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Recent advances for higher sugarcane productivity in India

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ABSTRACT

Sugarcane is a crop of global importance and is used for manufacturing sugar, jaggery, biofuel, and several other co–products. It requires a significant amount of inputs to achieve the maximum production level. Fulfilment of the requirements of ever–increasing population under limited resources has become a major challenge in changing climatic scenarios. Advancement in sugarcane–production techniques is related to ensure the sustainability of the ecosystem. To produce more from the same input has become the major thrust of researchers. We can achieve this through integration of various technologies available for different situations. In this paper, important recent advancements in sugarcane–production technologies have been discussed. Intercropping of potato (*Solanum tuberosum* L.), Indian mustard [*Brassica juncea* (L.) Czernj.], French bean (*Phaseolus radiates* L.), garlic (*Allium sativum L.*), maize (*Zea mays* L.) etc. with autumn–planted sugarcane, is a viable option to increase land–use efficiency besides improving farmers' profitability and sustainability of the production system. Integrated weed–management in ratoon through trash mulching, one hoeing and a single application of atrazine @ 2 kg ai/ha during ratoon initiation minimizes crop–weed competition during the tillering phase. Adoption of skip furrow/ alternate furrow techniques affected water saving up to 35–40% without yield reduction. Planting of sugarcane and component crops in the furrow–irrigated raised–bed system (FIRB.) improves the sugarcane yield besides improving water–use efficiency (WUE) and nutrient–use efficiency (NUE). Organic bio–fertilizers reduce the number of chemical fertilizers and improve the NUE and crop response to nutrients. Besides, increased water–holding capacity and nutrients availability provide sustainability to the sugarcane–based system. Owing to the adoption of some of these technologies, sugarcane productivity at the national level reached > 80 tonnes/ha. However, there is a huge scope of increasing sugarcane productivity, keeping the achievable potential in view. Thus, sugarcane yield to the level of 100 tonnes/ha by 2030 at the national level could be achieved by adopting available technologies.

Keywords **:** Crop diversification: Crop residue recycling; Mechanization; Soil microbes; Water use efficiency; Weed management

INTRODUCTION

Sugarcane is an important cash crop popularly cultivated for producing sweeteners (sugar, jaggery), as well as some other bioproducts, including bioenergy (heat, electricity, and ethanol) and other byproducts (pressmud, bagasse ash) (Hiloidhari, 2021). It is a major C_4 crop and perennial bunchgrass, predominantly cultivated in tropical to subtropical regions. Sugarcane has significant social, economic and environmental importance in many developing countries where nearly 75% of global production is concentrated in Brazil, India, China, Thailand and Pakistan (FAO, 2019). In India, sugarcane is one of the main crops of foreign exchange (Venkatesh and Venkateswarlu, 2017), which occupied 5.114 million ha of land. Brazil, being biggest producer of sugarcane, grows over 40% of the world crop (Solomon and Yang–Rui Li, 2016).

It is a high–biomass energy crop, with the sugar stored in its stalk and the lignocellulosic residue remaining after the extraction of sugar used to produce biofuel or other bio–products (Awe *et al*., 2020). Biofuels are increasingly seen as an alternative to petroleum derivates to reduce carbon emissions to the atmosphere and recent escalating petroleum prices. Recently, the Government of India has formulated a policy to encourage sugar mills to produce ethanol directly from sugarcane juice which could avoid surplus sugar and improve sugar mills viability besides fulfiling multiple needs. Bagasse, produced during the sugarcane–crushing process, generates heat and electricity through cogeneration (Hiloidhari, 2021). The current demand for sugarcane and its many valuable byproducts remains projected to rise globally (Figueroa–Rodríguez *et al*., 2019).

The sugarcane plant growth developmental phases are affected by environmental temperature and radiation

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(Verma *et al*., 2020). The CO_2 enrichment in ambient air was beneficial for biomass accumulation in C_4 crops like sugarcane (Tripathi *et al*., 2019). The optimum temperature for growth and higher sugar yield is 25°C–30°C and suboptimal temperature (below 15°C–12°C) diminishes the growth rate, sugar accumulation and biomass production of sugarcane (Li and Yang, 2015). Sugarcane grand growth (elongation phase) coincides with high temperature along with high humidity. In subtropical India, this situation occurs in the rainy season (July to September). During this period, larger amounts of nutrients are released (mineralized) from organic sources. The sugarcane–based system improved the soil in upper and lower strata because of the deep root–system than the rice (*Oryza sativa* L.)–wheat (*Triticum aestivum* L.) system. Higher total biomass is produced in the sugarcane–based system than the rice–wheat system, ultimately improves the soil C stock (Shukla *et al*., 2017b). Growing of Indian mustard, French bean, potato (*Solanum luberosum* L.), chickpea (*Cicer arietinum* L.), lentil (*Lens culinaris* Medik), maize (for green cobs), vegetable pea (*Pisum sativum* L.), coriander (*Coriandrum sativum* L.), garlic with autumn–planted sugarcane and mung bean [*Vigna radiate* (L.) R. Wilczek], urd bean [*Vigna mungo* (L.) Hipper], cowpea [*Vigna unguiculata* (L.) Walp.] with spring–planted sugarcane in subtropical part of India has been found remunerative (Shukla *et al*., 2017). Wheat (*Triticum aestivum* L.) has been extensively tested as an intercrop in autumn–planted sugarcane and reported to be advantageous compared to sole cropping of cane. The short–duration legumes, oilseeds and vegetables were the most suitable intercrops in autumn–planted sugarcane. Similarly, in tropical India, soybean [*Glycine max* (L.) Merr.], sun hemp (*Crotalaria juncea* L.), greengram or mung bean and cowpea can be profitably intercropped with sugarcane (Geetha *et al.,* 2019) compared to sole cane.

