednearly 4% per year and TFP growth jumped to nearly 1.8%, contributingabout 45% to total output growth.

The Impact of Research on Integrated Pest Management could be substantiated from the success story of IPM in cotton.With the passage of time, theindiscriminate use of chemicals in agriculture caused several undesirableexternalities. Cotton, which coverd only 5% of the total cropped area, received as high as 55% of total pesticides in 1980s. To overcome the problems of pesticide overuse,environmental degradation, and management of innocuous pests and diseases, the Integrated Pest Management (IPM) was developed. As a result of IPM incotton, mustard, and Basmati rice, pesticide use declined, yields increased, andnatural fauna were protected. The positive impacts of the technology were also reflectedby decreased incidence levels, improvement in productivity, and a high cost-benefit-ratio.

In case of the impact of sugarcane research in India, which initiated with the establishment of Sugarcane Breeding Institute, Coimbatore in 1912,a large number of improved cane varieties “Co” varieties in the initial years” for commercial cultivation in different agro-climatic zones have been developed. A quantum jump in sugarcane productivity through development of improved cane varieties and by replacing low-yielding, indigenous cane varieties was achieved in the country. At present, there are around 100 improved “Co” varieties under remained in cultivation in different years in different states.As a result, average sugarcane productivity increased from 35 t ha^{-1} in the 1930s to 76 t ha^{-1} during 2016-2020 period. Studies have revealed that 50 to 70% of the increase in productivity has been due to HYVs. The increase in sugarcane acreage and sugar factories clearly indicates the contribution of varieties and inputs.Research efforts addressed the issue of improving the efficiency of sugar production through early-maturing varieties. The area under early-maturing varieties has gradually increased over the years. Sucrose production too improved (by 0.9 per cent points in initial years to more than 3 per cent points in the last 2 decades).

The need was also felt for decentralized selection and location-specific varieties to maximize sugarcane productivity.The seedling raising and selection program was expanded in the mid-1970s by incorporating the expertise available with the State Agricultural Universities (SAUs). The All India Co-ordinated Research Project on Sugarcane was launched in 1976 to create a network of seedling evaluation and selection centers. A national hybridization garden was established to facilitate national breeding programs in collaboration with state departments and SAUs. The research programs yielded popular varieties such as CoC 671, CoJ 64, Cos 687, CoM 7125, CoS 767, CoS 737, Co Lk 8102, Co Pant 84211, Co Pant 90223, CoLk 94184, Co 0238, which were commercially grown in different agro-climatic environments.These varieties further facilitated the expansion in sugarcane cultivation in nontraditional areas. These efforts have resulted in the identification and release of many new varieties with different maturity levels to provide raw material to meet the rising demand from agro- based industries. When, the crop improvement strategy was critically reviewed to meet future challenges, the emphasis got shifted to developing sugarcane varieties tolerant to drought, waterlogging, soil salinity, diseases and insects, number of varieties have also been developed to address these challenges. Of late, the emphasis is on developing varieties for enhanced ethanol production too.

Developing a cane variety requires rigorous effort of a multidisciplinary team of scientists, and a research lag of 8 to 10 years. In India, mainly two research institutions, the SBI and the Indian Institute of Sugarcane Research (IISR), Lucknow, are involved in diverse areas of sugarcane research. Using their data on research resource allocation, it was estimated that a rupee invested in sugarcane research and development yielded an input-output ratio of 1:21 at 1977-78 prices (IISR 1997). The relationship between investment in sugarcane research and productivity (Table 3) reveals that investment increased from Rs 128.2 lakh in the IV Five-Year Plan to Rs 3514.8 lakh in the VIII Five-Year Plan. It has increased to Rs 6730 lakhs by 2019-20. After the introduction of change in budgetary allocation at the Centre level, the investment to sugarcane research has again reduced significantly, by around 48% in 2021-22 and by 78.5% in 2022-23 budgetary allocations. Despite these developments, a steady and positive growth in sugarcane productivity can be seen since 1950-51, explaining the positive association between research investment and productivity. Besides improved varieties, expenditure on R&D has resulted in many crop production, protection, and farm mechanism techniques for cane growers.

As a result of research and development, sugarcane production has increased from 124 Mt in 1966-75 period to 339 Mt during 2006-15 period (Table 4). This increase is attributed to area expansion and yield enhancement. The increase in production every 10 years was 33-40% in the initial 3 decades (due to higher growth in productivity) and 17-24% in the last 2 decades having comparatively less growth, 2 to 5 % in every 10 year period. During the last decades, the growth in sugarcane productivity has been more in sub-tropical India compared to tropical region (Table 5).

Table 3. Budget of ICAR institutes involved in sugarcane R&D and crop productivity.

Plan period	**IISR, Lucknow (in lakh Rs)**	**SBI,Coimbatore (in lakh RS)**	**AICRP on Sugarcane**	**Average Productivity (t ha^{-1})**
I (1952-56)	4.57	-		39.1
II (1956-61)	41.03	-		42.7
III (1961-66)	36.82	-		44
IV (1969-74)	66.84	61.36		49.4
V (1974-79)	166.71	202.99		51.9
VI (1979-84)	384.9	429.47		54.7
VII (1984-89)	788.81	716.21		59.16
VIII (1992-97)	1825	1689.8		67.3
2017-18	369.0	3701.4	916.0	79.66
2018-19	1890.4	4721.8	139.0	78.25
2019-20	2545.3	4619.0	235.0	80.50
2020-21	2194.7	4335.1	200.0	81.98
2021-22 RE	1867.38	1136.70	212.75	-
2022-23 (BE)	1284.00	1050.00	192.00	-

Sources: IISR and SBI Annual Reports and EFC Memos.

Table 4. Change in area, production and productivity of sugarcane (Five yearly averages: 1966 to 2017-18)

Period	Area under sugarcane (000 ha)	Increase over theprevious 10- year average (%)	Production of sugarcane (milliont)	Increase over The previous 10- year average (%)	Yield (t/ha)	Increase over The previous 10- year average (%)
1966-67to1975-76	2549.5	-	123.86	-	48.41	-
1976-77to1985-86	2984.0	17.04	165.56	33.67	55.42	14.48
1986-87to1995-96	3565.5	19.49	232.62	40.50	64.83	16.99
1996-97to2005-06	4357.0	22.20	289.31	24.37	66.24	2.17
2006-07to2015-16	4870.5	11.79	338.86	17.13	69.52	4.95

Table 5. Sugarcane area, production, productivity levels (QE year 2017-18)and its growth over time in different states of India

States	Area	CGR*	Production	CGR*	Yield	CGR*(%)
	(000ha)	(%)	(000 t)	(%)	(t/ha)	
Sub-TropicalRegion(STR)	2793.3	0.575	184492.9	1.800	66.0	1.218
Uttar Pradesh	2186.4	0.423	146067.5	1.678	66.8	1.249
TropicalRegion(TR)	2038.7	1.633	165286.5	2.169	81.1	0.527
Maharashtra	897.9	4.279	74105.2	5.632	82.7	1.297
AllIndia	4832.0	1.010	349779.4	1.968	72.4	0.948

Note:Area,productionandyieldfiguresareforQEyear2017-18;*CGRreferstocompoundgrowthratesfortheperiod2001-02to 2017-18.

The average annual production of sugar increased sharply from less than 2 Mt in the 1950s to 12.85 Mt in the 1990s, and more than 30 Mt in the last 5 years.The country is now a net exporter of sugar in the world continuously for the last 5 years. With research efforts, the sugar content in sugarcane has also improved over the years.

Though, it is however difficult to quantify the contribution of improved sugarcane varieties on productivity, sucrose content, and sugar recovery, some studies have revealed that 50 to 70% of the gain in productivity was due to improved varieties (Sreenivasan and Bhagyalakshi 1997).Important sugarcane varieties with high sugar content were released in 1928, when Co 313 was released to serve the industry in subtropical India. Cane growers and the industry as a whole commercially exploited several varieties such as Co 527, Co 658, CoL 29, Co 957 and Co 997. Even in climatically unfavorable locations, varieties like CoC 671 with a high recovery rate changed the situation as in Maharashtra. Similarly, CoJ 64 created a revolution in Punjab during the 1980s when the state was rated as number one in terms of high sugar recovery. The potential of improved varieties was fully exploited in states where there was a greater awareness among cane growers to adopt improved varieties. The area under improved cultivar CoJ 64 was the highest in Punjab, followed by Haryana, West Bengal and Uttar Pradesh. After the spread of this variety, sugar recovery in Punjab, which was static at 8.5% increased to 10.6% by 1983-84.Recovery rates of up to 11% have been observed from sugar mills in Gurdaspur and Batala. Achieving higher sugar recovery in sub-tropical conditions was once considered a dream, a few sugar mills in UP (Sitapur and surrounding areas) have achieved more that 13% sugar recovery levels during the last decade. In addition to development of improved sugarcane varieties, number of production and protection technologies have been developed. The mechanization of sugarcane cultivation has also received considerable attention in sugarcane research.

Estimation of Impact of sugarcane research and technologies

As a result of ICAR's continuous support to agricultural research and extension, and sustained efforts of the scientific community, a large number of improved technologies have been developed, contributing significantly in achieving growth in production. Though the contribution of agricultural research has been immense, such information is not well documented, scattered (if available) and based on anecdotal evidence. Consequently, on many occasions, there are insufficient evidences to support when investment in agricultural research is questioned. Ever since Schultz (1953) attempted the first major quantitative evaluation of agricultural research investment, literature on it has grown many fold (Schwartz et al. 1993). Governments in many countries are now emphasizing the need to evaluate agricultural research investment in order to set future research priorities. The Indian Council of Agricultural Research (ICAR), has now accorded high priority to tracking adoption of technologies by farmers, assessing their impacts and learning from such experiences. The ICAR completed a study on national level priority setting (Jha et al. 1995). The World Bank, while funding under the NATP project to SAUs and ICAR institute, insisted on a prioritized research investment.

There are different methods to estimate the impact of agricultural or sugarcane research and technologies. Total factor productivity (TFP) is one measure of quantifying sustainability of any system. Measuring productivity is essential in order to account for economic growth. The efficiency change analysis of total factor productivity (TFP) attempts to measure the increase in total output which is not accounted for by increase in total inputs. In the production function framework, TFP growth indicates technical progress, which represents shifts in the production function over time. In the Indian context, technical progress measures the impact of shifts in production technology on account of irrigation, high-yielding varieties (HYVs), modern agricultural equipment, fertilizers, pesticides, etc. It also captures the effects of improved labor quality, better management practices, and intensive use of resources which lead to increased crop intensity, changes in cropping pattern in favor of high value-added crops, etc. Accordingly, TFP is defined as the total value of all output produced by the system over one cycle divided by the total inputs used by the system over one cycle of the system. It measures the amount of increase in total output, which is not accounted for, by the increase in total inputs. A sustainable system would have a non-negative trend in TFP over the period of concern. The TFP index is a composite measure of productivity, which relates output to all inputs simultaneously and the change in TFP index can be used as one measure of technological change. Different studies have estimated TFP growth in sugarcane in India.

TFP during 1971-2000: Examining (by undertaking the analysis with more disaggregated perspective on changes in output, input and TFP based on micro-farm level data covering the period 1971-72 to 1999-00), it was found (Kumar and Mittal, 2006) thatthe technological gains have not occurred in sugarcane during the 1990s (Table 6), or the gains occurred during early years of Green Revolution have exhausted their potential in some areas. Analysis at the regional level (Table 7 and Table 8) reveals that two regions(North and South) were having positive TFP growth during 1971-86 period. Also only two states AP and Karnataka were having greater than 2% growth in TFP during this period. Bihar was having decrease in TFP growth and all other major cane growing states were having no change. During the period 1986-2000, except for eastern region, in all other regions (West, South, North and all India level), there was negative growth rate as well as negative share of TFP in output growth. In individual cane growing states, except for Bihar, none other states have experienced growth in TFP during the period. UP has shown a decline in TFP growth in sugarcane during period 1986-2000. All other major cane growing states viz Maharashtra, Karnataka, TN, AP, Haryana have not observed any change in TFP growth. Further analysis w.r.t. the distribution of area according to TFP growth in India during (1986-2000) revels that 90.9% of sugarcane area is under stagnant TFP, 5.4% with less than 1% TFP growth and only 3.7% area is having >1% annual TFP growth in India. Hence, it may be concluded that sugarcane has remained at a disadvantage w.r.t. TFP growth in comparison to major competing crops during the period.

Table 6. Annual growth rate in input, output, TFP of sugarcane grown in different regions of India: 1971-2000

Region	Period	Input	Output	TFP	Share of TFP in Output
East	1971-86	0	0	0	Negative
	1986-00	2.22	11.9	9.68	81.34
West	1971-86	4.74	4.46	-0.28	Negative
	1986-00	6.47	5.97	-0.5	Negative
North	1971-86	0.9	1.35	0.45	33.1
	1986-00	3.6	3.11	-0.49	Negative
South	1971-86	0.66	3.48	2.82	81.05
	1986-00	6.27	5.84	-0.43	Negative
India	1971-86	1.24	2.02	0.79	38.92
	1986-00	4.36	4.26	-0.1	Negative

Table 7. Trends in Total Factor Productivity (TFP) growth in sugarcane and competing crops in different states (1971-2000)

Change in TFP growth	Period 1971-86			Period 1986-2000		
	Sugarcane	Rice	Wheat	Sugarcane	Rice	Wheat
Less than 1%	-	-	-	-	WB	-
1-2% increase	-	AP, Assam	Punjab, Rajasthan	-	AP, Bihar, TN	Haryana, Punjab
Greater than 2%	AP and Karnataka	Haryana, Punjab, TN, UP	Haryana, UP	Bihar	-	-
No change	Haryana, Maharashtra, TN, and UP	Bihar, Karnataka, MP, WB	MP, WB	AP, Haryana, Karnataka, Maharashtra, TN	Karnataka, UP,	Bihar, UP
Decrease	Bihar	-	Bihar	U.P.	Haryana, Punjab	

In an another study by Chand,,et.al., 2012, the total factor productivity (TFP) and its share in output growth, and returns to public investments on research in agriculture in India for the period 1975-2005 were estimated. The estimates of TFP have shown considerable variations across different states for sugarcane crop (Table 3). These wide variations in TFP growth further indicate that technological gains have not been experienced in sugarcane in many states

Table 8. Annual growth rate in factor productivity, productivity share in output and real cost of production of crops in India: 1975-2005

(per cent)

Crop	Total factor productivity growth	Productivity share in output growth	Growth in real cost of production	States with negative TFP growth
Sugarcane	-0.41	(-)	-0.36	Bihar, Karnataka, Haryana, Andhra Pradesh, Maharashtra, Tamil Nadu, Uttar Pradesh

TFP growth in States (Maharashtra and Karnataka) : One study carried out in Maharashtra measured total factor productivity of sugarcane crop in Marathwada Region for the period 1999-00 to 2008-09 by using the Tornquist-Theil chained Divisia index approach, and used farm-level data on yield, level of inputs use and their prices collected from the cost of cultivation scheme. Total factor productivity growth was negative at -1.62 % (Table 9). The share of TFP growth in total output growth was 69.06%. TFP is influenced by a number of factors such as research, extension, human capital, intensity of cultivation, balanced use of fertilizers, infrastructural facilities, health of natural resources, climate, etc. Area under irrigation, area under high yielding varieties, number of tractors and road density was found to have a positive and significant impact on total factor productivity of sugarcane crop in Marathwada region.

Table 9: Output, Input and TFP indices growth rates of Sugarcane in Marathwada

Time period	Output Index	Input Index	TFP	TFP Share in output (%)
Period 1999-00 to 2008-09	-2.35	-0.73	-1.62	69.06

Source: Sanap, D.J., 2015

In Karnataka, input and output index have showed negative growth during 1980s. However, high input growth as compared to output growth has resulted in negative TFP growth of 5.27 per cent in 1990-91 to 1999-00. During 2000s growth in output and TFP was 0.97 and 1.51 per cent, respectively (Table 10). Overall, TFP of sugarcane has registered positive growth of only 0.73 per cent indicating that sugarcane production is input based with technology playing some role in it.

Table 10. Annual Growth in Input, Output and TFP Index of Various Crops in Karnataka (%)

Sugarcane	Input	Output	TFP	Share of TFP in Output growth
1980-81 to 1989-90	-7.03	-0.34	6.69	Negative
1990-91 to 1999-00	6.04	0.78	-5.27	Negative
2000-01 to 2007-08	-0.55	0.97	1.51	156.45
1980-81 to 2007-08	-0.27	0.46	0.73	157.93

Sugarcane TFP growth during 1990-91 to 2016-17

Cane production across the country is diverse and input use depends on the physical environment, which includes factors such as soil quality and climate. Sugarcane productivity is cyclical in India. The post-Green Revolution phase is characterized by high input-use and decelerating total factor productivity growth. Sugarcane productivity attained during the 1980s could not be sustained during the1990s and early 21st century. However, adoption of improved sugarcane varieties giving high sugar recovery in tropical as well as sub-tropical India and efficient crop management techniques have accelerated the productivity growth since 2005-06 and is still sustaining at the National level. Total factor productivity (TFP) at the all India level recorded steady growth over the time since 1990 with annual variation ranging from 0.5 to 1.3 per cent (Table 11). Large influence of weather, particularly of rainfall on crop performance is evident from the data with conspicuous dips in TFP growth rates for the years experiencing drought (2002-03, 2003-04 and 2013-14). The productivity measures are divided into two sources of growth, namely, input use efficiency change and technological change (varieties and crop management technologies). The results indicate phenomenal growth in the TFP brought about by technological change rather than input use efficiency. In both the periods, productivity was sustained through technological progress brought about by the introduction of new & improved varieties, and better crop management practice like trench planting and wide-spread use of trash as mulch in sugarcane fields. Data reveals that the variation in TFP trend is almost entirely due to the variation in output, as total input use sustained smoothly over time. The rate of growth in TFP during the period of 1990-2017 was 1.03 percent per annum.It is thus clear, that from a growth accounting perspective, sugarcane production in India in the post-liberalization period achieved positive total factor productivity growth leading to substantial expansion of sugar sector all over the country. There was economic viability of the sector at the farm and mill level. Fluctuations in TFP growth in different states for particular durations may be ascribed to local weather, state government policies and input supply situations. Given this, the factors that can further enhance TFP of sugarcane in India are: science led technological support to minimize the influence of weather; farmer friendly government policies including marketing of sugarcane and sugar; and improved input and credit availability.