Sugarcane is a resource–intensive crop, as it has grown over the year. Fertilizer is the most under–utilized, whereas setts and irrigation are the most over–utilized resources in Indian sugarcane–production. Establishing rural–based agricultural machinery custom–hiring centres, proper irrigation structures, selection of suitable varieties, single–bud chips and cane node as planting material, planting techniques, efficient nutrient–management strategies, integrated weed–management, and crop diversification involving high–value crops would certainly increase the economic viability of sugarcane–production system. Nowadays, higher seed–cane requirement, gradual decline in water availability increasing for irrigation, declining soil organic carbon contents and multi–nutrients deficiencies, hardpan formation in plough layer, higher weed growth in ratoon and various biotic and abiotic stress situations are some of the key issues faced by sugarcane growers. In this direction, cane node and bud–chip technology for reducing seed–cane requirement, irrigation through drip method to economize irrigation water use, soil organic–carbon sequestration through trash mulching and intercropped grain legumes, integrated weed–management approach, adopting skip–furrow technique under moisture–deficit condition and management of iron chlorosis in ratoon cane, besides the selection of recommended varieties, have been some of the management issues discussed to address these bottlenecks and improve sugarcane productivity as well. Reduction in cost of production and improving crop yield through managing various resources will certainly help in doubling farmers' income in times to come. The recent advancements for profitable sugarcane–production are being discussed as here.

VARIETIES

Selection of suitable varieties as per the sugarcane–growing zones of India is most important to derive the benefit of production. The newly developed high–sugar and biotic and abiotic stress–tolerant varieties are suited to the cane–growers. Few important sugarcane varieties in different maturity groups have been notified and released by the Central Varietal Release Committee (CVRC). The salient features of released sugarcane varieties are given in Table 1. Famous varieties in different states of the country are included in Table 2.

SEED AND PLANTING

Since good planting material (seed) contributes higher yields, the supply of healthy seed–cane is the main prerequisite for improving the productivity of the sugarcane crop. Sugarcane–sett planting (2–budded/ 3–budded) is most prevalent in India. The introduction of new seed–multiplication methods like bud chip and cane node (Fig. 1) can reduce the seed bulkiness and provide ease of transportation.

Bud chip method

Bud–chip method facilitates saving of seed material, availability of leftover cane and ease of transportation (Jain *et al.,* 2014). Bud chips are scooped out from harvested healthy sugarcane stalks soaked with plant–growth regulators. After fungicide treatment, chips are planted in cups/ trays filled with a mixture of soil, sand and organic matter in the ratio of 1: 1: 1. The seedlings prepared transplanted in fields after 6–7 weeks. This method provides a higher seed multiplication ratio (1 : 60) and a fast multiplication rate of newly released varieties. It can attract private entrepreneurs in taking up the business and encouraging contract farming in sugarcane.

Table 1. Recently released improved sugarcane varieties for different growing zones

Sugarcane–producing zone (s) for which recommended	Name of variety	Year of release and notification	Key characteristics (duration, yield level, quality characteristics etc.)		
			Maturity	Cane yield (t/ha)	Sucrose (%)
Peninsular Zone (Gujarat, Maharashtra, Karnataka, Kerala, Interior of Tamil Nadu and Andhra Pradesh, Madhya Pradesh and Chhattisgarh)	'Co 0403'	2012	Early	101.60	18.16
	'Co 06027'	2013	Mid–late	110.56	19.18
	'CoSnk 05103'	2014	Early	105.97	17.21
	'CoSnk 05104'	2014	Mid–late	106.86	17.52
	'Co 09004'	2017	Early	109.85	18.94
East Coast Zone (Coastal Tamil Nadu and Andhra Pradesh and Odisha)	'Co 06030'	2013	Mid–late	103.33	16.60
North West (Punjab, Haryana, Rajasthan, Central and Western Uttar Pradesh and Uttarakhand) and North Central (Eastern Uttar Pradesh, Bihar, West Bengal and Jharkhand) Zone	'CoH 128'	2012	Mid–late	76.23	17.70
	'Co 0237'	2012	Early	71.33	18.78
	'Co 05011'	2012	Mid–late	81.87	18.00
	'CoPK 05191'	2013	Early	81.12	17.06
	'Co 05009'	2013	Early	75.89	17.44
	'Co 09022'	2017	Mid–late	83.59	17.49
North East Zone (Asom)	'CoSe 01421'	2013	Early	65.87	17.36
	'CoP 06436' (CoP 2061)	2015	Mid–late	74.25	17.35

Assam is now Asom
Source: Shukla *et al.* (2018c)

Table 2. Prominent sugarcane varieties adopted in various states of the country

State	Prominent varieties
Punjab	'Co 0238'; 'CoJ 85'; 'CoJ 88'; 'Co 118' and 'CoPb 91'
Haryana	'Co0238'; 'Co89003'; 'CoS 8436'; 'CoH 119' and 'CoH 128'
Uttar Pradesh	'Co 0238'; 'CoS 767'; 'CoS 8436'; 'CoJ 64' and 'Co. 88216'
Rajasthan	'CoS767'; 'CoS 8436'; 'CoJ 64'; 'Co 527' and 'CoH 119'
Bihar	'BO 91'; 'BO 110'; 'CoP 9301'; 'CoP 2061' and 'BO 153'
Assam	'Lohit'; 'Dhansiri'; 'Co997'; 'Kalong'
Tamil Nadu	'Co 86032'; 'CoC (Sc) 24'; 'CoV 09356'; 'TNAU Si (Sc) 7' and 'CoSi 6'
Karnataka	'Co 86032'; 'CoM 0265'; 'CoSnk 03632'; 'SNK 07680' and 'CoC 671'
Maharashtra	'Co 86032'; 'CoM 0265'; 'Co 92005'; 'CoC 671' and 'Co 94012'
Gujarat	'Co 86032'; 'CoM 0265'; 'CoN 05071'('GS–5'); 'Co 86002' and 'Co 97009'
Odisha	'Co 6907'; 'Co 86249'; 'Sabita' ('CoOr03151'); 'Co 87044' and 'Raghunath' ('CoOr04152')
Andhra Pradesh	'Viswamithra'; 'Bharani'; 'Krishna'; '93V297' and 'Co86032'
Tamil Nadu	'Co 86032'; 'CoC (Sc) 24', 'TNAU Si (Sc'); 'CoG 93076' and 'Co 85019'

Source: Shukla *et al.* (2018c)

Cane–node technology

In this method, select a cane node having a viable bud and keep it in the slurry of decomposed farmyard manure with 60% moisture for 4–5 days in a container (Singh *et al.,* 2020). In this period, buds get sprouted. Sprouted bud transported into the field and planted in furrows. This technology facilitates the early sprouting of buds and easy transport of seed material. With this method, 1–2 tonnes of seed is required for planting of 1–ha area.

Planting methods

Wider row spacing of 120 cm/ 30 : 150 cm is recommended for the subtropical zone, to facilitate mechanized harvesting and maintain a higher cane yield level. However, sugarcane planting at 120–150 cm in the tropical zone is better to facilitate mechanization and harvest a good yield.The planting method should be such that it encourages root spread and development in the maximum soil horizon so that nutrients and water are utilized effi-

Fig. 1. Cane node–cutting machine

ciently from the soil profile.

Trench method: Trench method of planting has been recommended for higher cane yield of plant and ratoon crops. It avoids crop lodging and is suitable for light soils also. The Indian Institute of Sugarcane Research (IISR), Lucknow, has developed a mechanized method of trench planting with the following features:

- Making 30 cm wide and 25–30 cm deep trenches
- Keeping centre to centre distance of 120 cm (90 cm : 30 cm) between 2 trenches
- Mechanized planting of sugarcane setts in paired–row system by trench planter

Furrow irrigated raised bed planting: Innovative wheat + sugarcane under Furrow Irrigated Raised bed (FIRB) system has been developed at IISR, Lucknow to reduce the loss in cane yield under late planting conditions. In this method, 2–3 lines of wheat are sown on raised beds (October–November), and sugarcane is planted in furrows at its optimum planting time (February–March). The FIRB configuration is 50–30–50 cm. In this technique, sugarcane crop gets optimum period for tillering, and grand growth and the yield of both wheat and sugarcane is enhanced due to timely planting and better rhizosphere (Singh *et al.,* 2012).

Ring pit planting: In this technology, tillering in sugarcane is suppressed, and the growth of mother shoots is facilitated. Thus, a higher number of millable canes with higher length and weight are produced. This technology is also called ‘No Tiller Technology’. Pits of 75/90 cm diameter and 30 cm depth are dug with a mechanized pit digger. Approx. 9,000/ 6,900 pits/ha are dug with a centre to centre distance of 105 cm/ 120 cm. The dugout soil is kept on the periphery of each pit. Fifteen treated 2–bud sets are placed in each pit in a similar pattern as spokes in a cycle wheel. *Trichoderma* @ 20 kg mixed with 200 kg FYM or pressmud–cake/ha is applied over the setts. The general recommended dose of manure, fertilizers and chemicals is also applied on a per ha basis. The pits are filled gradually with the dugout soil up to 5 to 7 cm depth during intercultural operation. This method can increase–yield by 1.5–2.0 times, water–use efficiency by 30–40% and nutrient–use efficiency by 30–35%. On–farm experiments were conducted in the fields of 96 farmers in 8 districts of Punjab to compare the yield and juice quality of sugarcane under ring–pit and conventional flat–planting methods. The results revealed higher sugarcane yield in all the districts recorded under ring–pit planting than conventional flat method. On an average of locations, cane yield was 64% higher in the ring–pit method than the conventional flat method because of the formation of 114% higher millable canes and owing to the use of higher amounts of plant nutrients (N and P) in the ring–pit method than that in conventional flat method (Yadav and Kumar, 2005).

Sugarcane planting seasons in different growing zones are given in Table 3.

INTEGRATED NUTRIENT–MANAGEMENT

We can sustain higher sugarcane yield for a longer period by modifying the soil–crop–environment. Optimum soil physical and chemical environment leads to establishing a good stand of vigorous plants, exploiting extra nutrients. Organic (FYM) application to agricultural soil provides better fertility, crop yield, and lower off–site impacts than other disposal mean. Consequently, crop nutrition partially through organic and inorganic is a viable proposition for improving soil fertility, crop yield, and system sustainability. Optimizing 50% N (75 kg/ha) through organic and the remaining 50% through inorganic fertilizer is a viable option in a sugarcane–based system. This practice increases soil organic carbon content, soil microbial biomass carbon, nitrogen, and respiration rate (Shukla *et al*., 2015). Bioaugmentation, the addition of microbes to agricultural soils, has a valuable influence on soil microbial processes, and the addition of organic matter strongly influences these processes (Lily and Mary, 2015). The decomposition of sugarcane residues in the field increases soil microbial population and cellulose activity and decreases the total cellulose content of the residue. Use of biostimulants in the context of mitigating adverse effects of global climate change and expecting better returns from sugarcane cultivation. *Kappaphycus* seaweed extract (KSWE) applied at 5% concentration enhanced cane productivity by 12.5 and 8%, respectively, in plant and ratoon crops. The potential of the KSWE in lowering greenhouse gases is manifested by saving at least 260 kg CO_2 equiva-

Table 3. Sugarcane planting seasons in India

S. No.	Sugarcane agro–climatic zones	Planting Seasons				
		Autumn/ pre–seasonal	Spring season/ seasonal/ suru	Late spring / early summer	Early spring planting	*Adsali* planting
1.	North West Zone	September to October	February to March	March to April	–	–
2.	North Central Zone	October to November	February to March	March to April	–	–
3.	North Eastern Zone	October to November	February to March	March to April	Late January to February	–
4.	Peninsular Zone (I and II)	October–November	January–February	–	–	July to August
5.	East Coast Zone	October to November	2 fortnight of December to end of February	–	–	2 fortnight of June to end of July

lents (Mg cane production)/ha when applied at 5% concentration. This will translate into savings of 9.3 million Mg CO_2 equivalents if one assumes employing KSWE for at least 10% of the total cane production in India. Bio–intensive agronomic practices, which will include massive use of manures, biofertilizers and biopesticides (Yadav *et al*., 2009a and b), provide a sustainable option for a sugarcane–production system. Integrated sulphation pressmud/ cane trash/ vermicompost/ bio–fertilizers, especially *Gluconacetobacter diazotrophicus* and bioagent like *Trichoderma viride* inorganic fertilizers, brought about an economy of 20–30% in fertilizer N for sugarcane by improving the use efficiency of N, P and other micronutrients.

Composting byproducts from the sugarcane (*Saccharum* spp.) industry can help achieve sustainable biofuel production by replacing mineral fertilizers and good crop/ residual industrial disposal. The compost of filter cake and ash enriched with/ without phosphate rocks (apatite–A and phosphorite–P) and phosphate–solubilizing bacteria can replace mineral P fertilizers and improve sugarcane–production (Lopes *et al*., 2021).