Table 11. Total Factor Productivity in sugarcane

Period	EFFCH	TECH	TFP
1991 – 2000	0.98	1.04	1.01
2001-2010	0.92	1.03	0.97
2010-2017	1.04	1.16	1.10
1991-2017	0.98	1.08	1.03

Note: EFFCH- input use efficiency change (seed, fertiliser, labour and etc.); TECH- technical/technological change and (varieties and improved technologies); TFP- Total factor productivity. The farm level data on sugarcane yield and the use of inputs and their prices from 1990-91 to 2016-17 collected under the "Comprehensive scheme for the study of cost of cultivation of principal crops," Directorate of Economics and Statistics (DES), Government of India (GOI), were used in the analysis of TFP. The output prices were collected from the Co-operative Sugar Journal. The missing year data on inputs and their prices were collected using interpolations based on the trends of the available data. The time-series data on sugarcane area, yield, production, irrigated area and coverage under high-yielding varieties (HYV) was collected from the various published reports of the DES (GOI).

For the impact assessment of individual technologies, there are number of methodologies which may be used. However, not all methodologies are universally applicable to all technologies. The choice has to be made keeping in view the objective of technology developed. An holistic approach to estimate the impact is to carry out number of analyses. These are market analysis, technical analysis, financial analysis and social cost benefit analysis including environmental considerations.

Impact assessment of identified IISR developed technologies

IISR Lucknow since its inception is continuing to develop technologies, some of which have been adopted by the farmers and have made a great impact on the income and standard of living of the farmers. The quantification of the benefits of the proven technologies on farmers' fields is desired. Four technologies are well proven and has been transferred to the fields, these technologies have made a great impact, however, its proper assessment was lacking. Impact assessment of four technologies such as the development of sugarcane cutter planter, popularization of intercropping in sugarcane, varieties developed, biological Control of insect-pests and diseases was carried out.

Impact assessment of IISR developed sugarcane cutter planter was carried out and the returns to research due to sugarcane cutter planter were estimated at Rs 35.1 per rupee invested in research. The monetary contribution of the machine due to labour saving (in terms of the extent of cost reduction in sugarcane cultivation) was estimated to range from Rs 150 to 180 Crores per annum. It has an impact on labour displacement. The use of this planting machine results in the saving of 25-35 mandays per ha in the planting of cane, and therefore, in the reduction of operational cost of cane cultivation per ha. By considering labour saving at 25 man days per ha, the aggregate saving of labour days is around 45.20 lakh man days at national level.

The adoption of sugarcane varieties developed by the Institute has significant economic gain to the sugarcane farmers and sugar mills in subtropical region after its entry in the seed chain. The variety ensures higher yield and more recovery in the risk prone areas.The overall impact of the cultivation of CoLk 94184 along with other ICAR developed varieties has reflected in terms of high sugar recovery levels in UP sugar mills.The variety has contributed to raise the sugar recovery by 1.00 percentage point in mills compared to other available general varieties. The annual economic gains due to cultivation of CoLk 94184 were worked out at Rs. 400 to 510 Crore per year during 2016-17 to 2018-19 in sub-tropical region, out of which around 24% accrued to growers by way of higher prices and 76% to sugar mills in terms of higher recovery. The returns per rupee invested in the development and popularization of this variety were worked out at Rs. 24.7. Its impact with respect to labourabsorptionis neutral.

For assessing the impact of bio-control technology, the analysis was carried out wrtthe bio-control of woolly aphid in sugarcane. The pest assumed the status of economic importance from 2001-02 when it infested large areas of sugarcane (Maharashtra and Karnataka) and caused considerable loss to cane tonnage (25%) and sucrose content (26.71%) under severe infestation. The severe infestation was reported during 2003-4 to 2005-06 and about 3.2 lakh ha area was reported to be affected. As per survey based estimates, the sugarcane area got affected on farmers fields in Karnataka was to the extent of around 19.08%(range 6.2% to 31.1%) and in Maharashtra was around 29.34%. The economic yield loss with plant protection chemicals was found to be 22.89% and without plant protection chemicals, it was up to 51.52%. The loss to sugar mills was in terms of loss in sugar recovery. The reduction in sugar recovery in sugar mills was to the extent of 16.07 to 38.71%. The sugar recovery levels reduced to 5.6% to 8.37% in different sugar mills. The assessment of mean loss due to management practice was also carried out. The Biological control only was found to be practiced by 2% farmers and the loss reported was 23.86%. The chemical control only was followed by 35.5% farmers and the mean loss was around 9.84%. Around 18.9% farmers followed the cultural+ biological+ chemical practices and the mean yield loss reported was 9.55%. The practice of chemical+ biological, was followed by 28.9% farmers and it resulted in the mean yield loss of 10.45%. Hence the mean yield loss due to cultural+ biological+ chemical management practice was minimum at 9.55%, however the practice was followed by 18.9% farmers. Its impact is positive on labour absorption and it led to increase in labour use per ha.

For assessing the impact of intercropping in sugarcane, the information on the extent and nature of intercropping in sugarcane was assessed through surveys in Punjab and UP State. There is large scale adoption of intercropping of sugarbeet, wheat and cauliflower to the extent of 1.5, 2.8 and 0.4 acre, respectively per farmer in Punjab. In UP, number of intercrops are grown in autumn, spring as well as on ratoon crop. The ratio of gross returns to cost were found to vary for different crops in Central UP conditions. These were higher for vegetables compared to short duration pulse crops and oilseed crops. These ratios were 2.5 for vegetables, 1.7 for potato and 1.65% for rapeseed (sarson) crop for autumn sugarcane crop, 1.45 for pulses in spring sugarcane crop and around 2.0 for fodders in ratoon crop. The ratio for sole sugarcane varies from 1.4 to 1.5 for sole sugarcane crop grown in different seasons. Consequently, the average added benefits per ha due to intercropping were found to be quite varied as per the crop selected (Rs 3750 for pulses, Rs. 4930 for sarson; potato: Rs.14360 and Rs. 67565 for vegetables. Its impact is positive on labour absorption. The intercropping of vegetables including potato has led to significant increase in labour absorption per ha.

Implications and way forward

Agricultural research systems all over the world are known for their significant contributions to food and nutritional security and poverty alleviation.There is empirical evidence that agricultural growth induced by the Green Revolutiontechnologies have benefited the rural and urban poor through reduction in foodprices. India's success story of the Green Revolution is one of the examples of the impact of research. The Indianexperience has proven that appropriate technologies, facilitating public policies support and the efficient institutions can transform smallholderagriculture. These three major sources ofagricultural growth are highly interactive and dynamic, and these respond to internal and externaldevelopmental changes. However, in the era of privatization and globalization, the ways and means of modern technologies and institutions interactionsas well as that of harmonizing national agricultural policies with international agreements on trade, exchange of resources, property rights, etc, need to be evolved for accelerating the flow of technologies to millions of smallholders.Research impacts are not uniform across different sub-sectors of agricultureowing to differences in the degree of market orientation, efficiency of input andservice delivery systems, dominance of smallholders, etc. Sector-specificinstitutional and policy constraints need to be understood and addressed in orderto enhance the flow of technology to farmers and to realize large-scale impacts.Similarly, greater attention needs to be paid to understand institutional constraintsto the dissemination and adoption of technologies promoting sustainable use ofnatural resources. The same holds true for the sector-specific and capital intensive technologies (in livestock, horticulture and agro-processing sectors).

Agricultural research has made significant contribution in the agricultural and non-agricultural sectors. Yet, more systematic research is needed to empirically measure the research impact on social welfare and conservation of natural resources. An appropriate policy environment, infrastructure, and institutions are the pre-conditions for a greater impact of agricultural research. Appropriate policies are also necessary for the distribution of research benefits to society.

In view of the low research intensity, it is essential to accord high priority to agricultural research in the budgetary allocation of research funds, and increase public expenditure so that research intensity is raised to the commonly prescribed level of 1% of AgGDP. Since India’s research funding for agricultural research is quite low, there is a need to accelerate public as well as private resources. At the same time, it is important to address institutional constraints in the efficient allocation and use of scarce resources.

The TFP growth rate in sugarcane remained falling over the years. Such a fall is natural assuming there have been less innovations either in research or on development side. Declining productivity trends can be directly associated with ecological consequences of intensive cultivation systems, such as a build-up of salinity and water logging, declining soil-nutrient status, increased soil toxicity, and pest build-up. Longer time gains in productivity may be more dependent on sources of technical change, stemming both from research within and outside the agricultural sector, greater input-use efficiency related to increased human capital in agriculture, and possibly, infrastructural development. A constant R&D effort is the most effective way of sustaining productivity growth.

The need of the hour is context-based, client-oriented, problem-focused research in a system perspective to improve its efficiency and efficacy. Till now, qualitative and informed judgments have formed the basis of problem definition. However, more concrete socioeconomic data are required to make a judicious research plan. Sustainability of natural resources should therefore be the major goal of any research.

Social scientists allocate considerable resources towards this work. However, the non-availability of relevant time series data on investment incurred and technologies developed by the organizations is the main limiting factor in assessing the impact of investment in technologies, adoption level, and performance in farmers’ fields. The Indian research system needs to be made operational under a multi-discplinary approach and must have a compulsory on-farm (farmers' farm) testing component.

References:

Chandra, Prasanna (2006). Projects Planning, Analysis, selection, Financing, Implementation and Review, 6th edition, Tata McGraw Hill, New delhi.

IISR (Indian Institute of Sugarcane Research). 2015. Vision 2050, Perspective plan. Lucknow, Uttar Pradesh, Indian: IISR. 57 pp.

Jha, D., Kumar, P., Mruthyunjaya, Pal, Suresh, Selvarajan, S. and Singh, Alka. 1995. Research priorities in Indian agriculture. Policy Paper 3. New Delhi, India: National Centre for Agricultural Economics and Policy Research. 84 pp.

Kanwar, R.S. 1989. Early-maturing high sugar varieties of sugarcane. Paper presented at the National Seminar, 25-26 Mar 1989, Indian Institute of Sugarcane Research, Lucknow. 183 pp.

Mittal, S. and Kumar, P.2005. Total factor productivity and sources of growth of wheat in India. Pages 57-68 in Impact of Agricultural Research: Post-Green Revolution Evidence from India (Joshi, P.K., Pal,S., Birthal, P.S., and Bantilan, M.C.S., eds.) New Delhi, India: National Centre for Agricultural Economics and Policy Research.

Pal, Suresh and Singh, Alka (1997) Agricultural research and extension in India: Institutional structure and investments. NCAP Policy Paper No. 7. New Delhi, India, National Centre for Agricultural Economics and Policy Research. 63p.

SBI (Sugarcane Breeding Institute). 2015. Vision 2050, Perspective Plan. Coimbatore, Tamil Nadu, Indian: SBI. 54 pp.

Schultz, T.W. 1953. The economic organization of agriculture. New York, USA: McGraw Hill Book Company. 374 pp.

Sreenivasan, T.V. and Bhagyalakshi, K.V. 1997. Genetic improvement of sugarcane. Indian Journal of Sugarcane Technology 12(2): 1-10.

Chapter No. 56: Recent advances in Transfer of Technology (ToT)

Ajay Kumar Sah
Principal Scientist
ICAR-Indian Institute of Sugarcane Research, Lucknow
Ajay.Sah@icar.gov.in

Extension and Advisory services in India

Since independence, extension services were being provided mainly by the public sector. Public sector is a major extension service provider through a two-tier system. At the central level, the Indian Council of Agriculture Research (ICAR) being the nodal institute for agriculture research and extension; while at the state level, the State Agricultural Universities (SAU) via the Krishi Vigyan Kendra (KVKS) and Agriculture Technology Management Agency (ATMA) at the district level, facilitate agriculture extension. However, the public extension is highly skewed towards crop husbandry ignoring allied sectors. Besides the existing public extension service system, there are several private players, civil-society organizations including farmer-based organizations and NGOs that play a major role in providing extension services.

Major Institutions Providing Extension and Advisory Services

1. Public Institutions

a) Department of Agriculture and Cooperation

The Department of Agriculture and Cooperation comprises several technical directorates (also called divisions) and one of them is agricultural extension. The Directorate of Extension, headed by a Joint Secretary cum Extension Commissioner, is the nodal extension organ at the national level. The Joint Secretariat shall be assisted by three Joint Members. The directorate provides policy guidelines and operational backstopping to the state level extension organizations. The directorate's technical units are extension management, extension training, farm information, and National Gender Resource Center in Agriculture (NGRCA).

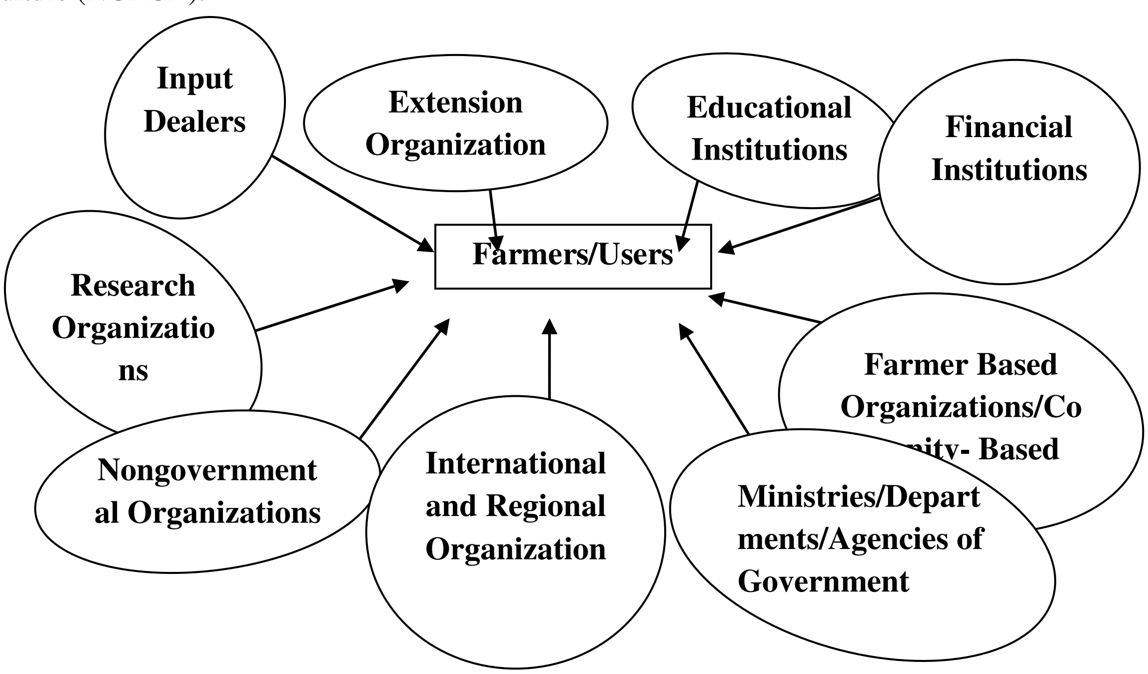


Fig. Linkage among various stakeholders

b) Indian Council of Agricultural Research

The Indian Council of Agricultural Research (ICAR) is an autonomous body under the Department of Agricultural Research and Education Ministry of Agriculture. The council serves as the national apex organization for coordinating, guiding and managing agricultural research and education including horticulture, fisheries and animal sciences throughout the country. It comprises 99 ICAR institutes (such as the Indian Agricultural Research Institute (IARI) and 53 agricultural universities spread across India. ICAR plays a central role in promoting excellence in higher education in agriculture. It's Agricultural Extension Division covers extension activities.

c) Agricultural Extension Division

The Agricultural Extension Division which is a part of the ICAR is headed by a Deputy Director- General (Agricultural Extension), who is supported by two Assistant Director-Generals. Activities of this Division are technology assessment and demonstrations, training of farmers, training of extension staff, and creation of awareness of improved technologies among farmers.

The Division performs extension activities through the following institutional mechanism:

- At least 721 Krishi Vigyan Kendras (KVK), is now available in India but have played a somewhat inactive role in implementing the ATMA model of extension
- About 44 Agricultural Technology Information Centers (ATIC) have been established as parts of ICAR institutes and state agricultural universities, which are well connected with the KVKS.
- National Research Center for Women in Agriculture (NRCWA), located in Bhubaneswar, Odisha.

d) State Agricultural Universities

There are about 43 state agricultural universities in India and most of them are involved in some type of extension work, that is, in addition to their academic programs. Apart from conventional universities, there are five institutes deemed to be universities (examples: Indian Agricultural Research Institute (New Delhi), Indian Veterinary Research Institute (Izatnagar), and Allahabad Agricultural Institute (Allahabad). In addition, there are four central universities with faculties of agriculture (e.g.. Banaras Hindu University and Aligarh Muslim University).

e) National Institute of Agricultural Extension Management (MANAGE)

MANAGE, which is located near Hyderabad city, is an autonomous organization established by the government in 1987. The mandate of the organization is to assist the central government and the state governments to help improve their pluralistic extension systems by bringing positive changes in policies, programs, and personnel skills. The main activities undertaken by the institute are extension capacity building, research, consultancies, education in management, and documentation.

This institute offers dozens of training courses advertised well in advance. It also offers two post-graduate diploma programs, one in general management and the other in agricultural extension management. In addition, a one-year diploma program in agricultural extension services for input dealers was started in 2004 for imparting formal agricultural education to the dealers. MANAGE is also responsible for implementing the Agri-Clinics and AgriBusiness Centers Scheme (ACABC), which aims at providing value-added extension services to the doorsteps of farmers by agricultural professionals. The scheme involves two-month residential training to eligible agricultural professionals, one-year post-training in handholding support, start-up loans by banks, and subsidy by the National Bank for Agriculture and Rural Development (NABARD).

f) State Agricultural Management and Extension Training Institutes (SAMETT)

There are SAMETI's in most Indian states and they are autonomous state level institutes with a mandate of conducting training courses on new agricultural technologies, extension management, gender issues, extension reform and new information technologies: SAMETIS provide extension management training for extension agents and functionaries for all the line departments, including how to make extension more bottom-up, farmer-led and market-driven. In addition to training, they also facilitate the infrastructure for holding workshops and journals.

g) Commodity Boards

Given the vast area and diverse agro-climatic regions, many different crops, commodities, animals and fish species are produced across India. There are a total of 20 agri-export zones within India. There are five statutory commodity boards under the Department of Commerce. These boards are responsible for the production, development and export of tea, coffee, rubber, spices and tobacco. In order to promote other commodities, several commodity development boards were established at national and state levels. In most cases, the organizational structure, research, extension, and marketing systems are in the process of changing. Thirteen centrally governed commodity boards are listed below.