CARBON SEQUESTRATION

The sugarcane sector is recognized for its potential to mitigate greenhouse gas emissions, since a considerable part of the carbon (C) emitted from the biofuel combustion is offset by crop uptake during photosynthesis (Cherubini *et al*., 2011), which can later be stored into soil organic carbon (SOC) by straw decomposition and exudation of roots C–compounds (Carvalho *et al*., 2017). A large amount of sugarcane straw (10–20 Mg/ha) deposited over the soil result in an annual addition of about 3–5 Mg C/ ha and 40 kg N/ha, providing some potential to accumulate soil C and supply part of the N demanded by crop (Trivelin *et al*., 2013). Developing and implementing management strategies that maintain soil quality is essential to enhance the performance and sustainability of an agroecosystem. Carbon is the key attribute of soil quality because it influences nutrient cycling, soil structure, water availability, and other important soil properties (Tirol Padre *et al*., 2007). The benefits of using organic manure and straw in maintaining soil quality have been increasingly recognized (Chander *et al*., 1997). Soil microorganisms and the processes they control are essential for the long–term sustainability of agricultural systems and are important factors in soil formation and nutrient cycling. The rhizosphere is the region of soil where roots influence the microbial activity. The physicochemical properties of the region create different growing conditions for microorganisms in comparison to root free soil. Land–use activities particularly related to residue–management practices, can considerably impact the size and activity of the soil–microbial community and the biological health of the soil. Some researchers have shown that incorporating organic amendments increased soil–microbial activity and densities of bacteria (Van Bruggen and Semenov, 2000). Most research has shown increased microbial diversity in soils from organic farming systems than conventional farming systems (Shannon *et al.,* 2002). Organic matter decomposition serves 2 functions–providing energy for growth and supplying carbon to form new cells.

NANO–FERTILIZERS IN SUGARCANE

Nano–fertilizers are an important area of research for nutrients management and increase crop production and productivity in sugarcane. Nano–fertilizers have site–specific effects, boost nutrient uptake, and require in small quantities. Due to lesser requirement, it has no adverse effect on plant–growth and development called nutrient toxicity and reduces the cost of crop production. The nutrient–use efficiency of chemical fertilizers is very poor, 30–35%, 18–20%, and 35–40% for nitrogen, phosphorus, and potassium, respectively. As we know that excess application of nitrogenous chemical fertilizers, crop–burning issue is commonly noticed. At the same time, nano–fertilizers support a better photosynthesis pathway, vigorous crop growth which results in a greater crop yield. Recently, nano–fertilizers products have been developed using synthetic zeolite–based fertilizers. They are being called N nano–fertilizer, P nano–fertilizer, K nano–fertilizer etc. Reports are available that, while using nano–fertilizers in greengram and blackgram, yields increased by 13% and 38% compared with chemical fertilizers (Al–Juthery *et al.,* 2021)

CROP RESIDUE MANAGEMENT AND USE OF BENEFICIAL MICROBES

Sugarcane is a huge biomass–generating crop. Harvested cane is used for sugar production after processing at sugar mills. Left–over sugarcane trash in the field is a very big issue to manage. From 1 ha of a sugarcane field, almost 10–12 tonnes of trash is obtained. Farmers used to burn it earlier, but now, due to government initiatives and farmer's awareness, trash is mulched/recycled in the field. Trash helps in controlling weeds, conserves soil–moisture and maintains soil carbon levels for a longer period. Recently some microbial formulations consisting of *Trichoderma* spp. are used to fasten the decomposition process *in–situ* conditions. Reports are available that using trash with microbial inoculants, can maintain good soil health. It also improves soil–nutrients status as well as soil aeration, which supports better crop performance. The soil which has more than 0.5% organic carbon is characterized for better sugarcane–production and productivity. Still, much research is needed to manage trash faster, particularly under low–temperature conditions (during winter) without delaying other crop–production activities.

Microbes are available everywhere. Microbes have been identified for plenty of plant–growth promoting–attributes. The microbes which have plant growth–promoting attributes are called beneficial microbes. Beneficial microbes assist in providing and fixing nutrients, protect from insect–pests and diseases, degrade toxic chemical compounds to less or non–toxic conditions. All over the world, many microbial formulations have been developed and commercialized and are being used for crop growth and development. For sugarcane crops, microbial inoculants are also formulated and validated in field conditions. It has been recorded that up to 15–20% of crop production can be increased easily. In comparison, the burden of chemical fertilizers can be minimized up to 25% without compromising crop performance.

MANAGING ABIOTIC STRESSES

Iron chlorosis

Iron chlorosis is a widely occurring nutritional deficiency, especially in calcareous soils. It aggravates more in succeeding ratoon crop. The following recommendations may be applied in different situations to manage iron chlorosis in sugarcane. Two to three times foliar sprays of 1% solution of $FeSO_4$ and 0.5% $MnSO_4$ and 2% urea have been found suitable to manage the iron chlorosis in sugarcane ratoon. Soil application of $FeSO_4$ @ 25 kg/ha is also recommended to manage the problem. Soil application of farmyard manure (25 t/ha) + foliar application of 1.5% $FeSO_4$ with 1% urea at weekly intervals and 1% $ZnSO_4$ at monthly intervals also manage the deficiency.

Contingency planning for drought

Frequent light irrigations are advised during a prolonged dry spell in the rainy season. Furrow irrigation with cut off at 85% furrow length should be adopted, and flood irrigation needs to be discarded to save the water and cover more crop area. Irrigating only alternate furrows would further enhance irrigation efficiency and water saving. A spray of ethrel (12 ml in 100 litres water) should be done on sugarcane leaves during the dry spell to mitigate the adverse effects of moisture stress. To maintain the crop growth and resilience against dry weather, foliar spray of urea (2.5%) alone or in combination with muriate of potash (2.5%) should be done. Earthing–up on sugarcane rows should be done, especially in autumn–planted and autumn initiated ratoon crops to prevent wasteful tillering and effectively harvest likely water rains.

IRRIGATION WATER MANAGEMENT

The growth response to photosynthesis and plant productivity depends on environmental variables, which also includes soil–moisture. Insufficient water availability was one of the big challenges that impair plant performance and crop yield (Verma *et al*., 2020). Physiologically, sugarcane is a C_4 plant based on a specific carboxylation profile having 4 developmental phases, viz. germination, tillering, elongation, and maturity, which experiences various degrees of water stress at different stages. However, after the germination phase, the tillering period has been found critical for managing water stress. During the tillering phase, the third order of tillering has been found more critical than the second order and first order. Thus, water stress at third order of tillering affects major survival and growth of the crop (Singh *et al.,* 1984). During the elongation phase, water deficit reduces crop growth and sugar yield; however, water deficit affects the survival of crops and production of millable canes during the tillering phase. These growth phases get affected by limited irrigation, which causes loss in plant development and productivity (Tripathi *et al*., 2019). It is recommended that the sugarcane plant crop be irrigated at 50% available soil–moisture compared to ratoons at 75% available soil–moisture in sandy loam soils and medium black soils. Ratoons are more prone to soil–moisture stress than plant crops.

In India, 89% of the 5.0 million ha under sugarcane (*Saccharum* sp.) receives irrigation. Irrigation quantum is one of the most important abiotic stress factors limiting sugarcane–production worldwide. In tropical India, the number of irrigations ranges from 30 to 36, while in the subtropics, 5 to 10 irrigations are required with a depth of 80 mm (Singh *et al*., 2007). On an annual basis, the total crop evapotranspiration (ETc)/ water–use is 1,100–1,800 mm, with peak daily rates varying from 6 to 15 mm/day (Carr and Knox, 2011). The water requirement for sugarcane in India varies widely from 1,143 to 3,048 mm since farmers apply more water than the requirement. Irrigation to sugarcane crop at 0.75 (tillering), 0.75 (grand growth), and 0.50 irrigation water: cumulative pan evaporation (IW:CPE) ratio (maturity phase) resulted in the highest cane yield.

A deficit–irrigation strategy with 0% water deficit at tillering, 30% at grand growth and 60% at maturity stage was found appropriate, as it represents the non–significant reduction in yield over water deficit–free condition, besides it leads to a 13.3% lesser water use (Dingre and Gorantiwar, 2021). In subtropical India, irrigation should be applied at an IW: CPE ratio of 0.75 for a silty clay–loam soil and 1.00 for sandy–loam soil during the tillering period in sugarcane plant and ratoon crops (Singh *et al*., 2007)

Low–cost drip irrigation (LCDI) has been a recent introduction to India, and it may be an inexpensive means of expanding irrigation into uncultivated areas, thereby increasing land productivity. The LCDI is a drip–irrigation system, using the thin–walled, low–cost, flexible plastic hose as laterals and micro–tubes instead of costly drippers as emitters. These systems present the opportunity for improving the livelihood of marginal farmers. In India, LCDI systems were introduced in 1997 by the International Development Enterprizes (IDE), a non–profit organization. The LCDI recorded 118.6 t/ha of cane yield, and it was on par with the single row CDI, which recorded the highest mean yield of 120.4 t ha^{-1}. Benefit: cost ratio analysis confirmed that, LCDI performed better compared to other irrigation methods (Surendran *et al*., 2016a)

WEED MANAGEMENT

Weeds are the most important biotic stress creator in the sugarcane crop. The crop–weed competition is quite effective for the first 120 days in spring–planted cane and up to 150 days in autumn–planted cane. The extent of loss to cane yield due to weeds varies from 10%–70% (Srivastava and Kumar, 1996). Weed–management options are discussed below:

Weed management in plant crop

Atrazine @ 2.0 kg ai/ha as pre–emergence/ metribuzin @ 1 kg ai/ha in 800–1000 litres water/ha is recommended. Either of these herbicides should be coupled with the application of 2,4–D @ 1.0 kg ai/ha at 60 days after planting (DAP) and one hoeing at 90 DAP or 3 manual hoeings at 30, 60 and 90 days after planting (Verma, 2000).

Weed management in ratoon crop

At 1, 4, and 7 weeks after ratoon initiation, 3 hoeing are recommended, but this practice is seldom adopted due to scarcity of human resources. Pre–emergence application of either of atrazine @ 2.0 kg a.i/ha or metribuzin @ 1.0 kg a.i/ha (800–1,000 water/ha), followed by either of 2, 4 D Na salt @ 1.0 kg/ha (600–800 litres water/ha) and hoeing at 45 days after ratooning has been found better option. Further, trash mulching @ 8 tonnes/ha between rows and hoeing within rows after harvesting plant crop/ ratoon initiation is also a good option to save the person–days and benefit trash mulching (Yadav *et al.,* 2009b).

Management of binding weeds (Fig. 4)

Application of Atrazine @ 2 kg ai/ha or metribuzin @ 1.25 kg ai//ha as pre–emergence followed by DICAMBA @ 350 g ai/ ha at 75 days after planting (Shukla *et al.,* 2017a).

Weed management in intercropping system

Pre–emergence application of oxyfluorfen 0.234 kg/ ha and pendimethalin 0.75 kg/ ha provided a similar level of weed control to hand–weeding. It increased the yield of cabbage (*Brassica oleracea* var. *capitata*), peas (*Pisum sativum* L.), and garlic than the weedy check (Kaur *et al*., 2015). The intercrops could compete with weeds and enhance the total productivity and profitability of autumn sugarcane. The selection of intercrops for this purpose needs to be done carefully to avoid the risk of excessive inter–specific competition with sugarcane. Indian mustard exhibited higher weed suppression than oilseed rape (*Brassica napus* subsp. *napus* l.) and sole sugarcane, which may be associated with greater production of secondary branches and planting arrangement of Indian mustard (2 rows) than oilseed rape (1 row). Pre–emergence application of pendimethalin at 0.75 kg/ ha and alachlor at 1.875 kg/ha provided adequate control of weeds in these intercropping systems. It increased the seed yield of oilseed rape and Indian mustard relative to the weedy check by an average of 41% and 15% respectively (Kaur *et al*., 2016).

CROP DIVERSIFICATION

Crop diversification provides the farmers with a wider choice in producing various crops in a given area to expand production–related activities on various crops and bring down the possible risk. Sugarcane provides better options for crop diversification owing to its longer duration and early slow growth. Crop diversification can increase total system productivity, monetary returns, and resource utilization in sugarcane.

Intercropping of short–duration crops in sugarcane could improve profitability and make it more attractive for growers. Sugarcane planted in the autumn season is more suitable for intercropping, as low temperature during the winter slows down the growth of sugarcane plants. Intercropping can increase productivity, monetary returns, and resource utilization (Kaur *et al*., 2015). Sugarcane–garlic intercrop had the highest net monetary returns of US$ 4384/ha and the highest benefit: cost ratio of 2.45; net returns from intercropping of sugarcane with peas and cabbage varied from US$ 2,873–3,094/ha (Kaur *et al*., 2015).