- Central Silk Board (CSB)
- Coconut Development Board (CDB)
- Coffee Board (CB)
- Coir Board
- Rubber Board (RB)
- Spices Board (SB)
- Tea Board (TB)
- Tobacco Board (TB)
- National Dairy Development Board (NDDB) National Horticulture Board (NHB)
- Cashew Export Promotion Council (CEPC)
- National Jute Board (NJB)
- National Federation of Cooperative Sugar Factors (NFCS)

2. Private sector

Several efforts have been applied in India towards privatization of agricultural extension services mainly through experimental and pilot projects, as well as schemes during the past decade yet the bulk of extension services remain by and large public and free of charge for farmers. There are a large number of agricultural companies (about 2,80,000) but none can be regarded as a private agricultural consultancy company in their own right. Whatever provision of private extension services is done, it is done by farm inputs suppliers, consulting firms, and contracting companies. The forms of service obtained by farmers through payment include contract farming (mostly by commercial agricultural companies), marketing of high-value crops (usually by commercial export companies), value addition (normally by agro-processing companies) troubleshooting on farms (mostly by consultants), and charge-based services centers for farmers (usually by private agricultural companies). Names of a few private agricultural companies, which provide one or more services like contract farming, agro-processing, inputs supply, consulting, multi-services, and export, are as follows.

- Indo-American Hybrid Seeds www.indamseeds.com/
- ASPEE India www.espee.com/
- Agro Tech www.agrotech-india.com/
- Good Earth www.goodearth.in/
- Mahindra Shubhlabh Services, Ltd. www.mahindra.com
- ITC Limited www.itcportal.com/-India
- CASCO www.caicoin/
- Rasi Seeds www.rasiseeds.com
- DuPont India

- National Agro Industries www.nationalagroinds.com/
- Poabs Organic www.poabsorganic.com
- Phalada Agro Research Foundation www.phaladaagro.com
- Advanta India, Ltd. www.advantaindia.com/
- Monsanto India Ltd. www.monsantoindia.com
- Syngenta India Ltd. www.syngenta.com/country/in/en/

3. Non-Government Organizations (NGOs)

In India, about 3 million registered NGOs are there, out of which many are actively involved in the development of rural areas and naturally oriented themselves towards land-based livelihoods. Hence, they accommodate an essential component of extension in their intervention (Gulati et al., 2018). To name a few of the NGOs which are PRADAN, BAIF, Syngenta Foundation, India, etc are some of the leading NGOs working in agriculture.

4. Farmer-based associations, cooperatives and societies

Farmers' associations, cooperatives and societies in India have been quite active for years in ventures like self-help for development, specific commodity production, marketing, collective bargaining and many other purposes. Some of these associations have been instrumental in the fight against poverty and the empowerment of rural women. A few examples of farmers' associations are given below.

- Federation of Small Farmers' Associations of Khaddar Area, North India and Sunstar Overseas, Ltd,
- Consortium of Indian Farmers Associations.
- Turmeric Farmers' Association of India.
- Farmers' Association Pomegranate.
- Association of Farmer Companies http://www.aofcindia.org/
- Organic Farming Association of India (OFAI) http://ofai.org/
- Punjab Young Farmers Association (India).
- Indian Farmers' Association.

India has about 5,80,000 cooperatives including 3,75,000 agricultural cooperatives with 280 million-member farmers. Types of agricultural cooperatives are primary agricultural credit/service societies, agricultural non-credit societies, agricultural cooperative marketing societies, and cooperative farming societies. They all deal in credit, inputs, marketing, agro-processing and farm extension services. There are fertilizer cooperatives, sugar cooperatives, and dairy cooperatives The Indian Farmers Fertilizer Cooperative Limited (IFFCO) www.iffco.coop/ is one of the biggest manufacturers of fertilizers in the world. The National Agricultural Cooperative Marketing Federation of India (NAFED) www.nafed-india.com is the focal organization of marketing cooperatives for agricultural produce in the country. NAFED, founded in 1958, is under the Ministry of Agriculture and is now one of the largest procurements and marketing agencies for agricultural products in India. Issues facing primary agricultural cooperative societies include low member participation, shortage of capital for inputs, government control and interference, outdated management practices, and political influence.

5. Training options for extension professionals

Pre-service education in extension may be obtained at any of the 50+ SAUS spread across India Also, facilities for in-service training of extension staff are available at many institutions such as MANAGE, Agriculture Extension Division of ICAR, the Department of Agriculture and Cooperation, and the Department of Agricultural Research and Education, both under the Ministry of Agriculture. Certain well-established NGOs, public agricultural universities and research institutes like the Indian Agricultural Research Institute (IARI) http://www.iari.res.in/, and some private agricultural companies can also organize in-service training courses for the extension staff under mutually agreed arrangements.

6. Information and communication technology (CT) for agriculture and extension

In India, out of 179 million rural households, 47.5% has access to cell phones, while 35.4%, 19.2% and 0.8% have ownership of television, radio, and computer with internet access, respectively. The data shows that the majority of the districts in all rural districts in central India lack ICT services and fall into the category of ICT services with very low access. In 447 districts in India, where cell phones are a primary source of ICT service, covers more than 80% of farmers (primary occupation is cultivator). Coverage of ICT services such as television and radio were in second and third rank in the districts (Gangopadhyay et al., 2019).

India has made impressive progress in the application of ICT to its rural and agricultural development programs. Dozens of agricultural commodities focused and technical discipline- based public and private IT networks exist, with many of them reaching the village level. A few examples are as follows:

a. **Bhoomi:** Under this program, 20 million land records of 6.7 million land owners in 176 taluks of Karnataka State have been computerized. Other states have followed the suit.

b. **e-Choupal:** http://www.echoupal.com The program links farmers directly to agricultural and aquaculture products companies dealing in soya, coffee, prawns, etc. for the purchase of these commodities at competitive rates thus eliminating the middlemen. The program's principle is to inform, empower, and compete. Presently, there are more than 6,500 e- Choupals across 10 states in India.

c. **Ikisan: Ikisan** has been developed by the Nagarjuna Group, based in South India, with an interest in agriculture, fertilizers and insecticides, among other areas. It is a comprehensive agriculture portal addressing the information, knowledge, and business needs of farmers, traders and farm input agencies (http://www.ikisan.com).

d. **Agriwatch:** is said to be the largest agribusiness portal in India. It enables access to agribusiness information covering more than 15 sub-sectors of the agricultural and food industry. The website carries daily, weekly and fortnightly trade research reports.

e. **aAqua:** It is one of the initiatives of the Indian Institute of Technology, Bombay presenting an online multilingual, multimedia agriculture portal for disseminating information from and to the grassroots agricultural communities. The program integrates multiple databases.

f. **DEAL:** DEAL is an initiative of the Indian Institute of Technology, Kanpur. It is an ICT enhanced network based on an established telecenter system for rural institutions such as village schools and agricultural extension centers at village level. It constitutes a digital knowledge base for the farmers and agricultural practitioners.

g. **e-Sagu:** http://www.esagu.in/It is an IT-based personalized agricultural extension system for disseminating expert advice on agriculture to the farmerson time.

h. **Akshaya:** http://www.akshaya.kerala.govt.in/ The Akshaya Project is a market-driven agricultural initiative through IT-enabled Agricultural Business Centers in Kerala State. It provides web-based solutions to all categories of farmers.

i. **The National Informatics Center (NIC)** www.nic.in/ is a part of the Indian Ministry of Communications and Information Technology. It has launched several ICT initiatives for the benefit of rural people some of which are as follows:

j. **Computerized Rural Information Systems Project (CRISP)**

k. **Land Records Computerization Project (LRCP)**

l. **e-NRICH** (for addressing the needs of rural people through networking, and facilitating communication between the government and citizens)

m. **AGMARKETNET** (for providing information on marketing prices of agricultural produce

n. **ASHA:** http://www.ashanet.org/(for providing agribusiness information for farmers and for linking buyers and sellers directly) produce

0. **Rural Bazar:** http://www.rural nic.in/sites/rural-bazar.asp (for showcasing of the agricultural products for rural producers as well as facilitating offline and payments) online

p. **National Panchayat Portal** http://panchayat.nic.in: (Ensures vertical and horizontal integration in rural Panchayat raj facilities, facilitates communication, messaging, transfer of funds, monitoring of programs, etc.)

q. **e-Gram Vishwa Gram:** (Keep records on village families and provide income, caste, home, etc. certificates to the rural population.)

Many NGOs, research organizations, and national ministries have improved access to technologies and knowledge for the rural advisory services by utilising rural telecentres and online forums. Throughout the developing world, ICTs are being integrated into rural advisory services in a variety of forms, including rural radio, television, internet and mobile services. The advice and information provided via ICTs is becoming more varied, ranging from information about specific technologies and practices to information that enables climate change mitigation and adaptation; disaster management; early warning of drought, floods, and diseases; price information; political empowerment; natural resource management; agricultural information; production efficiency; and market access. ICTs also open new channels for farmers to document and share experiences with each other and with experts.

References:

1. Gulati, A., Sharma, P., Samantara, A. and Terway, P. (2018). Agriculture extension system in India: Review of current status, trends and the way forward. Indian Council for Research on International Economic Relations. Retrieved from: http://hdl.handle.net/11540/8400. Print ISBN 978-81- 937769-0-2
2. Gangopadhyay, P. K., Khatri-Chhetri, A., Shirsath, P. B. and Aggarwal, P. K. (2019). Spatial targeting of ICT-based weather and agro-advisory services for climate risk management in agriculture. Climatic change, 154(1), 241-256.

Chapter No. 57: Economic Analysis of Sugarcane, Sugar and Bioethanol Production in India

L.S. GANGWAR
Principal Scientist
ICAR-Indian Institute of Sugarcane Research, Lucknow 226 002, Uttar Pradesh

Introduction

Sugarcane produced by the farmers is used as raw material for sweeteners production (sugar, energy and jaggery), fresh juice, seed and chewing.Indian sugar industry provides livelihoods to 7.0-7.5 million sugarcane growers and 1.0-1.25 million skilled workers employed in sugar mills, jaggery and allied industries. The Indian sugar sector faced challenges due to extreme climatic conditions especially in tropical states, water scarcity, input cost, low organic carbon content and higher labour wages. In spite of these production constraints, sugarcane productivity has increase from 65.2 to 81.5 tonne/ha and sugar recovery had also improved from 9.54 % to 11.73% during year 2014-15 to 2019-20 in U.P.Approximately28 integrated sugar-energy complexes having in house distillery units have diverted B-heavy molasses for bio-ethanol production. There are wide fluctuations in sugarcane productivity and stagnation in sugar recovery due to unfavourable climatic conditions such as low rainfall, drought, and flood and water scarcity in Maharashtra during last five years. The adoption of high sugar varieties, irrigation water saving techniques, sugarcane planting, inter-culturing mechanization, ratoon management, area increase in autumn, inter cropping with short durational crops and mechanized trench planting. The area under EMV sugarcane varieties has increase from 18.5percent to 87.3 percent during last five years in U.P. The key production constraints were sugarcane mono cropping, low soil organic carbon, poor availability of quality seed cane, indiscriminate application of plant protection and chemical fertilizers and heavy infestation of white grab in some part of Maharashtra. The majority of cane farmers do not apply FYM/bio-fertilizers and green manuring. The farmers should adopt integrated nutrient and pest management, trench, wider row spacing, cane seed and water saving techniques to enhance productivity per unit resources utilizedto minimize cost of production, enhance income and improve profitability. The use of mechanical power in sugarcane cultivation has upward trends in Maharashtra and U.P as the application of machine for sugarcane planting, inter-culturing and ratoon management operations have improved over the years to address labour problems and wage issues. The cane farmers realize higher productivity and higher netincome with adoption of Co 0238, CoLk 94184 in U.P., Co 86032 and Co M 265 in Maharashtra. They also adopted sugarcane cutter planter/trencher for crop planting, multi-purpose power tillers and Rotavator for intercultural operations.The study reveals that the inclusion of intercrops in sugarcane based farming systems enhance profitability, enrich soil health, supplement income and employment; food and nutritional security.

The states announce State Advised Prices (SAP), above the Fair Remunerative Price (FRP), which lead to huge cane price arrears on sugar mills. It was basic reason for unrest, anguish and hardship to the farmers. There is an urgent need to enable the de-reservation of sugarcane area, minimum distance criterion and adopt hybrid approach for sugarcane prices in combination with Revenue Sharing Formula (RSF) and FRP. The R & D should be strengthened to develop product quality standards for export promotion of traditional sweetener products in niche markets. The self-help groups, FPOs/FPCs, NGOs should be involved in packaging and marketing of value added jaggery products in metro city hyper Malls. The results revealed that the sugarcane utilized by sugar mills has increased from 50.8 to 74.4 per cent during 1990-2020. The quality norms for jaggery should be standardized for its export promotion in high end cities Malls and niche markets, where India has logistic as well as comparative cost advantages. The products marketing in hyper or super Malls, direct online selling through mobile apps or internet based websites such as Amazon, Flip carts etc., must be utilized to enhance producer's share in consumer's rupee so that farming community may reap economic benefits.

Data and Methodology

The simple tabular analysis and appropriate statistical methods were applied to study investment-return and relative profitability of sugarcane production with leading completing crops. The impact of improved cane production technologies was assessed at farmers' level. The impact of sugarcane production and processing technologies was assessed in terms of percentage change in parameters The adoption of improved cane varieties, efficient water and nutrient management techniques minimizes cost of production and processing have shift supply function and economic benefit to producers and consumers.The selected sugar mills were classified as standalone or integrated complex owned by cooperative or private/corporate mills. Besides the sugar mills, primary data were also collected from 80 sugar mills and 480 sugarcane farmers to study adoption level of sugarcane production technology and examine the comparative economics of sugarcane in ISPT and traditional method. Simple tabular analysis and appropriate statistical methods were applied to estimate cost, return and net profit.

Results and Discussion: Profitability and financial viability of sugar sector in India:
Economics of sugar production in India:

The sugar cost processing includes operational expenses such as sugarcane price, harvesting and transportation cost as well as overheadexpenses incurred by the sugar mills and various conversion costs parameters, depreciation, interest paid and other expenses incurred in sugar and other primary co-products processingin achieving food and energy securitygoals. The comparative cost of sugar processing in two major sugar producing states have workout and presented in Table1. This reveals that the cost of sugar production in comparing states varies from ₹3403 to ₹3512/ quintal in standalone sugar mills having crushing capacity less than 4000TCD. The integrated sugar-energy production units of more than 7000 TCD have sugar production cost ₹3270 to ₹3230 per quintal in Uttar Pradesh and Maharashtra respectively.Due to surplus sugar production and its excess supply in domestic as well global market lead to decline prevailing ex-mill sugar price ₹3200 -3750 per quintal during study period in an integrated sugar-energy complex owned by cooperative or private sector. The cost of sugarcane has a lion's share of 78 to 80% of total cost of sugar production in standalone sugar mills. The average cane crushing capacity of the surveyed sugar mills varies from 1750 to 11000 TCD in Uttar Pradesh and Maharashtra. Some of the sugar mills having in house distillery had also diverted its B-heavy molasses for bio-ethanol production. Hence, their sugar recovery was low. The efficiently managed sugar mills belongs to different groups in U.P. achieved sugar recoveries 11.70 to 12.50 %. The integrated sugar- energy complexes used upgraded technologies to make them economically viable, self-reliance and competitive with efficient private sector sugar mills in U.P. and Maharashtra.

The sugar recovery and production varies in sugar mills owned by cooperative or private sector. There are wide fluctuations in sugarcane supply to sugar mills during past four years which affects economic feasibility, profitability, cane price payment and outstanding cane price arrears on sugar mills. The integrated sugar-energy complex with more than 7000 TCD capacity in Maharashtra have comparative cost advantage as compare to similar sugar complex in Uttar Pradesh as indicated in Table 1. Indian sugar sector have facing problems of cyclic sugar production due to climate change and water scarcity. The sugar production scenarioshould be diversified as per product market demand through creation of new innovative products and pathways of revenue generation for maintaining economic viability in sustainable manner.

Table1.Economic analysis of sugar production in major producing states during 2016-20

(In ₹/quintal sugar)

Sl.	Parameters/ Cost Components	Stand alone < 4000 TCD		Sugar + Co-gen 4000-7000 TCD		Sugar+ Distillery+ Co-gen >7000TCD	
		U.P	MH	U.P	MH	U.P	MH
1	Sugarcane price	2764	2105	2676	1837	2618	1993

2	Harvesting &Transport	0	644	0	597	0	641
	Total Sugarcane Cost	2764	2748	2676	2433	2618	2634
3	Power/ Electricity price	36	18	38	24	18	28
4	Chemicals expenses	14	32	19	33	26	21
5	Salary and wages	279	297	267	363	256	211
6	Packaging	42	35	43	36	37	42
7	Repair and Maintenance	31	83	28	82	42	47
8	Overheads	61	125	66	89	68	42
	Cash Conversion Cost	463	591	461	627	447	393
9	Depreciation	33	42	34	64	57	36
11	Interest on						
	Working capital	136	127	143	145	109	111
	Term loans	6	4	8	43	27	13
	Deposits	2	0	3	23	13	42
12	Total interest	144	131	153	211	148	166
13	Total Conversion cost	639	764	648	903	652	595
	Cost of Sugar production	**3403**	**3512**	**3324**	**3336**	**3270**	**3230**

The probable options for diversification of sugarcane processing would be power co-generation, bio-ethanol production from B-heavy or directly from cane juice, automation, establishment of agro-processing hubs by utilizing sugar mills infrastructural round the year, development of cane varieties for higher biomass and sugar. To reduce sugar supply in domestic market and opening sugar stock, government have decided sugar export target ofmore than 10.0 mt for year 2020-21. Besides of various policy majors and sops offered to the sugar mills for reducing the glut in domestic sugar market and support mills to pay cane price to farmers and clear cane arrears, the government had announced variable price policy for bio-ethanol produced from final molasses, B-heavy molasses or directly from cane juice for optimizing sugar production and diversion of sugarcane forbio-ethanol production. The sugar mills would gain better returns from bioethanol as compare to sugar. The government also supported entrepreneurship development programme under various schemes for other value added product processing sector for judicious use of bagasse, molasses, press mud etc. for gainful employment generation and enhancing income of farmers and Indian sugar sector. It essential to design suitable policies for financial viability and sustainability of sugarcane based farming system.

Economics of ethanol production from sugarcane juice, B-heavy molasses and final molasses:

To maintain sugar prices and demand –supply equilibrium, enhance bio-ethanol production, government of India announced differential price policy for bio-ethanol produced through various routes like Final (C-molasses), B-heavy molasses or sugarcane juice. The surplus sugar production during past few seasons leads to low sugar price in domestic market. The sugar mills have to face economic hardship and some of them are running in losses due to high cost of sugar production and low revenue realization. The vapour thin profit margins led to accumulation huge cane price arrears on sugar mills. To minimize sugar production, Govt. of India has taken policy decisions and allowed diversion B-heavy molasses and sugarcane juice for ethanol productionduring season 2018-19.The government of India maintained the differential prices for bioethanol production from various raw materials and declared premium ₹54.27and ₹59.48 per litre as bio-ethanol price produced from B-heavy molasses and directly from sugarcane juice respectively as compared to bioethanol price ₹43.75 per litre produced from Final C molasses through conventional route. Besides these incentives, applicable GST and transportation charges has to be paid by the OMCs. The OMCs had given directives to give priority for bioethanol procurement produced directly from sugarcane juice, B-heavy molasses over final C molasses. Table 2 reveals that the bioethanol production through B-heavy molasses gives net income of ₹15.29 per litre to the distillery as compare ₹12.68 per litre by conventional final molasses route. The minimum sugar prices ₹31000 per tonne, declared by government were used to work out the economics of bioethanol production in integrated sugar-energy complexes. The sugarcane fair remunerative price (FRP) ₹2750 per tonne on base recovery 10% declared by CACP for sugar season 2019-20 were applied to estimate economic returns and net profit from bioethanol production by using sugarcane juice. The bioethanol production directly from sugarcane gives net income of ₹5.69 per litre to the distillery as compared ₹15.29 per litre by B-heavy molasses. Therefore, the study concludes that the diversion of B-heavy molasses could be a potential option for enhancing sugar mills economic feasibility and to mitigate 10 % EBP targets.