In autumn, intercropping of *rajmash*, winter maize, potato, Indian mustard, chickpea (Fig. 2) and grain *amaranth* can generate mid–season income and enhance the system's profitability for small and marginal cane–growers. Several studies demonstrated that, the total productivity of crops in sugarcane + winter (*rabi*) crops (vegetables, pulses, oilseeds, spices, cereals, medicinal and aromatic plants etc.) intercropping system is substantially higher than the total productivity of sole rabi crop in winter, followed by sole sugarcane planted in the spring season. 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 9 months after the harvesting of the legumes (Shukla *et al.,* 2017).

Fig. 2. Intercropping of chickpea with autumn–planted sugarcane

The area of sugarcane intercropping system in Uttar Pradesh has increased significantly in the recent past owing to higher net returns than that of other field crops. Out of the total area under sugarcane cultivation (2.678 million ha) in Uttar Pradesh during 2019–20, the acreage under intercropping in sugarcane (autumn and spring seasons) was 424,000 ha in different districts across the state, as per information obtained from the office of the Cane Commissioner, Government of Uttar Pradesh. Different intercrops in sugarcane–based systems (for tropical zone) are listed in Table 4.

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 sugarcane, space between 2 rows of sugarcane remains unutilized for an initial 90–120 days due to slow crop growth. Companion cropping offers an opportunity for the profitable utilization of available space. Sugarcane–growers take advantage of this and grow various short–duration crops like cereals, pulses, vegetables and spices as an intercrop to obtain an additional return. Small sugarcane–growers need not wait until the harvesting of the sole crop to obtain financial returns.

Legume intercropping in cropping systems enhances 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 it remains in the field for over nine months after the harvesting of the legumes. Further, the 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. With the introduction of machinery in sugarcane cultivation to address the scarcity of workforce besides cost reduction and the adoption of high tillering and wide yielding varieties of

Table 4. Intercrops in the sugarcane–based system in the tropical zone

Planting season	Intercrops
Seasonal (*Suru*)	Summer groundnut, soybean, watermelon, cucumber
Pre–seasonal	Potato, gram, cabbage, cauliflower, onion
Adsali	Groundnut, soybean, cowpea, radish, coriander, fenugreek

sugarcane, there is a possibility to adopt wider row spacing and still sustain cane productivity. Such wide row spacing allows intercropping without adversely affecting the cane yield and thus increasing the overall productivity and profitability of system. The present problem of labour shortage may worsen in future, affecting the survival of the sugar industry and cane–growers. Wide row spacing becomes an important agronomic consideration in future in developing countries like India.

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 winter and remains in the field without much growth until the spring season. During this period, the cane does not make much demand for the growth resources. This condition facilitates the raising of any winter (*rabi*) season crop as an intercrop with autumn–planted sugarcane. Several studies demonstrated that, the total productivity of crops in sugarcane + *rabi* crops (vegetables, pulses, oilseeds, spices, cereals, medicinal and aromatic plants etc.) intercropping system is substantially higher than the total productivity of sole *rabi* crop in the winter, followed by sole sugarcane planted in the spring season.

SUGARCANE BASED INTEGRATED FARMING SYSTEM

Sugarcane occupies the prime situation in the sugarcane–based integrated farming system. The sugarcane-–based integrated farming can act as a prime source of protein in different components like pisciculture, backyard poultry, piggery, duckery, and dairy (Moraine *et al*., 2017). The sugarcane-–based integrated farming is favoured owing to efficient use of resources, recycling nutrients, and reduced fluctuations in economic returns (Bell and Moore, 2012). Integrating sugarcane with different enterprizes like poultry, fisheries, apiculture, mushroom production, vermicomposting, and horticultural crops (including fruits, vegetables and flowers) enhances resources recycling, provides livelihood, nutrition, and income security reduces dependence on external inputs. At the ICAR–IISR, Lucknow, the following integrated farming systems have been identified as profitable autumn and spring–planted cane system under subtropical conditions (Dwivedi *et al.,* 2020).

Autumn sugarcane–based integrated farming system as sugarcane + vegetables (garlic, fenugreek (*Trigonella foenum–graecum* L.), coriander, tomato (*Solanum lycopersicum* L.), cauliflower, spinach (*Spinacea oleracea* L.), carrot, fababean, onion (*Allium cepa* L.), brinjal (*Solanum melongena* L.), green chilli (*Capsicum* sp.), cabbage, pea, soybean, fennel (*Foeniculum vulgare* L.), bottle gourd [*Lagenaria ciceraria* (Molina) Standl.], okra [*Abelmoschus esculentus* (L.) Moench], cowpea, cucurbit, maize) + horticultural crops [karonda (*Carisa carandas* L.) boundary plantation + papaya (*Carica papaya* L.) + banana (*Musa* × *paradisciaca* L.)] + backyard poultry (breed: Asheel, Nirbheek, Kadaknath, quail) + fisheries (rohu, catla, nain) + vermicompost (*Eisenia fotida*) fetched net income ₹ 454,412/ha. It fetched an additional income of (₹ 195,212/ha). The cost : benefit (C: B) ratio was recorded as 1: 3.26.

Spring sugarcane–based integrated farming system as sugarcane + vegetables, viz. (bottle gourd, sponge gourd (*Luffa aegyptiaca* Mill.), tomato (*Solanum lycopersicum* L.), brinjal, pumpkin, onion, maize Fenugreek, *pauchoi*, chinese gobhi [*Brassica rapa* subsup. *Chinensis* (L.) Hanelt]; + horticultural crops (banana, karonda, papaya) + backyard poultry (breed– asheel, nirbheek, kadaknath, quail) + fisheries (rohu, catla, nain) + vermicompost (*Eisenia fetida*) fetched net income of ₹ 448,990/ ha and fetched additional income of ₹ 193,190/ha. The C: B ratio of the system was worked out as 1: 3.42.

EFFECT OF DEEP TILLAGE AND SUBSOILING

Besides improving sugarcane yield, soil health could be sustained by adopting subsoiling (45–50 cm depth) and deep tillage (20–25 cm depth), with a soil–moisture regime of 0.75 IW:CPE and application of 150 kg N/ha in sugarcane plant crop (Shukla *et al*., 2018b). Subsoiling and deep tillage significantly reduced the bulk density in the plant as well as ratoon crops. Loosen soil in deeper layers increases aeration and infiltration of water, ultimately affecting root and plant–growth significantly.

Deep ploughing and subsoiling up to 30–45 cm and optimizing soil–moisture regime with N fertilizer may improve overall soil–quality parameters and yield subsequent ratoon crop (Mawalia *et al*., 2017). Minimum tillage through subsoiling had shown a major effect in reducing soil compaction in subsurface layers. During the tillering period, the basic infiltration rate could reach 7.5 mm/hr in subsoil (S.S.) plots compared to 5.5 mm/hr in conventional practice (C.P.). The minimum tillage through subsoiling significantly improved sugarcane (96.32 t/ha) and sugar yields (12.14 t /ha) compared to conventional tillage/ mouldboard ploughing. Minimum tillage recorded the highest soil organic carbon at all the crop growth stages. The highest mean soil organic carbon was recorded during the grand–growth phase (13.51 Mg/ha) (Shukla *et al*., 2020). Minimum tillage, through subsoiling, loosened soil in the subsurface layer and improved water intake, aeration etc., created a favourable environment for crop growth. Minimum tillage through subsoiling did not expose a higher amount of soil to the external environment than the conventional cultivator, rotavator or moldboard ploughing. The effect of minimum tillage could be recorded in increasing soil organic carbon and available N, K and crop yield (Perez Brandan *et al*., 2012).

TRASH MANAGEMENT

Sugarcane trash (tops and green leaves), produced during the harvesting stage, is used as a cooking/ heating fuel in rural areas and animal feed. Pressmud or filter cake, another byproduct of the sugar extraction stage, can be recycled back to the soil as organic manure or used to produce biogas (Hiloidhari, 2021). The presence of lignified compounds in sugarcane trash–based organics could be responsible for the slow release of nutrients in tune with the crop requirement, resulting in reduced losses and build–up of soil–available nutrient pools (Yadav *et al*., 1994). Application of sugarcane trash coupled with microbes and press mud improves soil organic carbon, and increased carbon helps sustain soil health for a longer period (Shukla *et al*., 2013). Trash and composted pressmud provided organic carbon for enhanced multiplication of inoculated microbial agents and provided a suitable niche for plant–microbe interaction. Trash mulching provides soil cover, minimizes C losses, controls weed and after decomposition, adds organic matter to the soil in subsequent ratoon crops (Yadav *et al*., 2009b).

INTEGRATED PEST AND DISEASE MANAGEMENT

Integrated pest and disease management reduce the use of chemicals without much interference to ecological balance. Treatment of cane in moist hot air (MHAT. at 54°C and 95–99% relative humidity for 2.5 hr eradicates sett–borne infections of ratoon–stunting disease, grassy–shoot disease and smut (99–100%). It also reduces the sett–borne infections of leaf scald and red rot up to 80%. Treatment of setts with fungicides like bavistin/ vitavax at the planting protects the setts from surface–borne pathogens and superficial infections. Management of seedling diseases in the nursery bed through the pre–planting application of formaldehyde and seed treatment with Thiram, pre–planting application of *Trichoderma*, and post–sowing application of Ridomil.

Management of insect–pests and diseases in sugarcane is a very old approach, but non–judicious use of agrochemicals polluted our environment and increased the cost of production (Figs. 3, 5 and 6). Hence, to reduce chemical requirements and the cost of production, several small operations are needed to keep crops in good stands. Prophylactic approaches play a major role to keep crops in good health. Improved quality seed–cane should be

Fig. 3. Wooly aphid symptoms in sugarcane

Fig. 4. Binding weeds in sugarcane

Fig. 5. Brown spot disease in sugarcane

Fig. 6. Pokka Boeing disease in sugarcane

planted, and replacement should be done at regular intervals. Regular monitoring is advocated to be done. Crop rotation practice should be followed. Rouging of infected cane/ clumps is done. Green approaches are adopted to keep insect–pests and pathogenic populations below the threshold level. Selective and effective chemicals should be applied when the crop is heavily infected with insect–pests and diseases.

MECHANIZATION IN SUGARCANE

Sugarcane is annual crop and has a well–developed root structure and good crop stand. A well ploughed field is required for better crop growth and development. Trench planting has proved beneficial over conventional shallow–furrow planting. Thus for sugarcane planting in trenches, Trench maker has been the most important machine for cane–growers. Besides these, various operations like intercultural, earthing–up, harvesting and ratoon management require different kinds of machines to perform timely and quality operations. Thus we can say that, from field preparation to cane harvesting, sugarcane–production is dependent on mechanical inputs, which can also reduce the cost of production and increase return on investment. In this concern, the ICAR–Indian Institute of Sugarcane Research, Lucknow, has developed several machines for sugarcane–production in the country. Few machines developed at the Institute are Trench planter, Pit digger, Seed cutter, Deep Furrow–type sugarcane cutter planter, Disc type sugarcane cutter planter, Raised–bed planter, Sugarcane and potato planter; paired row planter; intercultural machine and ratoon management device are commonly used on farmers fields.

Sugarcane cultivation requires heavy energy from field preparation to harvesting. The crop is very labour–intensive and remains in the field throughout the year in the field. Sugarcane accounts for 60–70% of the cost of sugarcane–production and thus has a vital role in making the sugar industry a commercially valuable venture (Singh *et al.,* 2011). In general, very little mechanization has been done in sugarcane cultivation in India. All farm operations from planting to harvesting are labour dependent. In a true sense, if we look at the prevailing degree of mechanization, mechanization is confined to tractorization only. General–use land–preparation equipment, mainly cultivator and harrow, are common on farmers fields (Sharma *et al.,* 2007). Thus the cost of production is also escalated because of the higher use of the workforce.

Mechanization also affects the quality of operation besides timely completion of the operation. Sugarcane–production is labour–intensive, requiring about 3,300 man–hr for different operations (Ali, 2015). This might be one of the reasons for the higher cost of cultivation of this crop. Thus, ways and means have to be evolved to produce more sugar per unit area, time and input to keep pace with the population growth while preserving the soil and water resources. For this purpose, it has been observed that, the use of modern machinery is inevitable. The use of machinery helps in labour–saving, ensures timeliness of operation, reduces drudgery, helps in improving quality of work, reduces the cost of operation and ensures effective utilization of resources. Although machinery has been developed in the case of the sugarcane crop, the adoption of these implements and machinery has not been up to the desired level. Thus, there is a considerable mechanization gap, especially in sugarcane planting, intercultural, harvesting and ratoon management. Therefore, concentrated efforts must be made to adopt, develop, and popularize sugarcane machinery for various cultural operations.