The huge initial investment on distillery modernization and higher storage capacity are the key constraints in adoption of flexi sugar- bio-ethanol production plan by mill owners. The sugar mills have apprehension and they are in dilemma that the flexi production policy would sustain in long run during short supply of sugarcane. The diversion of BH molasses for ethanol production would also reduce steam consumption in sugar led to bagasse saving, sugar color and quality improvement; enhance power supply to national grid from cogeneration.

Table2: Economics of Bio-ethanol production using sugarcane juice, B-Heavy and C molasses

Particulars/ Economic parameters	Final C-molasses	B-H molasses	Sugarcane juice
Mill crushing capacity, (TCD)	6500	6500	6500
Sugar recovery (%)	12.1	10.65	0
Molasses prod. (in % cane crushed)	4.5	6.5	0
Sugar production(t/day)	786.5	692.25	0
Molasses production (t/day)	292.5	422.5	0
Sugar price (₹/tonne)	31000	31000	31000
Sugarcane/molasses price (₹/tonne)	4500	8500	2750
Ethanol price (₹/litre)	43.75	54.27	59.48
Sugar production losses (tonne)	0	94.25	0
Sugar revenue losses (In ₹lakh)	0	29.22	0
Cost of cane/ C molasses (In ₹lakh)	13.16	13.16	178.75
B-Heavymolasses price(In ₹lakh)	0	35.91	0
Bio-ethanol recovery(litre/tonne)	230	365	70
Bio-ethanol production(litre/day)	67275	154213	455000
Revenue from ethanol((₹lakh/day)	29.43	83.69	270.63
Raw material cost (₹ /litre)	19.57	27.48	39.29
Conversion cost (₹/litre)	11.50	11.50	14.5
Cost of ethanol production (₹/litre)	31.07	38.98	53.79
Net profit to distillery unit (₹/litre)	12.68	15.29	5.69

Policy support for strengthening Indian Sugar Sector

The sugar production in two states Uttar Pradesh and Maharashtra has achieved new record of sugar production during the study period.It helps in achieving all time record sugar production of 35.5 mt and diversion of 3.5 mt. sugar for bioethanol production during past sugar production seasons. There was remarkable improvement in sugar recovery in subtropical states especially U.P.It is substantially higher than the sugar recovery achieved in past 4-5 sugar production season. Hence, ex-mill sugar prices innorthern states continue ranges from ₹ 3250-3700 per quintal during 2015-2021. It led to glut like situation in domestic and international market. The sugar recovery was slightly less as compare to last year as 28 integrated sugar-energy complexes have diverted BH molasses for bioethanol production.

- Need of integrated sugar-energy complexes for new value added product diversification such as bio-manure, bio-CNG from press mud, filter cake, fly ash;bio-degradable plastics from bagasse, flavored sugar and specialty sugar as per consumers demand to enhance revenue.
- Keeping in view cyclic nature of sugarcane production and inspired by flexi hybrid model of sugar-ethanol production, Govt. of India permitted to produce bioethanol from BH molasses and directly from sugarcane juice. The government also announced high premium price for bioethanol produced from BH molasses and sugarcane as an incentive to sugar mills for improving supply of bioethanol to achieve the targets of National Policy on Biofuels 2018.
- The Govt. of India has encouraged sugar export through reduction in export tax. The sugar export yet to improve as prices in global market is low. To improve economic viability of Indian sugar sector, Govt. of India had decrease GST on ethanol from 18 to 5 % and declared premium price to encourage product diversification for sustainable growth of Indian sugar sector.
- The Uttar Pradesh Power Corporation Limited (UPPCL) and UP Electricity Regulatory Commission (UPERC) has proposed to reduce power tariffs by 30-35% in next few years for bagasse-based co-gen power supply to national power grid. The electricity tariffs of ₹6.19 to ₹ 6.75 per unit for the purchase of cogenerated power had reduced by ₹2.00 - ₹2.25 per unit, beleaguered sugar mills to face economic revenue loss of nearly ₹500 crores as annual power supply bill by sugar mills to UPPCL was approximately ₹1,500 crores. The new tariffs have been determined for captive and non-conventional energy generation unit (CRE) regulation, applicable on power co-generation from bagasse, biomass, solar plants etc.
- The average cost of sugar production in Maharashtra sugar mills varies from ₹3451 to ₹3582/ quintal with ex-mill sugar price ₹33-37 per Kg in standalone, integrated sugar-energy complex owned by cooperative or private sector. The cost of sugarcane and conversion cost accounts for 78 and 22 % during year 2019-20

The government of India announced differential prices for improving bioethanol production and its supply to Oil Marketing Companies (OMCs) to meet the EBP blending targets of 10 % by 2022. To give a push for ethanol production from different raw materials and declared the premium price ₹57.61and ₹62.65 per litre to bio-ethanol produced from B-heavy molasses and sugarcane juice respectively as compared to bioethanol price ₹45.69 per litre produced from Final C molasses through conventional route. Besides it, applicable GST and transportation charges has to be paid by the OMCs. The Govt have given directives to OMCs forgiving priority in bioethanol procurement produced from sugarcane juice, B-heavy molasses over final C molasses. Table 4 reveals that the bioethanol production through B-heavy molasses gives net income of ₹19.37 per litre to the distillery as compared ₹12.02 per litre by conventional final molasses route. The market sugar prices ₹32000 per ton, declared by government of India as MSP for sugar was applied to estimate economics of bioethanol production in integrated sugar-energy complexes having 6500 TCD capacity. It is essential to develop high yielding feedstock varieties like energy sugarcane through cutting biotechnological tools. This high-volume biomass generation and agri-bio-residue, i.e., bagasse, press mud, feedstock would supplement 2G bioethanol and Compressed Biogas production. The energy cane has potential to produce 17-18,000 litre bioethanol per ha with proper utilization of 1G and 2G ethanol production technologies. It is presumed that with appropriate mix of plant based 1G and agri-residue based 2G technologies has potential to achieve 20 per cent bioethanol EBP with petrol in future.The sugar recovery was less as compare to last year because of heavy red rot infestation in leading sugarcane variety Co 0238 all over the Uttar Pradesh and 28 integrated sugar-energy complexes having in house distilleries have diverted BH molasses for bioethanol production.

Table 4reveals that the farmers realized higher sugarcane productivity and reap better economic returns in ISPT as compare to traditional method with adoption of EMV's such as Co 0238, Co Lk 94184, Co 0118 etc and inter cropping with pulses, oilseeds and vegetables in autumn planted cane, trench planting, wider row spacing, single / two bud setts in place of three bud setts, irrigation in trench/furrow for higher cane productivity per drop of water (Fig1). Farmers used sugarcane cutter planter/trencher for crop sowing, small tractor or multi-purpose power tillers for intercultural operations to minimize labour cost. Sugarcane harvesting by labour, loading and transportcharges were also high in U.P. and Uttarakhand

Table 4 Comparative economics of sugarcane production in U.P.

(In `₹/ ha)

Particulars/ cost components	Traditional	ISPT method
Cost A_1	125142	97659
Cost B_1	153374	127274
Cost C_1	159237	134826
Total Cost (Cost C_2)	**161439**	**139564**
Yield (tonnes/ha)	76	89
Price (Rs./tonne)	3220	3250
Cost of production (Rs./tonne)	2214	1568
Gross return	244720	289250
Net return on Cost A_1	119578	191591
Net return on Cost C	83281	149686
Benefit-Cost (BC)Ratio	**1.516**	**2.072**

It was observed that the farmers cultivate pulses (chick pea, lentil, cow pea, pea etc.), oilseeds (Toria, linseed) and vegetables (potato, cabbage, cauliflower, onion, garlic) as inter crops in autumn planted cane under ISPT to use row space (4-6 feet). They earned net income varies from ₹32521 to ₹44379/ ha based on inter crop sown and market price received. Farmers also grow summer pulses or cucurbits as inter crops in spring planted cane to get additional income in IPST method.. The high BC ratio of 2.072 reveals that the sugarcane was profitable in ISPT as compare to traditional method. Incorporation of pulses, oilseeds and vegetables crops as intercrops in sugarcane based farming systems add to their net profitability and nutritional security.

Comparative economics of sugarcane production in U.P.

The comparative economic analysis of sugarcane production intraditional and innovative sugarcane production techniques (ISPT) methods was worked out and presented in Table 5.Total cost of sugarcane production was ₹161439 and ₹134267per ha in traditional andISPT method respectively. The high production cost in traditional method was mainly because of high seed cost as farmers use three bud setts and flood or check basin irrigation,without green manuring, high fertilizer and pay more labour wages for manual intercultural operations. However, in ISPT method cost was less as they sow two/ single bud setts, grow green manure crop, precession field levelling, FIRB/raised beds/trench planting at wider row spacing, saving irrigation water as apply water in trench/furrow, use Rotavator, RMD, trench openers with mechanical power for cane planting and to perform inter cultural operations. The results reveals cost saving 25-45 % on seed, fertilizer, irrigation and labour in ISPT method. The labour wages and mechanical power have shown upward trends and fertilizers price escalation.Farmers have adopted sugarcane mechanization for crop planting and intercultural operations to address issue of labour scarcity.

Table 5: Comparative sugarcane cultivation cost in Traditional and ISPT methods

(In `₹/ ha)

Particulars/ cost components	Traditional	ISPT method	Cost saving (%)
Fixed cost components			
Depreciation	5207	5441	
Interest on fixed assets	4908	4612	
Rental value of owned land	28284	28663	
Total fixed cost	38399	38716	-0.83
Variable cost components			
Cane seed/setts	18543	10342	44.23
Fertilizer and manure	14572	11286	22.55
Plant Protection chemicals	3567	3538	0.81
Human labour	37676	27234	27.72
Mechanical power	33261	34733	-4.43
Irrigation	15421	8418	45.41
Total variable cost	123040	95551	22.34
Total cost (Cost C)	161439	134267	16.83

Table 6 Comparative economics of sugarcane production in U.P.

(In ₹/ ha)

Particulars/ cost components	Traditional	ISPT method
Cost A_1	123040	95551
Cost B_1	151324	124214
Cost C_1	156232	128826
Total Cost (Cost C_2)	**161439**	**134267**
Yield (tonnes/ha)	71	85
Price (Rs./tonne)	3120	3150
Cost of production (Rs./tonne)	2274	1580
Gross return	221520	267750
Net return on Cost A_1	98480	172199
Net return on Cost C	60081	133483
Benefit-Cost (BC)Ratio	**1.372**	**1.994**

Table 6reveals that the farmers realized higher sugarcane productivity and reap better economic returns in ISPT as compare to traditional method with adoption of EMV's such as Co 0238, Co Lk 94184, Co 0118 etc and inter cropping with pulses, oilseeds and vegetables in autumn planted cane, trench planting, wider row spacing, single / two bud setts in place of three bud setts, irrigation in trench/furrow for higher cane productivity per drop of water (Fig1). Farmers used sugarcane cutter planter/trencher for crop sowing, small tractor or multi-purpose power tillers for intercultural operations to minimize labour cost. Sugarcane harvesting by labour, loading and transportcharges were also high in U.P. The farmers also cultivate summer pulses or cucurbits as inter crops in spring planted cane to get additional income in IPST method and reap net income up to ₹27500-31000/ha. They utilize additional income from inter crops to purchase chemicals, fertilizers and labour wages payment. The high BC ratio of 1.994 reveals that the sugarcane cultivation was more profitable in ISPT as compare to traditional method. Incorporation of pulses, oilseeds and vegetables crops as intercrops in sugarcane based farming systems add to their net profitability and supplement nutritional security.

Summary and conclusions:

- Production constraints, factors contributing profitability and financial viability of sugar-energy processing in Maharashtra and Uttar Pradesh was worked out. The wider adoption of sugarcane production technologies has improved sugarcane productivity 25-35 % and better quality cane supply to mills improved the sugar recovery by 1.5-1.9 points especially in U.P. during last five seasons. Hence, U.P. ranks first in sugarcane production (217.25 mt with average productivity 81.5 t/ha) with sugar production 12.38 mt during season 2019-2020 with average sugar recovery 11.73 %. However, sugar mills faces economic crisis because of surplus sugar production, market glut and low ex-mill price. The integrated sugar-energy complexes of more than 7000 TCD has sugar production cost ₹3270 to ₹3230 per quintal in U.P. and Maharashtra respectively.
- Bioethanol production from B-heavy molasses gives income ₹`15.29 per litre to the distillery as compared ₹12.68 per litre by final C-molasses. The, bioethanol produced from sugarcane juice gives lowest net income ₹5.69 per litre. The huge initial investment on distillery modernization and additional storage capacity are the key constraints in adoption of flexi sugar- bio-ethanol production plan by the mills. They have apprehension and were in dilemma that the flexi production policy would sustain or not in long run. Therefore, the study concludes that the diversion of B-heavy molasses could be a potential option for enhancing sugar mills economic feasibility and bioethanol supply to mitigate 10 % EBP targets by year 2022.
- Production constraints, sugar and bioethanol production cost and factors contributing to economic viability of sugar-energy production in Maharashtra and U.P. has been analysed
- Sugarcane farmers in Maharashtra had faced challenges of drought and flood extreme climates, water scarcity, and incidence of disease, insects-pest (White grab). The cost of sugarcane production and its processing has enhanced both for farmers and sugar mills. The average cane price paid to the farmers were ₹ 2844 and ₹ 3032 per tonne during reported study period in Maharashtra
- The average cost of sugar production in Maharashtra sugar mills varies from ₹ 2953 to ₹ 3657/ quintal with ex-mill sugar price ₹ 32-37 per Kg in standalone, integrated sugar-energy complex owned by cooperative or private sector. The cost of sugarcane and conversion cost accounts for nearly 80 and 20% respectively
- The Government has announced the flexi price policy for bio-ethanol processed from different raw materials to enhance its supply for achieving 10% EBP targets by 2022 and advanced its EBP 20% by 2025. India has achieved 10% ethanol blending with petrol during year 2020-21. The price for bio-ethanol produced from B-heavy molasses and directly from sugarcane juice ₹54.27 and ₹59.48 per litre respectively for its supply to OMCs
- Bioethanol production from B-heavy molasses gives income ₹15.29 per litre to the distillery as compared ₹`12.68 per litre by final C-molasses. However, bioethanol produced from sugarcane juice gives net income ₹5.69 per litre.
- The utilization of B-heavy molasses for bioethanol production in an integrated sugar-energy complex would reduce sugar recovery 1.2 to 1.5 on point basis and help in reducing sugar production.

Chapter No. 58: Use of ICT and AI tools / techniques in sugarcane agriculture and sugar industry

S S Hasan
Principal Scientist
ICAR – Indian Institute of Sugarcane Research, Lucknow
E-mail: Syed.Hasan@icar.gov.in

Sugar industry, one of the major agro-based industries in India, has been instrumental in resource mobilization, employment generation, income generation and creating social infrastructure in rural areas. Indeed, sugar industry has facilitated and accelerated pace of rural industrialization. More than 4.50 crore farmers are engaged in sugarcane cultivation and about 50 lakh skilled and unskilled workers have got direct employment in the industry. Sugar cultivation is done on around 5 million hectares of land in India and its production has fluctuated between 230-350 million tones in past several years. Sugar industry in India has about 550 sugar mills with an average installed capacity of 1.8 million tones. India is the largest consumer of sugar and second largest producer in the world.

The main concern of sugar industry in India is fluctuations in sugarcane production due to inadequate irrigation facilities, lower sugarcane yield, and frequent droughts in tropical and sub-tropical areas where sugarcane is grown on a large scale. In addition, sugarcane yield and sugar recovery is also lower in comparison with other sugar manufacturing countries. This leads to escalation of production costs and weak competitive edge of the industry. Average crushing capacity of sugar mill in our country is about 300tcd. These mills cannot have economies of scale so they have to incur high production costs. There is need to lower the production cost, and increase sugar recovery by an effective management of sugar industry entire business cycle.

During last decade one can observe that progress in Information and Communication Technology (ICT) is affecting all spheres of our life. ICT is assuming ever increasing importance in agricultural development of the country. There is no doubt about potential of ICT, as it has a variety of tools / technologies available for sugarcane and sugar industry. Here we discuss some of the opportunities from ICT in general and Artificial Intelligence (AI) in particular, for an effective management of sugarcane and sugar industry.

Big Data

Database and data warehouse technologies are used to store and retrieve large amount of data efficiently at affordable cost. Database refers to a set of related data and the way it is organized. Access to this data is usually provided by a Database Management System (DBMS) consisting of an integrated set of computer software. The DBMS provides various functions that allow entry, storage and retrieval of large quantities of information and provides ways to manage how that information is organized. Data Warehouse on other hand stores historical data in one single place and are used for creating analytical reports for knowledge workers throughout an enterprise and also called enterprise data warehouse. It is a system used for reporting and data analysis, and is considered a core component of business intelligence in an enterprise and also acts as central repositories of integrated data from one or more disparate sources. In agriculture, temporal / historical data on crop production, utilization, meteorological facts and pest / disease survey data and other useful data may be managed using these repositories for further analysis and decision support to stakeholders. Data Mining and OLAP techniques make it possible to extract new finding and meaningful patterns from large historical database.

With advent of unstructured data in the form of images, videos, sound, text, etc, these technologies are now converting to deal with unstructured data formats. Big data technologies are new form of data management, to deal will both structured and unstructured data and its analytics. In agriculture domain data is now being generated and collected from environment, substrate and crop, and being collected automatically with incorporation of sensors, cameras, UAVs, robots, satellites, etc. IBM DB, Oracle, MySQL, and Microsoft SQL Server are the top database management systems used to manage the data, reporting and analysis.

Expert System / Decision Support System

In artificial intelligence, an expert system is a computer system that emulates the decision-making ability of a human expert. An Expert System is an intelligent computer program that uses knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution. Interpretation, prediction, diagnosis, design, planning, monitoring, debugging, repair, instruction and control are major categories of expert system applications. A decision support system (DSS) is a computer-based information system that supports business or organizational decision-making activities, typically resulting in ranking, sorting, or choosing from among alternatives. DSSs serve the management, operations, and planning levels of an organization and help people make decisions about problems that may be rapidly changing and not easily specified in advance. Expert System / Decision Support System in crop production and protection are the modern extension tools for decision support at farmer level. It can suggest suitable variety, method of field preparation & sowing, irrigation, fertilizer application, etc. Disorder diagnosis and treatment are one of oldest application of expert system.

Geographic Information System

A geographic information system (GIS) integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information. In general, the term describes any information system that integrates, stores, edits, analyzes, shares, and displays geographic information. It allows users to create interactive queries, analyze spatial information, edit data in maps, and present the results of all these operations. User can view, understand, question, interpret, and visualize data in many ways that reveal relationships, patterns, and trends in the form of maps, reports, and charts. GIS can relate unrelated information by using location as the key index variable. Locations or extents in the Earth space–time may be recorded as dates/times of occurrence, and x, y, and z coordinates representing, longitude, latitude, and elevation, respectively. Major application of GIS in sugarcane sector includes land use analysis, thematic mapping, demographic analysis, socio-economic studies and environment management.

Internet / Communication Technologies

Internet is the global system of interconnected computer networks that consists of private, public, academic, business, and government networks of local to global scope, linked by a broad array of electronic, wireless, and optical networking technologies. The Internet carries an extensive range of information resources and services, such as the inter-linked hypertext documents and applications of the World Wide Web (WWW), electronic mail, telephony, and resource sharing. The terms Internet and World Wide Web are often used interchangeably in everyday speech. However, the World Wide Web or the Web is only one of a large number of Internet services. The Web is a collection of interconnected documents (web pages) and other web resources, linked by hyperlinks and URLs.

Internet technology has revolutionized the world of information communication. . With this the information dissemination to farming community can be made instantaneously in parallel. Most traditional communications media, including telephony, radio, television, paper mail and newspapers has been reshaped or redefined by the Internet, giving birth to new services such as email, Internet telephony, Internet television, online music, digital newspapers, and video streaming websites. Newspaper, book, and other print publishing are adapting to website technology, or are reshaped into blogging, web feeds and online news aggregators. Internet has enabled and accelerated new forms of personal interactions through instant messaging, Internet forums, and social networking. E-Commerce is one of the most useful applications of Internet used almost by all industries. Use of virtual meeting and conferencing facilities of Internet are now preferable form of collaboration in post-Covid era. These technologies are extensively being used in sugarcane and sugar sector for almost all sort of communication.

Mobile technologies

It seems that change is the only thing that stays constant in the world of information and communication technologies. Just as the mainframe and minicomputers of the 1960's and 1970's, gave way to the workstations and personal computers of the 1980's and 1990's, another revolution is upon us. This revolution has become known as mobile revolution. Mobility is currently one of the most discussed subjects in the field of ICT. The integration of mobile technologies, software tools, Internet, and wireless technologies provides an exciting opportunity of knowledge management for mobile users. In comparison to desktop computing, mobile devices are portable and anywhere information accessible devices. Development of software applications for mobile devices has been recently spurred by the availability of more powerful operating systems such as Android, Mac, etc and transfer of standardized programming languages to these smaller computing platforms. The new generation of lightweight hardware and mobile software systems along with positioning technologies has converted it as an important media of knowledge management. Further, online app repositories for mobile platforms such as Google Play Store, Apple Store, etc enables instant availability of application suitable to requirement.

IoT technologies

Internet of Things (IoT) is a technology of ICT for internetworking of physical devices like smart devices, vehicles, electronics, embedded systems, wireless sensor networks, and control systems, etc. It allows objects to be sensed and/or controlled remotely, creating opportunities for more direct integration of the physical world into computer-based systems, and resulting in improved efficiency, accuracy and economic benefit. In IoT vision everyday objects are "things", such as all home appliances, furniture, clothes, vehicles, roads and smart materials, etc. and these are readable, recognizable, locatable, addressable and/or controllable. IoT is not a single technology, rather It has evolved with convergence of multiple technologies, including ubiquitous wireless communication, real-time analytics, machine learning, commodity sensors, actuators and embedded systems. Sensors, actuators, compute servers, and the communication network form the core infrastructure of an IoT framework. IoT has potential for numerous and diverse areas for individuals, enterprises, and society as a whole. Some of important application of IoT in sugarcane agriculture are precise fertilizer application, precise irrigation, monitoring of biotic and abiotic stresses, harvest scheduling, livestock management, warehouse management, etc.

Blockchain Technologies

Blockchain technology is an advanced database mechanism that allows information sharing within a business network. A blockchain database stores data in blocks that are linked together in a chain. The data is chronologically consistent because you cannot delete or modify the chain without consensus from the network. In sugarcane sector, blockchain technologies can track all types of information about plants, such as seed quality, farming operations, stresses faced, harvesting quality, etc and even generate a record of the journey of the plant after it leaves the farm. Similarly, in sugar production all aspects of sugar production can be tagged using blockchain technologies. This data can improve supply chain transparency and eliminate concerns of unethical and illegal operations such as contamination. When consumers have this amount of transparency, they can make informed purchasing decisions.

AI Machine Learning / Deep Learning

Machine learning is an application of artificial intelligence (AI) that provides systems the ability to automatically learn and improve from experience without being explicitly programmed. It can be defined as a process of building computer systems that. automatically improve with experience. While deep learning is a class of machine learning algorithms that extract higher-level features from the raw input for making intelligent decisions. Inspired by the structure and function of the human brain, deep learning works on the principle of artificial neural networks in which multiple layers of processing are used to extract progressively higher-level features from data. Although it is a new technique of artificial intelligence, but as of now it drives many artificial intelligence (AI) applications and services that improve automation, performing analytical and physical tasks without human intervention. These techniques are now extensively used in almost all application viz. varietal identification, planting, nutrient application, crop protection, irrigation, environment management, harvesting, etc.

Robotics and Automation

Robotics and automation processes are finding many uses in agriculture. It reduces overall labour costs and increase the consistency of quality and safety during production and postharvest cycles. Robotics deals with the design, construction, operation and application of robots as well as computer systems for their control, sensory feedback and information processing. Robotic applications in agriculture can be classified into several groups: sowing, transplanting, weeding, disease control, maintenance, harvesting and post-harvest handling. Drones are modern form of robots particularly used for aerial monitoring of farms and aerial application of chemicals for crop protection and growth enhancement.

Simulation and Modeling

Computer simulation is an attempt to model a real-life or hypothetical situation on a computer so that it can be studied to see how the system works. By changing variables in the simulation, predictions may be made about the behavior of the system. It is a tool to virtually investigate the behavior of the system under study. Simulation is used when the real system cannot be engaged, because it may not be accessible, or it may be dangerous or unacceptable to engage, or it is being designed but not yet built, or it may simply not exist. Computer simulations have become a useful tool for the mathematical modeling of many natural systems in physics, astrophysics, climatology, chemistry and biology, human systems in economics, psychology, social science, and engineering. The act of simulating something first requires that a model be developed; this model represents the key characteristics, behaviors and functions of the selected physical or abstract system or process. Thus, a computer model is the algorithms and equations used to capture the behavior of the system being modeled. By contrast, computer simulation is the actual running of the program that contains these equations or algorithms.

Modeling and simulation technology can be used to model an ideal crop situation and predict its growth through extrapolation and other techniques by considering a specific crop environment. Crop Simulation Models can be developed for environmental characterization, effective crop scheduling, pest / disease management, impact study of climate change, yield forecasting, etc.

Management Information System

Management information system (MIS) refers to the processing of information through computers and other intelligent devices to manage and support managerial decisions within an organization. Management information systems, produce fixed, regularly scheduled reports based on data extracted and summarized from database. It helps in monitoring, evaluation, and coordination of activities in entire business process. The terms management information system (MIS), information system, enterprise resource planning (ERP), and information technology management (IT) are often confused. Information systems and MIS are broader categories that include ERP. MIS systems may be applied in various functional disciplines of management like finance, personnel, estate, etc.

Publishing and Presentation

Desktop publishing is the creation of documents using page layout skills. Desktop publishing software can generate layouts and produce typographic quality text and images This technology allows individuals, businesses, and other organizations to self-publish a wide range of printed matter. There are two types of pages in desktop publishing, electronic pages (e.g. web page) and virtual paper pages to be printed on physical paper pages. Today's publishing software are generally interactive and "What you see is what you get" (WYSIWYG) in design. While many software have been developed for desktop publishing and presentation. Software provided by Microsoft, Adobe and Corel are mostly used in today's market for document publishing and presentation. With the advent of WWW, desktop publishing skills are also converging into web designing skills to support online documentation and presentation.

Multimedia

In common usage, multimedia refers to an electronically delivered combination of media including video, still images, audio, and text in such a way that can be accessed interactively. Multimedia means many media – text, video, narrated sound, music, graphics, animations, special effects, etc. which are controlled, coordinated and integrated by a computer. Multimedia based Instructional Tools, Encyclopedia, Tutorials, Videos, etc not only give enhancement over text only messages but also improves understanding and retention of information. Much of the content on the web today falls within this definition.

Chapter No. 59: Experimental layout, statistical designs and their effective applications in agricultural research

Rajesh Kumar
Principal Scientist
ICAR - Indian Institute of Sugarcane Research, Lucknow

The purpose of the "design of experiment in agricultural research" is to provide a means by which it is possible to detect any differences with a certain measurable confidence. That may be present in the effect of various comparable treatments when applied to a set of experimental units with the help of the observation representing the "response" of the experimental units. The experimental techniques for achieving this purpose is mainly based on the assumption that if the discrepancies of the kind under the test are absent, the results of the experiment.

Logic, Research and Experiment

"The purpose of statistical science is to provide an objective basis for the analyses of problems in which the data depart from the laws of exact causality. A general logical system of inductive reasoning has been devised, is applicable to data of this kind, and is now widely used in scientific research. Some understanding of its principles is, therefore, important both for research workers and for those whose interests lie in the employment of technological advances resulting from research. Especially is this true of the agricultural and biological sciences."

Research, Scientific Method and Experiment

Research can be broadly defined as systematic inquiry into a subject to discover new facts or principles. The procedure for research is generally known as the scientific method which, although difficult to define precisely, usually involves the following steps:

1. *Formulation of an hypothesis*-a tentative explanation or solution.
2. *Planning an experiment to objectively test the hypothesis.*
3. *Careful observation and collection of data from the experiment.*
4. *Interpretation of the experimental results.* A consideration of the results in the context of other known facts concerning the problem leads to confirmation, rejection, or alternation of the hypothesis.

The experiment is an important tool of research. Some important characteristics of a well-planned experiment are given below.

1. *Simplicity*. The selection of treatments and the experimental arrangement should be as simple as possible, consistent with the objectives of the experiment.
2. *Degree of precision*. The probability should be high that the experiment will be able to measure differences with the degree of precision the experimenter desires. This implies an appropriate design and sufficient replication.
3. *Absence of systematic error*. The experiment must be planned to ensure that experimental units receiving one treatment in no systematic way differ from those receiving another treatment so that an unbiased estimate of each treatment effect can be obtained.
4. *Range of validity of conclusions*. Conclusions should have as wide a range of validity as possible. An experiment replicated in time and space would increase the range of validity of the conclusions that could be drawn from it. A factorial set of treatment is another way for increasing the range of validity of an experiment. In a factorial experiment the effects of one factor are evaluated under varying levels of a second factor.

5. *Calculation of degree of uncertainty*. In any experiment there is always some degree of uncertainty as to the validity of the conclusions. The experiment should be designed so that it is possible to calculate the probability of obtaining the observed results by chance alone.

Field Experiments

The purpose of the "design of experiment in agricultural research" is to provide a means by which it is possible to detect any differences with a certain measurable confidence. That may be present in the effect of various comparable treatments when applied to a set of experimental units with the help of the observation representing the "response" of the experimental units. The experimental techniques for achieving this purpose is mainly based on the assumption that if the discrepancies of the kind under the test are absent, the results of the experiment.

Steps in Experimentation

The selection of a procedure for research depends, to a large extent, on the subject matter in which the research is being conducted and on the objectives of the research. The research might be descriptive and involve a sampling survey, or it might involve a controlled experiment or series of experiments. When an experiment is involved there are a number of considerations that should be carefully thought through if it is to be a success. The following are some of the more important steps to be taken:

1. *Definition of the problem*. The first step in problem solving is to state the problem clearly and concisely. If the problem cannot be defined, there is little chance of it ever being solved. Once the problem is understood, you should be able to formulate questions which, when answered, will lead to solutions.
2. *Statement of objectives*. This may be in the form of questions to be answered, the hypothesis to be tested, or the effects to be estimated. Objectives should be written out in precise terms. This allows the experimenter to plan the experimental procedures more effectively. When there is more than one objective, they should be listed in order of importance, as this might have a bearing on the experimental design. In stating objectives, do not be vague or too ambitious.
3. *Selection of treatments*. The success of the experiment rests on the careful selection of treatments, whose evaluation will answer the questions posed.
4. *Selection of experimental material*. In selecting experimental material, the objectives of the experiment and the population about which inferences are to be made must be considered. The material used should be representative of the population on which the treatments will be tested.
5. *Selection of experimental design*. Here again a consideration of objectives is important, but a general rule would be to choose the simplest design that is likely to provide the precision you require.
6. *Selection of the unit for observation and the number of replications.* For example, in field experiments with plants, this means deciding on the size and shape of field plots. In experiments with animals, this means deciding on the number of animals to consider as an experimental unit. Experience from other similar experiments in invaluable in making these decisions. Both plot size and the number of replications should be chosen to produce the required precision of treatment estimate.
7. *Control of the effects of the adjacent units on each other*. This is usually accomplished through the use of border rows and by randomization of treatments.
8. *Consideration of data to be collected*. The data collected should properly evaluate treatment effects in line with the objectives of the experiment. In addition, consideration should be given to collection of data that will explain why the treatments perform as they do.
9. *Outlining statistical analysis and summarization of results*. Write out the sources of variation and associated degrees of freedom in the analysis of variance. Include the various F tests you may have planned. Consider how the results might be used, and prepare possible summary tables or

graphs that will show the effects you expect. Compare these expected results to the objectives of your experiment to see if the experiment will give the answers you are looking for.
At this point it is well to provide for a review of your plans by a statistician and by one or more of your colleagues. A review by others may bring out points you have overlooked. Certain alternations or adjustments may greatly enrich your experiment and make it possible to learn considerably more from the work you are about to undertake.

10. *Conducting the experiment*. In conducting the experiment, use procedures that are free from personal biases. Make use of the experimental design in collecting data so that differences among individuals or differences associated with order of collection can be removed from experimental error. Avoid fatigue in collecting data. Immediately recheck observations that seem out of line. Organize the collection of your data to facilitate analysis and to avoid errors in recopying. If it is necessary to copy data, check the copied figures against the originals immediately.

11. *Analyzing data and interpreting results*. All data should be analyzed as planned and the results interpreted in the light of the experimental conditions, hypothesis tested, and the relation of the results to facts previously established. Remember that statistics do not prove anything and that there is always a probability that your conclusions may be wrong. Therefore, consider the consequences of making an incorrect decision. Do not jump to a conclusion, even though it is *statistically significant* if the conclusion appears out of line with previously established facts. In this case, investigate the matter further.

12. *Preparation of a complete, readable, and correct report of the research*. There is no such thing as a *negative result*. If the null hypothesis is not rejected, it is *positive* evidence that there may be no real differences among the treatments tested. Again, check with your colleagues and provide for review of your conclusions.

Uniformity Trials Optimum Plot and Block Size in Experimentation

In planning the layout of a field experiment maximum efficiency in estimating and comparing treat effects should be carried at. The accuracy of the estimates of the treat effect is dependent, a part from the number of replications, on the magnitude of error variation. The error variation is known to be influenced by the size and shape of the slots and the grouping of plots into block. A uniformity trial enables us to determine optimum plot size, shape and optimum grouping or arrangement of plots.

A uniformity trial consists of growing a uniform crop under uniform condition in the selected field and dividing the experimental area into small units or plots of equal size and shape at the time of harvest and recording the yields for each such small units separately. The data so obtained are called uniformity data. Plots of different sizes and shapes are formed by adding the yield of contiguous plots of standard size (i.e. size for which originally yield are recorded). These plots are subsequently arranged in blocks of different sizes and for each such arrangement the coefficient of variation can be found out. The relation between coefficient of variation and size of plot can then be established for the given experimental area and the optimum plot sizes can be worked out in the sense that optimum size is that for which the percentage standard error is minimum for treatment means based on a given area.

In most of cases, it is found that coefficient variation decreases with increase in plot size in some cases a relation of the type, where y denotes the coefficient of variation and x the plot size and a and f are constants is established between the C.V. and plot sizes. This relation does not take into consideration the shape of the plot. Fitting the relation for plots of different sizes with same shape, we find for a given experimental area, as one plot size is increased. C. decreases, but percentage and S.E. of a treatment based on a given area increases due to the decrease in number of replications, provided $0<g<.5$ where $0<f<.5$, smaller plots are optimum plots with $g=0$, C.V. is constant and the plot size has no effect unit but with decrease in number of replication i.e. with increase in plot size, percentage S.E. increase. So smaller plots are optimum. But with $g=0.5$, C.V.$=a/\sqrt{x}$ and for a given experimental area increase in plot size though decreases C.V. does not have any effect on the percentage S.E. so that decrease in plot size does not yield any additional information. In such a case let f(x) represent the cost of the experiment when we take the plot size as x. Therefore, we can minimize this w.v.t. and get optimum x. This is just one example as to show how the optimum plot size can be arrived at with the use of one uniformity data.

As regards the shape of the plot if we are considering plots of rectangular or square shape, we may denote x for its length and y for its breath and for all plots have the same length and breath, shape is given by x:y=1:1 and for a plot 5'x6' shape is x:y=1:1.2 and son on. Then for different shapes, keeping the area fixed, C.V. can be worked out and a relation between the shape and C.V. can be than established. Just as in the case of size of plots with the use of that relation optimum shape of plots can be arrived at.

The effect of provision of border on the C.V. can be assessed for different sizes and shapes of plots. Similarly, the efficiency of blocks and also the relative efficiency of different designs such as latin square randomized blocks or confounding can be studies with the help of such uniformity data.

Another important use of the uniformity data is to obtain indication of the extent of variability in the crops and these by determine the number of replications required to detect the treat difference with as assigned level of accuracy under the given set of conditions. Also uniformity trials are invaluable for suggesting useful calibrating variates for adjusting the experimental yields for the pre experimental performance of the crop.

As for example, in an experiment with perennials, the pre-treat yield of the trees, obtained with uniformity data can be used as a concomitant variable consists in first obtaining an analysis of covariance partitioning exactly in the same manner as in variance analysis excepting that the squaring operation is to be replaced by the operation of multiplying of the corresponding yields or total of the two variates. Afterword's, each of the error S.S. as also the (Treatment S.S. + Error S.S.) of the variates under study has to the adjusted.

$$Adjusted.Error.SS = \sum_i y_i^2 - (\sum_i xy)^2 / \sum x^2 \qquad (1)$$

$$Adjusted(Error.SS + Treatment.SS) = \sum_{i+e} y_i^2 + (\sum_{i+e} xy)^2 / \sum_{i+e} x^2 \qquad (2)$$

Where $\sum_i y^2$ denote the error SS of the variates

$\sum_{i+e} y^2$ denotes sum of error and treatment SS and so on.

The difference (2)-(1) gives the adjusted treat S.S. and the corresponding m.s.s. has to the tested against the adjusted error m.s.s. which will have a d.f. less after the adjustment.

The limitation of uniformity trials in planning experiments should however be clearly has in mind. Firstly, it is not possible to generalize the results obtained in uniformity trials to other experimental field. Secondly, delaying the experiment for completing the uniformity trials first will mean some loss of time and it may be often preferable to start straight away the experiment with whatever information is available.

Randomization, Replication and Local Control

Although most of the above steps are non statistical, statistical analysis is an important part of experimentation. Statistical science helps the researcher design the experiment and objectively evaluate the resulting numerical data. As experimenters, few of us will have the time or the inclination to become competent biometricians, but we can all learn and practice the three "R's" of experimentation.

The three principles in planning of experiment are

1. ***Replication* :** This is the only way you will be able to measure the validity of your conclusions from an experiment. Replication which permits estimation of experimental error and increases one precision of estimates of both the treatment and error.
2. ***Randomization*** : Statistical analysis depends upon the assignment of treatments to plots in a purely objective, random manner. Randomization which is essential for a valid estimation of error an also leads to unbiased estimate to treatment means.
3. **Local control:** Local control or control of error through suitable grouping of experimental units into homogenous blocks or through utilization in the statistical analysis of measurements on ancillary variate (Covariance technique).

Completely Randomized Design

The simplest design using only two essential principles of field experiments viz. replication and randomization. Experimental material should be homogeneous. The design is useful for laboratory or greenhouse experiments. ANOVA is given below.

Sources	**D.F.**	**S.S.**	**M.S.**
Between Treatments	4	A	A/ B
Within Treatments (Error)	15	B	
Total	**19**		

Randomized Block Design

In order to control the variability in one direction in the experimental material, it is desirable to divide the experimental units into homogeneous groups of units known as block. The treatmenst are allocated separately to each of these blocks. This procedure gives rise to a design known as Randomized Block Design (RBD). ANOVA is given below.

Sources	**D.F.**	**S.S.**	**M.S.**
Between Blocks	**r-1**	**A**	**A/ C**
Between Treatments	**n-1**	**B**	**B/ C**
Error	**(n-1) (r-1)**	**C**	
Total	**nr-1**		

Split Plot Design

In Agricultural experiments it is usually found that certain treatments like irrigation, dates of sowing etc. require large plots. Consequently for operational convenience such treatments are allotted (or allocated) too plots which are relatively larger that there which are allocated to treatments like seed rate, spacing, manorial application etc. In such cases the former treatments are allocated to the main plots while the levels of the later treatments are allocated to sub plots which are formed by subdividing the main plots. The layout so obtained is called a split plot design.

Since neighboring plots tend to be similar in fertility and in other agronomic properties, in the statistical analysis of a split plot design, account must be taken of the fact that observations from different sub plots in the same main plot may be correlated. Suppose, for example, a factor A is tried at p levels is the main plots in r replication, while a factor B is tried at a levels within each main plot. Then if c_{ijk} denote the error component for the observations in Kth sub unit of Jth main plot is the i-th replication, we may suppose.

And E (i.e. the sub units in the different main plots are assumed to be uncorrelated) Since the main effects of A are calculated entirely from totals, or mean of main plots, the error variance per subunit applicable to the main effects of A is given by Since the main effects of Bare derived from the differences between the subunits within main plots the error variance per unit applicable to the main effects of B is
In the split plot design also. Thus the increased precision on Band AB is obtained by scarifying the precision on A. Since the treatment comparisons have different basic error variances, the sesused for different treatment comparison are not the same as in a corresponding R.B.D. For a split plot design with p whole plot treatments and q sub plot treatments arranged in randomized blocks with r replication, following is one analysis of variance. ANOVA is given below.

Sources	**D.F.**	**S.S.**	**MS**
Blocks	**r-1**		
Main Plot Treat (A)	**p-1**		
Error (a)	**(p-1) (r-1)**	**Ea**	
Total	**rp-1**		
Sub plot treatments (B)	**q-1**		
Main x Sub (AB)	**(p-1) (q-1)**		
Error (a)	**p (r-1) (q-1)**	**Eb**	
Total	**rpq-1**		

Advantage of Split Plot Design

The main effect of one of the two factors are large enough to be detected even with a lower precision, so that factor m ay be allotted to the main plot. The main effect of the factor allotted to main plots are not much interest as compared to the effects of the factor allocated to the subplots and the interaction between the two factors is of primary interest. Some treatments by their vary nature, require large plots for convenient application.

Disadvantages

Sometimes the whole plot error is much larger that the subplot error, so that the effects of main plot treatments though large and exciting are not significant, where as those of subplot treatments, which are too small to be of practical interest are statistically significant. The fact that different treatment comparison have different basic error variance makes one analysis more complex than with the corresponding R.B.D. especially if some unusual type of comparison is made. When missing data occur the increase in complexity of one analysis for one split plot design is greater than for C.R.D.

Strip Plot Design

An arrangement in which the sub plot treat instead of being randomized independently within each main plot as in the case of split plot design, are arranged is strip across each replication is known as strip plot design. The layout is convenient for field experiments when it is necessary to test both factors on relatively large areas and to have free access at both ends. As with ordinary split plot design the average precision overall treatment comparison is the same as that of corresponding Randomized blocks arranged on the sub units. The strip plot design sacrifices precision on the main effect of both the factors in order to provide higher precision on the interaction which will generally be more accurately determined than is either randomized blocks or simple split plot designs. Also the number of degrees of freedom for estimating the error variances applicable to the main effects of both the factors are likely to be small, as compared with split plot design. Consequently this design is not recommended unless practical consideration necessitate its use or unless the interaction are the principal object to study.

Sources	**D.F.**	**M.S.S.**	**E (m.s.s.)**
Replications	**r-1**		
A	**p-1=4**		
Error (a)	**(r-1) (p-1) = 16**	**Ea**	
B	**q-1=2**		
Error (b)	**(q-1) (r-1) = 8**	**Eb**	
AB	**(p-1) (q-1) = 8**		
Error (c)	**(r-1) (p-1) (q-1)= 32**	**Ec**	
Total	**Rpq-1= 74**		

Chapter No. 60: Role of KVK in disseminating technologies and implementation of ICAR programmes

A.K.Dubey* and Deepak Rai
Krishi Vigyan Kendra, Lucknw
ICAR-Indian Institute of Sugarcane Research, Lucknow
E-mail: akdubeykvkiisr@gmail.com

Indian agriculture has witnessed phenomenal growth during last four decades with manifold increase in production of major commodities like food grains, vegetables, fruits, milk, eggs and fish. As a result, the per capita availability of important food items has increased despite of increasing population. The ratio of agricultural land to agricultural population has shrunk to 0.3 ha per person in India as compared to 11.0 ha per person in developed countries. The resources are getting marginalized and there is tremendous pressure on natural resources with divergence of agricultural land and water towards industrial, urban and non-agriculture sector. Food security is one of the major concerns. It is estimated that India's population during the last three and half decades have increased from 551 million to 1122 million, which implied that the country had to feed double the population. Food security is attached to national sovereignty and thus, agriculture sector has to gain strength and vision to uphold the national concern. Knowledge and technology empowerment of farmers is the key to achieve the food security.On recommendation of the Education Commission (1964-66) and discussion of Planning Commission and Inter-Ministerial Committee as well as recommendation by the committee headed by Dr. Mohan Singh Mehta appointed by ICAR in 1973 the idea of establishment of Farm Science Centre (Krishi Vigyan Kendra) was developed. The first KVK, on a pilot basis, was established in 1974 at Pondicherry under the administrative control of the Tamil Nadu Agricultural University, Coimbatore. Further in 1976-77, the Planning Commission approved the proposal of the ICAR to establish 18 KVKs during the Fifth Five Year Plan. In 1979, 12 more KVKs were approved and established from Agricultural Produce Cess Fund (AP Cess). Additional 14 KVKs were again approved in 1981 and established during 1982-83 from AP Cess fund. A High Level Evaluation Committee on KVK constituted by ICAR in 1984, after through review strongly recommended establishment of more KVKs in the country. Keeping this in view the Planning Commission approved scheme of ICAR to establish 44 new KVKs during the Sixth Plan. End of Sixth Plan saw functioning of 89 KVKs and during Seventh Plan, 20 new KVKs were established. The success of KVKs at many locations created a great demand for establishment of more KVKs in the remaining districts of the country so the Planning Commission approved 74 new KVKs to be established during the period 1992-93 than again in the Eighth Plan (1992-97), 78 new KVKs were approved and established making total number of functional KVKs by the end of the Eighth Plan to 261. The numbers increased to 290 during Ninth Plan with establishment of 29 KVKS, increase of 551 KVKs at the end of Tenth Plan and its became 630 in eleventh plan and 642 more in twelve five year plan. At present there are 731 KVKs established in the country. There are 38 KVKs under the control of State Governments, 66 under ICAR Institutes, 103 under NGOs, 506 under Agricultural Universities, 3 under Central Universities, 3 under Public Sector Undertakings, 7 under Deemed to be Universities and 5 under Other Educational Institutions.

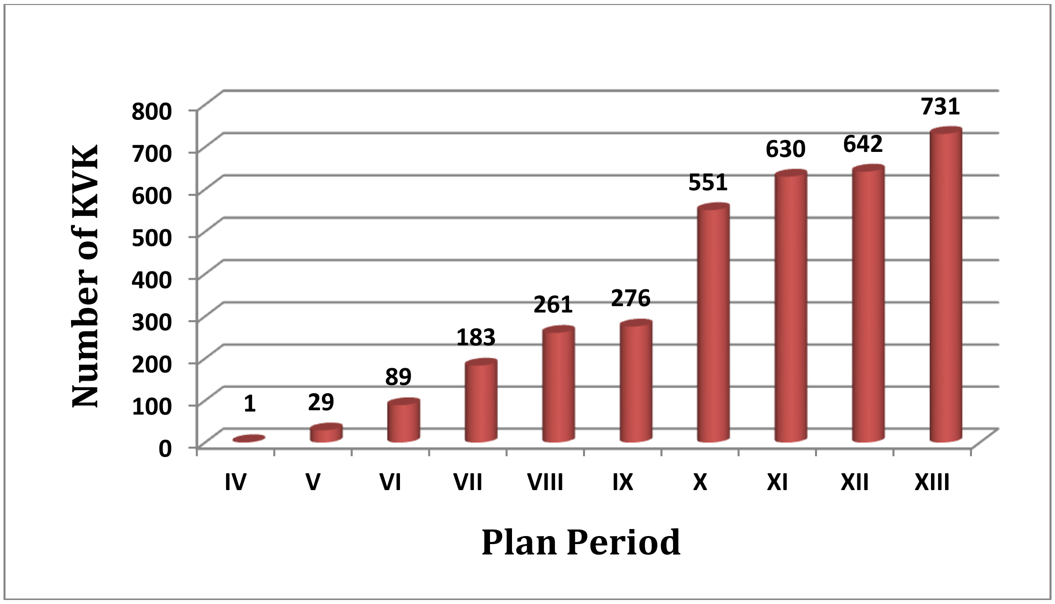


Figure1: No. of KVKs established in India (Plan wise)

Krishi Vigyan Kendra (KVK) is the only institution at the district level in India for technological backstopping in agriculture and allied sectors. While some of the KVKs have been effectively contributing to the technology development and promotion process, many are plagued with several problems. All KVKs are envisaged to reduce the time lag between generation of technology at the research institution and its application to the location specific farmer fields for increasing production, productivity and net farm income on a sustained basis.

Mandate of KVKs:

KVKs are to provide a key facilitating role in the refinement of technologies to specific conditions, by acting as a two-way link between research and farmers. Application of technology/products through assessment, refinement and demonstration for adoption, thus, is the
main mandate of the KVKs. To achieve this mandate effectively, each KVK is expected to perform following activities:

- On-farm testing to identify the location specificity of agricultural technologies under various farming systems.
- Frontline demonstrations to establish its production potentials on the farmers' fields.
- Training of farmers and extension personnel to update their knowledge and skills in modern agricultural technologies.
- Work as resource and knowledge center of agricultural technologies for supporting initiatives of public, private and voluntary sector for improving the agricultural economy of the district.
- Produce and make available technological products like seed, planting material, bio-agents, young ones of livestock etc. to the farmers.
- Organize extension activities to create awareness about improved agricultural technologies to facilitate fast diffusion and adoption of technologies in agriculture and allied sectors.
- The HighPowered Committee on Management of KVKs (ICAR, 2014) in its report has suggested a new vision, mission and mandate for the KVKs defining its activities as follows:
- On-Farm Testing (OFT) to assess the location specificity of agricultural technologies under various farming systems.

- Out scaling of farm innovations through Frontline Demonstration (FLD) to showcase the specific benefits/ worth of technologies on farmers' fields.
- Capacity development of farmers and extension personnel to update their knowledge and skills in modern agricultural technologies and enterprises.
- Work as Knowledge and Resource Centre for improving overall agricultural economy in the operational area.
- Conduct frontline extension programmes and provides farm advisories using ICTs and other media on varied subjects of interest to farmers.
- Data documentation, characterization and strategic planning of farming practices.

Staffing Pattern:

ICAR has frame lined following 16 numbers of staffs. The break up is as follows:

Sl. No.	Name of Post	Number
1	Sr. Scientist & Head	1
2	Subject Matter Specialists	6
3	Farm Manager	1
4	Programme Assistants	2
5	Assistant	1
6	Stenographer	1
7	Drivers	2
8	Skilled Supporting Staffs	2
	Total	**16**

Functioning of KVKs:

All KVKs are being 100% financed by Indian Council of Agriculture Research in respect to Pay Allowance, Travelling Allowance, Office Contingencies and Carry out On Farm Trials, Front Line Demonstrations and Trainings. ICAR is also rendering full financial help to all KVKs to develop infrastructure facilities viz. Administrative Building, Soil laboratory, Training Hostel, Vehicle. Besides, as per demand and necessity of respective KVKs grants are being provided to develop further infrastructure facilities as and when required. ICAR during the course of establishment of KVKs has streamlined that all KVKs will be administratively controlled by following organizations:

- Research Institute of ICAR
- State Agriculture University
- NGOs

Funds are being released by ICAR to head of aforesaid Institutes who in turn transfer the fund to respective KVKs to carry out activities under administrative control of said Institute.

KVK serve as a knowledge and resource centers:

KVK is an agro-based capacity building institution for the farmers to provide need based teaching on various aspects of agriculture and allied sectors. KVKs impart latest technical know-how and do-how to different clientele by formulating various programmes with the principles of learning by doing, seeing is believing, earn while you learn to achieve the desirable changes pertaining to their knowledge, skills and attitude with a view to help them live better by improving their farm and allied enterprises. KVK plans, executes and evaluates its programmes with the people. Knowledge "Management" is given emphasis for improved efficiency of KVKs. Knowledge management is all about converting data into information and knowledge, and then applying wisely. Knowledge and technology plays a key role. In this context, how KVKs act as centers of knowledge and wisdom is presented in Figure-2. The KVKs facilitate translation of data into knowledge leading to effective technology application. KVK can work as effective knowledge and resource centers through adopting KRCTO model. **Knowledge:** The acquisition of competence of KVK on existing farming systems and production systems, agricultural technology, markets (demand and prices) and policy are key to its performance.

Resources: Infrastructure building to provide necessary technological backstopping and capacity building are crucial for knowledge and technology dissemination.

Competency: Evaluating technologies, processing and value addition, weather based agro advisories, market intelligence and agro-logistics.

Technology products: Critical technology products, and problem solving consultancy is to be provided by the KVK.

Organizing farmers groups: Building farmers network around KVK to exchange information, facilitating learning from experience and support in decision making.

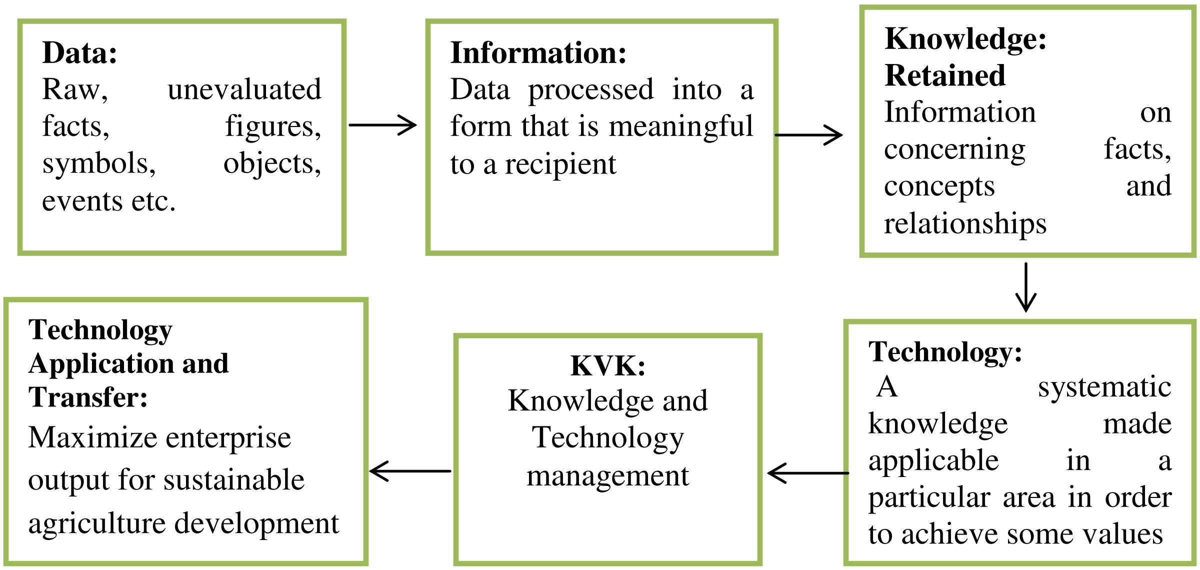


Figure 2: Knowledge Management Process

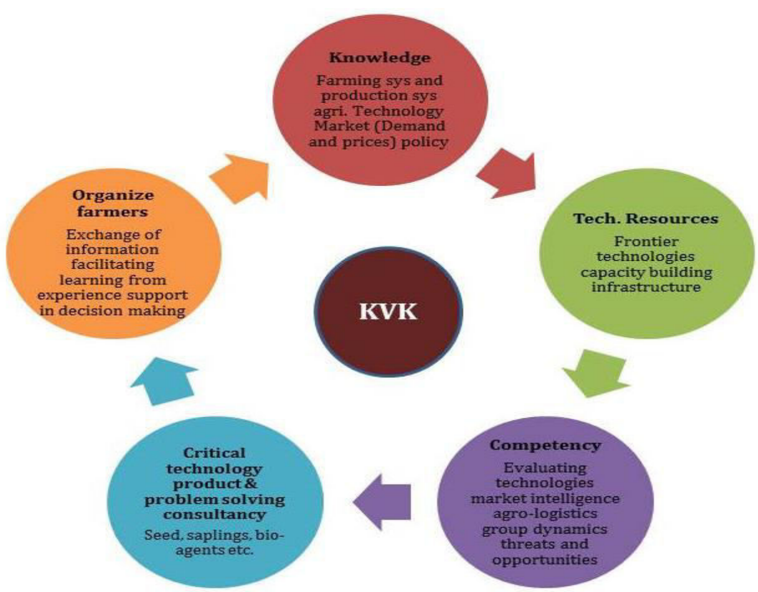


Figure 3: KVK: Knowledge Resource Centre

Activities of KVKs:

Keeping in mind with the aforesaid mandates and activities, all Krishi Vigyan Kedras are carrying out on farm trails for location specific sustainable innovative technologies. All On Farm Trials are being conducted thrice in different blocks of the district in consecutive years with an intention to refine technologies during the course of three years. Successful technologies of KVKs along with normal conventional technologies of SAUs/ICAR are being disseminated to farmers. Front line demonstration on different high yielding verities of Oil seeds and Pulses, Wheat, Paddy, Potato, potential vegetables, fruits, flowers as per feasibility of the respective district, Poultry, Duck (Khaki Campbell), Goatary, Dairy, Fodder (Maize), Poly Culture of Fish & Prawn, Fish Feed, Paddy Puddler, Improve Implements, Kitchen Garden are being carried out through Farmers Club developed by KVKs/NGOs/Lead Banks. Trainings are being conducted for all disciplines of Agriculture Science for Farmers, Rural youth, Extension functionaries. The broad areas of training for farmers and rural youth are as follows:

Imparting training for practicing farmer and farm women:

Organic farming, promotion of Food production in waste land, efficient utilization up slope medium land by scientific cultivation of cereals, oil seeds pulses, vegetables, fruits, flowers etc, promotion and production of ducklings, goatary, poultry birds, promotion and production fresh water prawn and carp culture in small seasonal ponds.

Training for rural youth on:

i) Quality seed production
ii) Agro-processing for small scale entrepreneurship development like
iii) Production and quality management of Vermi - Compost
iv) Nursery management
v) Poultry farming (Broiler, Kuroiler and Duck)
vi) Para vet nary training for Dairy management, Vet nary AID and Artificial Insemination for making of high milk production.
vii) Utilization of perennial water bodies through Carps and Prawn culture.
viii) Repair and maintenance of Diesel engine Pump set.
ix) Repairing of sprayers.
x) For Women Empowerment training on Value addition for Fruits, Vegetables and preservation.(Jam, Jeli, Pickkles etc)
xi) Training on Naksha body making.
xii) Training on Tailoring, Embroidery, Knitting,
xiii) Training on Sal Leaf plate and Batti making,
xiv) Training for Post-harvest technology in Agro-horticultural crops

Extension activities are being implemented in the form of Field day, Technology week, Krishi Mela, Scientists visit to farmer's field and vice versa. Besides carrying out Mandatory activities, KVK is also rendering service to farming community by supplying good quality critical inputs in terms of seeds, saplings, breeds which are being produced in KVK's farm. KVKs are also carrying out Soil and Water analysis in their own laboratory to test major nutrients of soil with minimum cost with an objective to rationalize fertilizer policy for farmers of different blocks. The development indicators emerged out through PRA, survey, ex-trainees' meet, exhibition diagnostic visit, appraisal reports of ICAR, workshop, seminar, SAC recommendation, local need and people' representatives recommendation were taken into accounts to take care of local problems and make awareness about latest technological advancement to the farmers of the districts. Accordingly the action plan has been chalked out to fulfill the KVK mandates. KVKs are required to work is close collaborative mode with District Line Departments, Lead Bank, NABARD, Radio/ Doordarshan to disseminate KVKs activities to all corners of district. With limited manpower, it would be uphill task for KVKs to reach to the furthest corner. The strategic approach and targets of KVKs are highlighted:

Adoption of strategic Approach:

Methodology	Details of function of the methodology
▪ Alternative land use strategy for establishment of progeny orchard	Delineation of wasteland → Zilla Parishad → Panchayat Samiti → Gram Panchayat → Capacity building to selected rural youth → Support with training & planting Materials → Monitoring & follow up → Exist protocol
▪ Cluster village approach	Cluster villages → Adopt a village → PRA → Formation of grass-root organization (SHGs, FSC, FIG, FLEK/Mahila Samiti, GPM) → Support with Monitoring & Follow up → Convergence of other stake holders → TOT → Sustainable livelihood
▪ Dovetailing of Progressive Farmers/ ▪ Farmers Led Extn. Workers/Institute	Organize an Annual Agril. Exhibition & Mela → Rewarding provision for best farmers/farm women/rural youth/ Krishak Bhandar → training & support with latest technology package → Monitoring & follow up

Research–Extension and Development Linkages:

Each KVK has a provision of Scientific Advisory Committee (SAC), the function of this Committee is to provide advice to the KVK in formulation of annual technical programme and also to review the performance mandated activities. The Committee consists of the representatives of National Agriculture Research System, various line departments functioning in the district, media, credit and input organizations / agencies and representative of the farmers and farm women. The idea of constituting this Committee is to see that the Annual Plan of Action is in harmony with the needs of the farmers, resources and location specificity of the technologies, existing government programmes and support. The committee meets once or twice in a year to provide guidance and direction to the KVK to meet the emerging challenge of different crop seasons. Besides, it also serves as a mechanism for research-extension and development linkages. The KVKs also participate in Zonal Agricultural Research and Extension Advisory Committee (ZAREAC), attend workshops and specialized training programmes in the concerned State Agricultural University and ICAR Research Institute. The participation of staff in these forums helps the KVK scientists to get continuous up-to-date technical backstopping and also enable them to help the farmers in timely adoption of latest agricultural technologies.

CONVERGENCE

As per mandate of ICAR, KVK is required to work in close association with all line departments of district viz. Agriculture, Horticulture, Animal Science, Fishery, DRDC, Marketing. In this respect KVK is converging in following ways to cater the need of the farmers of district as well as to generate revenue/resource of their own:

Sl. No.	Funding Agencies	Area of Activities
1	ATMA	Short term research, Training, Publication, Farm School, Hatchery units
2	RKVY	Integrated Farming System, Augmentation of irrigation facilities, Infrastructure development
3	NABARD	Training, Model Village, Krishi Mela
4	DRDC	Training for SHGs, SGSY
5	FPI & Horticulture	Model Nursery, Poly House, green house

All KVKs have developed District Agriculture Plans for respective district along with Department of Agriculture.

Entrepreneurship Development:
KVKs must develop farmer entrepreneurs to help in technology transfer through farmer to farmer extension. KVK trainings should promote entrepreneurship among rural youth, helping them in gaining self-employment.

Promotion of diversified farming systems including Agro-tourism:
KVK farms and KVK adopted villages can be developed as agro-tourism sites, to demonstrate diversifying farm income portfolio and which should be cost effective for adoption by farmers.

Resource Generation:
KVKs can compete and tap funds available from various government schemes/NABARD /Agricultural Skill Council of India for skill & entrepreneurship development in rural areas as well as generate a part of their resources from the sale of planting materials and other produce from their farms, funding relationship with NGOs, and national and international organizations.

ATMA-KVK link:
Lot more needs to be done to achieve the convergence between ATMA and KVK (as envisaged under the joint circular) operational. There might be some success stories, wherein, the proposed changes like quarterly joint meetings, earmarking of funds to KVKs, visit of ATMA staff to the cluster villages of KVKs and ATMA sponsorship for Technology Weeks (being organized by KVKs) are achieved successfully, which may be shared for wider replication in other districts.

KVKs need to be strengthened by increased technological backstopping by ICAR and SAUs for playing the role of knowledge and resource centres effectively and efficiently. There is also a need for extension research by ICAR research institutes and SAUs to suggest innovative approaches and methodologies to KVKs for critical assessment of location specific technologies, frontline demonstrations and effective capacity building of stakeholders, vocational training, and entrepreneurship development for sharing successful experiences.

ICAR programmes implemented by KVK:
Attracting and Retaining Youth in Agriculture (ARYA): Project ARYA focuses on **empowering** and involving the **rural youth** in various agricultural and allied sector entrepreneurial activities. The aim of the project is to generate employment, ensure sustainable income and further develop agriculture and allied activities in rural areas.This project is running in different district of 25 states of country. ARYA indicates that the income from about 17 major enterprises like Apiary, Mushroom, Seed Processing, Poultry, Dairy, Goatry, Carp-hatchery, Vermi-compost etc. can provide average income of Rs. 10,000 to 12,000 per month based upon the economy of scale of the enterprise.

National Innovations on Climate Resilient Agriculture (NICRA): National Innovations on Climate Resilient Agriculture (NICRA) is a network project of the Indian Council of Agricultural Research (ICAR) launched in February, 2011. The project aims to enhance resilience of Indian agriculture to climate change and climate vulnerability through strategic research and technology demonstration. The research on adaptation and mitigation covers crops, livestock, fisheries and natural resource management. The project consists of four components viz. Strategic Research, Technology Demonstration, Capacity Building and Sponsored/Competitive Grants. In the strategic research, the main thrust areas covered are (i) identifying most vulnerable districts/regions, (ii) evolving crop varieties and management practices for adaptation and mitigation, (iii) assessing climate change impacts on livestock, fisheries and poultry and identifying adaptation strategies. So far, 7 climate resilient varieties and 650 district agricultural contingency plans have been developed besides assessing the risk and vulnerability of Indian agriculture to climate change. Under technology demonstrations, location specific technologies have been demonstrated in 151 climatically vulnerable districts. In the past nine years, 16,958 training programs have been conducted throughout the country under NICRA project to educate stakeholders on various aspects of climate change and resilient technologies, covering 5,14,816 stakeholders so as to enable wider adoption of climate resilient technologies and increase in yields.

- **National Food Security Mission(NFSM):** The **National Food Security Mission** has been launched by the government of India. Through this mission, various steps will be taken in order to improve the annual production of rice, wheat, and pulses. The annual production of rice will be increased by 10 million tonnes, wheat will be increased by 8 million tonnes and pulses will be increased by 2 million tonnes. The government launched this mission in October 2007. The government is going to achieve the objective of this scheme through area expansion and productivity enhancement in a sustainable manner in the identified districts of the country. Other than that measures like restoring soil fertility, improving productivity at the individual farm, enhancing the farm-level economy, etc will also be taken in order to improve production. Special focus will be on the low-productivity areas and high-potential districts.

- **In-situ Crop Residue Management**: A special scheme to support the efforts of the governments of Punjab, Haryana and Uttar Pradesh and NCT of Delhi to address air pollution and to subsidize machinery required for in-situ management of crop residue for the period 2018-19 to 2019-20 has been approved.The scheme is a Central Sector Scheme (100% Central share) being implemented by the Ministry of Agriculture & Farmers Welfare. The total outgo from the Central funds would be Rs. 1151.80 crore (Rs. 591.65 crore in 2018-19 and Rs. 560.15 crore in 2019-20).Under the project "Awareness for In-situ Crop Residue Management", 60 KVKs of Punjab, Haryana, Uttar Pradesh and Delhi are working with focus on promotion of agricultural machineries, demonstrations, training and other Information, Education and Communication (IEC) activities for in-situ management of crop residues. Across the three states under IEC activities, selected villages were targeted to sensitize people about the harmful effect of residue burning, benefits of in-situ residue management and government schemes of availability of subsidized machines.

- **Jal Shakti Abhiyan:** Jal Shakti Abhiyan -I (JSA-I) was launched in 2019 in 1592 blocks in 256 water stressed districts of the country to promote water conservation and water resource management by focusing on accelerated implementation of five targeted interventions viz. water conservation and rainwater harvesting, renovation of traditional and other water bodies, reuse of water and recharging of structures, watershed development and intensive afforestation. Besides, the special interventions included development of Block Water Conservation Plans and District Water Conservation Plans, Krishi Vigyan Kendra Melas, Urban Wastewater Reuse and 3D contour mapping of all villages. In all, 466 farmers fair have been organized by 243 KVKs under Jal Shakti Abhiyan with participation of 257408 farmers and school children in first phase up to 30.09.2019. Likewise, 91 farmers have been organized by 91 KVKs under Jal Shakti Abhiyan with participation of 56746 farmers and school children on 02.10.2019.

- **Nutri-Sensitive Agricultural Resources and Innovation (NARI):** ICAR has started **NARI programme** for promoting family farming linking agriculture to nutrition, nutri-smart villages for enhancing nutritional security and location specific nutrition garden models are being developed and promoted by KVKs to ensure access to locally available, healthy and diversified diet with adequate macro and micronutrients. Its objective is to promote family farming linking agriculture to nutrition, nutri-smart villages for enhancing nutritional security.

- **Value Addition and Technology Incubation Center in Agriculture** (**VATICA**): ICAR is also implementing project **VATICA** for Sustainable Approaches for Nutritional Security' and 'Nutritional Security and Health Promotion of Farm Families'

Under the project, nutri-gardens were established in 100 district of India by KVKs in schools and villages in which nutrition education awareness programmes were conducted.

- **Knowledge Systems and Homestead Agriculture Management in Tribal Areas (KSHAMTA):** ICAR has initiated a programme keeping in view on the importance of the tribal agriculture, called Knowledge system for Homestead Agricultural Management in Tribal Areas. The predominant attitude of agriculture officials towards tribal communities is to try to convince them to give up their backward agriculture and adopt more modern and high productivity agricultural practices. Often no attempt is made to try to understand the traditional agricultural systems and practices of tribal communities. It is taken for granted that this is bound to be backward and hence in need of replacement by modern solutions available with officials. These indigenous or traditional knowledge systems of the tribal communities are to be harnessed to extract maximum benefits in terms of agriculture production. KVKs working across the country can take the leading role in mainstreaming tribal agricultural system due to their deep connections at grass-root level. Presently about 125 KVKs are working in tribal districts of the country facilitating technology support and related inputs to the tribal farmers locate in remote places.

- **District Agricultural Meteorological Units (DAMU):** DAMU utilizes the relevant output products including weather data from conventional/ automatic weather station (AWS) provided by IMD and ICAR to generate specific advisories for agricultural management for the respective districts of Agro-climatic zones identified under the area of its jurisdiction and disseminate the same to the farming community. Under the Gramin Krishi Mausam Sewa, the IMD proposes to establish District Agro-Met Units (DAMU) in 530 districts, in addition to already operating 130 AMFUs, in order to meet the said expansion. Among other responsibilities, DAMU will receive weather forecast from IMD to prepare and disseminate sub-district level agro-met advisory bulletins.

References

1. **Adhiguru, P; Birthal, PS; and Ganesh Kumar, B. (2009)**. Strengthening pluralistic agricultural information delivery systems in India. Agricultural Economics Research Review 22:71–79.
   DAC,(2010). National Seminar on Agriculture Extension Proceedings, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India, New Delhi, February 27-28, 2009.
2. **DARE and ICAR, (2006).** Report of the Committee on Independent Evaluation and Impact Assessment of Krishi Vigyan Kendras in India, DARE and ICAR, New Delhi.
3. Gupta, JJ; Singh, KM; Bhatt, B.P and Dey, A. (2014): A Diagnostic Study on Livestock Production System in Eastern Region of India. Indian Journal of Animal Sciences. 84 (2): 198-203. Available at https://mpra.ub.uni-muenchen.de/id/eprint/59517
4. **Kumar, Abhay and Singh, KM (2012)** Role of ICTs in Rural Development with Reference to Changing Climatic Conditions. In: ICT for Agricultural Development under Changing Climate, Ed: KM Singh and MS Meena, Narendra Publishing House, New Delhi. E-copy available at: http://dx.doi.org/10.2139/ssrn.2027782.
5. **Meena, M; Singh, KM and Swanson, BE, (2013).** Pluralistic Agricultural Extension System in India: Innovations and Constraints (July 15, 2013). E-paper available at:http://dx.doi.org/10.2139/ssrn.2293788.
6. **Pal, S. and A. Singh. (1997).** Agricultural research and extension in India: Institutional structure and investments, Policy Paper 7, New Delhi: National Centre for Agricultural Economics and Policy Research.
7. **Pal, Sah and Derek Byerlee (2006).** The funding and organization of agricultural research in India:Evolution and emerging policy issues. In: PG Pardey, JM Alston and RR Piggott (Eds), *Agricultural R&D Policy in the Developing World*. IFPRI, Washington, DC.

8. **Prasad, C, and Bhatia, P.C. (2010).** International horticulture development scenario: implications for India, pp: 1780-1788. Proceedings of International Conference on Horticulture for Livelihood Security and Economic Growth organized at Bangalore, India.
9. **Simpson, Brent; Singh, KM; Singh, A and Sinha, M. (2013).** Strengthening the Pluralistic Agricultural Extension System in Bihar State-India. *Modernizing Extension and Advisory Services (MEAS) Project*. E-copy available at: http://dx.doi.org/10.13140/2.1.2658.2725
10. **Singh, J.P., Swanson, B.E and Singh K.M., (2005).** Developing a Decentralized, Market-Driven Extension System in India*: The ATMA Model*. Good Practice Paper prepared for the World Bank, Washington DC.
11. **Singh, K.M., B.E. Swanson and J.P. Singh. (2005)**. Development of Supply Chains for Medicinal Plants: A Case Study Involving the Production of Vinca Rosa by Small Farmers in the Patna District of Bihar India, paper presented at the Workshop on Building New Partnerships in the Global Food Chain, Chicago, June 29–30, 2005.
12. **Singh, J.P, Swanson, B.E and Singh, K.M (2006).** "Developing a decentralized, market-driven extension system in India: The ATMA Model." In Changing Roles of Agricultural Extension in Asian Nations by A W Van den Ban and R.K. Samanta, New Delhi, B. R. Pub. Corporation.
13. **Singh, KM.; Meena, MS; Swanson, BE; Reddy, MN and Bahal, R. (2014).** In-Depth Study of the Pluralistic Agricultural Extension System in India. E-copy available at: http://dx.doi.org/10.13140/2.1.2933.7607.
14. **Singh, KM., and Swanson, BE. (2006)**. Developing a market-driven extension system in India. Annual Conference Proceedings of the Association for International Agricultural and Extension Education 22: 627–637.
15. **Singh, KM; Swanson, BE; Jha, A and Meena, MS, (2012)**. Extension Reforms and Innovations in Technology Dissemination – The ATMA Model in India. E-paper available at: http://dx.doi.org/10.2139/ssrn.2168642.
16. **Singh, KM; Meena, MS; Singh, RKP and Kumar, Abhay, (2011)** Dimensions of Poverty in Bihar. E-paper available at: http://dx.doi.org/10.2139/ssrn.2017506.
17. **Singh, KM, (2009).** Impact Assessment of Agricultural Extension Reforms in Bihar. Indian Research Journal of Extension Education, 9(2): 110-114, E-paper available at: http://dx.doi.org/10.2139/ssrn.1803157.
18. **Gupta, JJ; Singh, KM; Bhatt, B.P and Dey, A. (2014):** A Diagnostic Study on Livestock Production System in Eastern Region of India. *Indian Journal of Animal Sciences*. 84 (2): 198-203. E-paper available at https://mpra.ub.uni-muenchen.de/id/eprint/59517.

List of Participants of Winter School entitled "Recent Approaches for Doubling Farmers Income in Sugarcane Based Cropping System" held during December 08-28, 2022 at ICAR-IISR, Lucknow

1. **Dr. S.S. Nooli**
Scientist (Agronomy)
ARS, Sankeshwar
UAS, Dharwad, Karnataka
Mob: 9448752119; 7975472884
E-mail: ssnooli@gmail.com

2. **Dr. Shiddalingappa V. Hugar**
Assistant Professor (Agril. Entomology)
ARS, Sankeshwar
UAS, Dharwad, Karnataka
Mob: 7337781467
E-mail: hugars2000@gmail.com

3. **Dr. Manjunath B Chouraddi**
Assistant Professor (Agril. Entomology)
S. Nijalingappa Sugar Institute
Belagavi, Karnataka
Mob: 9035904805
E-mail: manjuento@gmail.com

4. **Dr Sanjay Kr. Yadav**
Senior Scientist (Agronomy)
Division of Crop Production
ICAR-IISR, Lucknow
Mob: 9402134428
E-mail: sanjaybhu05@rediffmail.com

5. **Dr. Pramod Kumar Mishra**
Assistant Professor
Agricultural Engineering (FMPE)
ANDUAT, Kumarganj
Ayodhya (UP)
Mob: 07837243594; 7814204593
E-mail: pramod.btag@gmail.com

6. **Mr. Lal Pankaj Kumar Singh**
Subject Matter Specialist
KVK, Mau, ANDUAT
Kumarganj, Ayodhya (UP)
Mob: 6388123584
E-mail: lpsinghfm@gmail.com

7. **Dr. Md. Shamim**
Assistant Professor-cum-Junior Scientist
MBGE, Dr Kalam Agricultural College
Kishanganj (BAU, Sabour), Bihar
Mob: 7782059489
E-mail: shamimnduat@gmail.com

8. **Dr. Kotgire Ganesh Sopanrao**
Scientist (Plant Pathology)
Vasantdada Sugar Institute
Manjari (B.K.), Pune (M.S.)
Mob: 9960833301
E-mail: ganeshkotgire@gmail.com

9. **Ms V A Blessy**
Scientist (Land and Water Management Engineering)
Division of Agricultural Engineering
ICAR-IISR, Lucknow
Mob: 9953766110
E-mail: blessy.va@icar.gov.in

10. **Dr Deepak Pandey**
Assistant Professor
Deptt. of Agronomy
C.B.G. Ag. P.G. College
BKT, Lucknow (UP)
Mob: 9005766426
E-mail: deepakpandey.agri@gmail.com

11. **Dr Shailendra Kumar Dwivedi**
Assistant Professor
KNK College of Horticulture
RVSKVV Campus, Mandaur (MP)
Mob: 8959025045; 8959025045
E-mail: shailendra.pht@gmail.com

12. **Dr. Niranjan Lal**
Senior Scientist
Krishi Vigyan Kendra-II
Lakhimpur Kheri (UP)
Mob: 9760476629; 8787684165
E-mail: lal_niranjan@yahoo.co.in

13. **Dr Vivek Kumar Pandey**
SMS, Plant Protection,
Krishi Vigyan Kendra-II
Lakhimpur Kheri (UP)
Mob: 9434268051
E-mail: vpandey84@gmail.com

14. **Mr. Arya Desh Deepak Misra**
SMS, Horticulture
Krishi Vigyan Kendra-II
Lakhimpur Kheri (UP)
Mob: 9401765014; 7035179279
E-mail: arya.misra@icar.gov.in

15. Dr. Vineet Kumar Sharma
Assistant Professor, Agricultural Engineering
College of Agriculture, NAU
Waghai, Dang (Gujarat)
Mob: 9512686833; 8057391339
E-mail: sharmavineet9@nau.in

16. Dr Jay Prakash Singh
Assistant Professor
Deptt. of Plant Pathology
S.M.M. Town P.G. College
Ballia (UP)
Mob: 9415471955; 9170668778
E-mail: jayap999@gmail.com

17. Dr Vijaya Nand Pathak
Associate Professor
Deptt. of Genetics & Plant Breeding
S.M.M. Town P.G. College
Ballia (UP)
Mob: 9450679914
E-mail: vijayanand.pathak76@gmail.com

18. Dr. Jay Kumar Yadav
SMS (Plant Protection)
ICAR-Krishi Vigyan Kendra
Dhaura, Unnao (UP)
Mob: 9161769487; 8052257451
E-mail: jaykumaryadav4556@gmail.com

19. Dr. Jai Pal
Scientific Officer (Agriculture Education)
UP Council of Agricultural Research
Lucknow
Mob: 09839978413
E-mail: drjaipalupcar@gmail.com

20. Dr. Dheeraj Kumar Tiwari
SMS (Agronomy)
ICAR-Krishi Vigyan Kendra
Dhaura, Unnao (UP)
Mob: 9795159279; 7985401481
E-mail: dk9hau@gmail.com

21. Dr Deepti Srivastava
Assistant Professor
IIAST, Integral University
Lucknow (UP)
Mob: 7355631492; 8765091899
E-mail: deeptinduat@gmail.com

22. Dr. Akhilesh Kumar Dubey
Senior Scientist
KVK, ICAR-IISR, Lucknow (UP)
Mob: 9454332536; 9984457457
E-mail: akdubeykvkiisr@gmail.com

23. Dr. Gaya Karan Singh
Chief Technical Officer
Division of Crop Production
ICAR-IISR, Lucknow (UP)
Mob: 9450017548
E-mail: gayakaraniisr@gmail.com

24. Mr. Adil Zubair
Chief Technical Officer
ICAR-IISR, Lucknow (UP)
Mob: 7007764436
E-mail: adizubi64@gmail.com

25. Dr Ram Kishor
Assistant Chief Technical Officer
Division of Crop Improvement
ICAR-IISR, Lucknow (UP)
Mob: 9450652915
E-mail: rkishor91@yahoo.com

List of Speakers of Winter School entitled "Recent Approaches for Doubling Farmers Income in Sugarcane Based Cropping System" held during December 08-28, 2022 at ICAR-IISR, Lucknow

1. **Dr. S. Soloman**
   Ex-Director
   ICAR-IISR, Lucknow &
   Ex-VC CSAU&T, Kanpur
   Mob: 9839040995
   Email: drsolomonsushil1952@gmail.com

2. **Dr. R. K. Singh**
   Assistant Director General (CC)
   ICAR, New Delhi
   Mob: 9450930028
   Email: adgcc.icar@nic.in

3. **Dr. (Mrs.) Seema Jaggi**
   Assistant Director General (HRD)
   ICAR, New Delhi
   Mob: 9873169418
   Email: Seema.Jaggi@icar.gov.in

4. **Dr R. Viswanathan**
   Director
   ICAR-IISR, Lucknow
   Mob: 9442543875
   Email: rasaviswanathan@yahoo.co.in

5. **Dr. A. D. Pathak**
   I/c Project Coordinator (S)
   ICAR-IISR, Lucknow
   Mob: 9450373565
   Email: Ashwini.Pathak@icar.gov.in

6. **Dr. V.K. Shukla**
   Additional Cane Commissioner
   Govt. of Uttar Pradesh, Lucknow
   Mob:6389025301
   Email: vkshukla28@yahoo.in

7. **Dr. J. Singh**,
   Principal Scientist & Head
   Division of Crop Improvement
   ICAR-IISR, Lucknow
   Mob: 9455038993
   Email: Jyotsnendra.Singh@icar.gov.in

8. **Dr. S. K. Shukla**,
   Principal Scientist & Head
   Division of Crop Production
   ICAR-IISR, Lucknow &
   Course Director of Winter School
   Mob: 9451188723
   Email: Sudhir.Shukla@icar.gov.in

9. **Dr. (Mrs.) Sharmila Roy**
   Principal Scientist & Head
   Division of Crop Protection
   ICAR-IISR, Lucknow
   Mob: 7742049376
   Email: Sharmila.Roy@icar.gov.in

10. **Dr A.K. Singh**,
    Principal Scientist & Head
    Division of Agril. Engineering
    ICAR-IISR, Lucknow
    Mob: 9415780095
    Email: Akhilesh.Singh2@icar.gov.in

11. **Dr. (Mrs.) Pushpa Singh**
    Principal Scientist & Head
    Division of Crop Physiology and Biochemistry
    ICAR-IISR, Lucknow
    Mob: 9415786036
    Email: Pushpa.Singh@icar.gov.in

12. **Dr. L. S. Gangwar**
    Principal Scientist & I/c PME
    ICAR-IISR, Lucknow
    Mob: 9411918705
    Email: Lal.Gangwar@icar.gov.in

13. **Dr. Rajesh Kumar**
    Principal Scientist &
    I/c AKMU Unit
    ICAR-IISR, Lucknow
    Mob: 9450465532
    Email: Rajesh.Kumar12@icar.gov.in

14. **Dr R.B. Doule**
    Chief Cane Adviser
    National Federation of Cooperative Sugar Factories Ltd.
    Angust Kranti Marg, New Delhi
    Mob: 9881853779
    Email: drrbdoule@gmail.com

15. **Dr. Sanjeev Kumar**
    Principal Scientist
    Biotechnology Division
    ICAR-IISR, Lucknow
    Mob: 9415224064
    Email: Sanjeev.Kumar7@icar.gov.in

16. **Dr. Arun Baitha**
Principal Scientist
Crop Protection Division
ICAR-IISR, Lucknow
Mob: 9415755261
Email: Arun.Baitha@icar.gov.in

17. **Dr. K.K. Singh**
Principal Scientist
Division Crop Production
ICAR-IISR, Lucknow
Mob: 9336101531
Email: Kranti.Singh@icar.gov.in

18. **Dr. V.K. Singh**
Principal Scientist
Division Crop Production
ICAR-IISR, Lucknow
Mob: 7379224565
Email: Vinay.Singh2@icar.gov.in

19. **Dr. A. P. Dwivedi**
Principal Scientist
Division Crop Production
ICAR-IISR, Lucknow
Mob: 9425153175
Email: Aditya.Dwivedi@icar.gov.in

20. **Dr. V.P. Jaiswal**,
Senior Scientist & I/c SWAPM Lab
ICAR-IISR, Lucknow &
Course Coordinator of Winter School
Mob: 9415047895
Email: Vijai.Jaiswal@icar.gov.in

21. **Dr. S. R. Singh**
Principal Scientist
Division Crop Production
ICAR-IISR, Lucknow
Mob: 7839252893
Email: Shiv.Singh4@icar.gov.in

22. **Dr Sanjeev Kumar**
Principal Scientist
Division of Crop Improvement
ICAR-IISR, Lucknow
Mob: 9450356968
Email: Sanjeev.Kumar6@icar.gov.in

23. **Dr. C Gupta**
Principal Scientist
Division Crop Production
ICAR-IISR, Lucknow
Mob: 9451568465
Email: chandra.gupta1@icar.gov.in

24. **Dr. A. K. Singh**
Director
Sugarcane Research Institute
Pusa, Bihar
Mob: 9415920101
Email: director.sri@rpcau.ac.in

25. **Dr. T. K. Srivastava**
Principal Scientist
Division Crop Production
ICAR-IISR, Lucknow
Mob: 9473607040
Email: tapendra.srivastava@icar.gov.in

26. **Dr Sushil Kr. Shukla**
Principal Scientist
ICAR-CISH, Lucknow
Mob: 7054419717
Email: skshuklacish@gmail.com

27. **Dr. S. P. Singh**
Principal Scientist
Division Crop Physiology and Biochemistry
ICAR-IISR, Lucknow
Mob: 8763671322
Email: surendrap.singh@icar.gov.in

28. **Dr. (Mrs.) Radha Jain**
Principal Scientist
Division Crop Physiology and Biochemistry
ICAR-IISR, Lucknow
Mob: 9451904106
Email: radha.jain@icar.gov.in

29. **Dr. A.K. Sharma**
Principal Scientist
ICAR-IISR, Lucknow
Mob: 8009010547
Email: ashwani.sharma2@icar.gov.in

30. **Dr. Sukhbir Singh**
Principal Scientist
Agricultural Engineering Division
ICAR-IISR, Lucknow
Mob: 7839455399
Email: sukhbir.singh@icar.gov.in

31. **Dr Ram Ratan Verma**
Senior Scientist
Crop Production Division
ICAR-IISR, Lucknow
Mob: 9956423695
Email: Ram.Verma3@icar.gov.in

32. **Dr. A. K. Sah**
Principal Scientist
I/c Extension Unit
ICAR-IISR, Lucknow
Mob: 9452063646
Email: Ajay.Sah@icar.gov.in

33. **Dr S.N. Singh**
Ex-Principal Scientist
Division of Crop Production
ICAR-IISR, Lucknow
Mob: 9415152102
Email: snsingh117@gmail.com

34. **Dr. J S Mishra**
Director
Indian Institute of Weed Science
Jabalpur, M.P.
Mob: 9494240904
Email: jsmishra31@gmail.com

35. **Dr. Sunil Kumar**
Head
Division of Crop Production
ICAR-IGFRI, Jhansi
Mob: 9415719637
Email: sktiwari98@gmail.com

36. **Dr. A.K. Tripathi**
Associate Professor
Banda University of Agriculture & Technology, Banda (UP)
Mob: 09450937647
Email: aktripathiak@gmail.com

37. **Dr. N.K. Bajpai**
Director Extension
Banda University of Agriculture & Technology, Banda (UP)
Mob: 8003618880
Email: nkbajpai69@gmail.com

38. **Dr. Jagannath Pathak**
Professor & Head
Department of Soil Science & Agri. Chem., CoA
Banda University of Agriculture & Technology, Banda (UP)
Mob: 9926733701
Email: jagannathpathak@yahoo.in

39. **Dr V.P. Singh**
Principal Scientist
Division Crop Production
ICAR-IISR, Lucknow
Mob: 9415195535
Email: Ved.Singh2@icar.gov.in

40. **Dr. A.K. Mall**
Principal Scientist
Division Crop Improvement
ICAR-IISR, Lucknow
Mob: 8009052220
Email: Ashutosh.Mall@icar.gov.in

41. **Dr. Dileep Kumar**
Principal Scientist
Agricultural Engineering Division
ICAR-IISR, Lucknow
Mob: 9312944581
Email: Dileep.Kumar2@icar.gov.in

42. **Dr. Sangeeta Srivastava**
Principal Scientist
Division Crop Improvement
ICAR-IISR, Lucknow
Mob: 9415001735
Email: Sangeeta.Srivastava@icar.gov.in

43. **Dr. Dinesh Singh**
Principal Scientist
Crop Protection Division
ICAR-IISR, Lucknow
Mob: 9452655352
Email: Dinesh.Singh3@icar.gov.in

44. **Dr. M. Swapna**
Principal Scientist
Division of Crop Improvement
ICAR-IISR, Lucknow
Mob: 9453195305
Email: Swapna.M@icar.gov.in

45. **Dr. M. R. Singh**
Principal Scientist
Crop Protection Division
ICAR-IISR, Lucknow
Mob: 9450652760
Email: Maharam.Singh@icar.gov.in

46. **Dr. Barsati Lal**
Principal Scientist
ICAR-IISR, Lucknow
Mob: 9918362934
Email: Barsati.Lal@icar.gov.in

47. **Dr. M. K. Tripathi**
Principal Scientist
Crop Production Division
ICAR-IISR, Lucknow
Mob: 9457243357
Email: Manoj.Tripathi2@icar.gov.in

48. **Dr A K Dubey**
Head
Krashi Vigyan Kendra
ICAR-IISR, Lucknow
Mob: 9454332536
Email: akdubeykvk@gmail.com

49. **Dr. R. D. Singh**
Principal Scientist
Division of Agril. Engineering
ICAR-IISR, Lucknow
Mob: 9450369614
Email: Ram.Singh11@icar.gov.in

50. **Dr. S. K. Yadav**
Senior Scientist
Division of Crop Production
ICAR-IISR, Lucknow
Mob: 9402134428
Email: Sanjay.Yadav@icar.gov.in

51. **Dr. Lalan Sharma**
Senior Scientist
ICAR-IISR, Lucknow &
Course Coordinator of Winter School
Mob: 8887960911
Email: Lalan.Sharma@icar.gov.in

52. **Dr. Rajesh U Modi**
Scientist
Division of Agril. Engineering
ICAR-IISR, Lucknow
Mob: 9623259151
Email: Rajesh.Modi@icar.gov.in

53. **Dr. S.I. Anwar**
Principal Scientist
Div. of Agril. Engineering
ICAR-IISR, Lucknow
Mob: 9450396065
Email: Saiyed.Anwar@icar.gov.in

Glimpses of Winter School Lectures and Field Visits


गन्ना किस्म प्रदर्शन
रस में शर्करा


ICAR-IISR
LUCKNOW













Advances in Sugarcane Planting Methods for Resource use Efficiency and Enhancing Cane Yield
Dr. A. K. Singh
Director


कृषि विज्ञान केन्द्र


कृषि विज्ञान केन्द्र
अम्बरपुर सीतापुर


Winter School
Recent Approaches for Doubling Farmers Income in Sugarcane Based Cropping System
December 08-28, 2022
ICAR
Organized by
ICAR - Indian Institute of Sugarcane Research, Lucknow
Sponsored by
Indian Council of Agricultural Research, New Delhi

भाकृअनुप
ICAR

ICAR-INDIAN INSTITUTE OF SUGARCANE RESEARCH
Post-Dilkusha, Raebareli Road, Lucknow-226002 (U.P.)
https://iisr.icar.gov.in