Conventional tillage system affects yield decline over the long term, and therefore, yield benefits are required and cost savings. A study analysis showed that minimum tillage before planting gave the best economic returns. About 29.3 to 39.4% higher profit could be derived through the adoption of minimum tillage as compared to the conventional and no–tillage treatments respectively (Grange *et al.,* 2004). Sugarcane cutter planter is the most important machine which performs the opening of furrows, cutting and placement of setts in furrows, application of insecticide, fungicide, fertilizer etc. and covering of setts. Its adoption may reduce the cost of cultivation by 60% compared to the conventional method of planting (Singh and Sharma, 2008). Timeliness of operation and efficient utilization of critical inputsis also made possible. Tractor–mounted multipurpose sugarcane planter has been developed at the ICAR–IISR, Lucknow. This is an improved version of the sugarcane cutter planter. The planter can be used for many other sugarcane operations. Sugarcane planters seem to have played an important role in managing sustainable sugarcane–production. A low hp tractor–drawn earthing–up–cum fertilizer–applicator unit is multipurpose equipment for performing mechanical weeding, earthing–up, and fertilizer–application operation simultaneously in wide–row–planted sugarcane. It covers 0.33 ha/hr or 2.64 ha/day, with a seeding efficiency of 94% and field efficiency of 82.70% developed by the Department of Farm Machinery and Power, Dr A.S. College of Engineering Mahatama Phule Krishi Vidyapeeth, Rahuri (Navale *et al.,* 2009). The IISR multipurpose planter is also used for intercultural operations. More advanced machines are now available in whole cane harvesting, which cut the cane stalk at the base and detop. The cut canes are placed in a single–window from 4–6 rows. Subsequently, depending on the availability of the labour, mechanical loaders/manual loaders can be employed for loading purposes. About 8–10% of the trash remains in the harvested cane. Later, the use of a separate de–trasher can be explored to minimize the level of trash in the cane to be supplied to the mills. Handling trash is another area requiring the attention of the researchers in the present scenario where manual harvesting is in vogue. At the ICAR–IISR, Lucknow, equipment for *in–situ* incorporation of sugarcane trash has been developed and is under extensive field trials. The equipment is mounted with the tractor and is operated by a P.T.O. shaft. The system picks up trash, passes it on to the chopping unit, where trash is chopped into small bits, which ultimately gets mixed up and buried under the soil with the help of a pair of discs provided at the rear end.

RATOON CROPPING

Ratooning is a practice of raising a sugarcane crop from the preceding plant crop stubble regrowth without fresh planting of setts and is an integral part of sugarcane cultivation practiced in most sugarcane–growing countries of the world. Sugarcane ratooning saves the cost of seedbed preparation, seed material and planting operations, thereby reducing 25–30% cost of sugarcane cultivation. Ratoon crop helps extend the crushing period of sugar mills as they mature earlier than the plant crop and normally give better quality. Unsprouted stubble causes gaps in subsequent sugarcane ratoon crops, resulting in lower initial plant stand and poor crop yield. Several agro–techniques, viz. stubble shaving, off barring, trash mulching (Yadav *et al*., 2009b), intercropping, ratoon gap filling, earthing–up, micronutrient application and fertilizers have been suggested to improve cane yield in ratoon and to reduce the yield gap of ratoon. The IISR developed tractor operated ratoon management device (RMD) that executes all the operations involved in managing ratoon crops such as stubble shaving, deep tilling, off–barring, placing manure, fertilizer/ bioagents, chemicals in liquid form and earthing–up operations in a single pass of operation.

The basal cut of stubbles and removal of decayed roots with tillage provides proper soil cover to stubble and enhances sprouting with vigorous tillers. The loose soil mass may create a favourable rhizospheric environment for the emergence of vigorous sprouts, thereby enhances rhizospheric biological activity, promoting new roots and ultimately helps in maintaining the plant population and yield. Microbial biomass C, although a small fraction of soil organic C (1–4%), plays a key role in governing nutrient recycling and energy flow due to its rapid turnover rate. Soil microbial activity, represented as soil microbial biomass carbon (SMBC), showed varying degrees of enhancement due to different organics in sugarcane ratoon at its initiation (Surendran *et al*., 2016b).

Management of multiple ratooning

Under multiple ratooning, integration of agro–technologies, viz. stubble shaving, gap–filling, trash mulching and cultivation in alternate rows with the use of phorate (15 kg/ha), has been advocated to sustain higher cane–ratoon yields. Keeping ratoon beyond third does not appear to be economical. As component technology, trash mulching and gap–filling have been identified as critical technologies to sustain multiple–ratoon productivity. Following points to be remembered during ratoon crop–cultivation.

1. In subtropical India, do not harvest the main crop before the end of January. If the crop is harvested earlier, there will be poor sprouting of the stubbles due to low temperatures during December and January.
2. Soon after the early varieties are harvested in November or December, remove the trash and irrigate the field. When the soil attains the optimum moisture conditions, loosen it by hoeing, ploughing or interculture with a tractor–drawn tiller. Do not cover the stubble with cane trash.
3. Harvest the canes as close to the ground as possible to promote better sprouting. If still some big stubbleleft, shave or lop them off close to the ground. Also, remove late tillers or water–shoots, as they inhibit the full sprouting of the stubbles (Shukla *et al.,*2018a).
4. Plough the harvested field twice with a *desi* plough or with a tractor–drawn tiller to check weeds. Alternatively, adopt chemical weed–control measures.

Table 5. Mean effect of plant cane harvesting on number of millable canes and yield of ratoon cane at Lucknow, Uttar Pradesh

Treatment	Millable canes	Cane yield (t/ha)
Harvesting of plant crop		
At ground level	90.3	64.4
At 5 cm above ground level	82.9	57.7
At 1o cm above the level	81.2	54.8

5. The stand of the ratoon crop can be improved by planting the gaps with three bud setts/ polybag single–bud setts at the beginning of March. More than 15% gaps decrease ratoon cane yield significantly (Shukla *et al.,* 2018a)
6. The nitrogen requirement of the ratoon crop is 25% higher than that of the plant crop. Hence, apply 3 split doses– one–third in February–March, one–third in April and the remaining one–third at the beginning of June. Drill phosphorus along the cane rows in March based on a soil test.
7. Irrigation, insect–pest and disease management in ratoon crop is required same as main crop.

HARVESTING

As per the planting schedule, the sugarcane crop matures within 10–12 months in north India and 12–16 months in south India. The crop can be harvested after attaining sucrose content in juice (> 16%) along with 85% juice purity{(Sucrose per cent/ Brix) × 100}. The yellowing of leaves, the emergence of arrows, cane brittleness, easily breaking of stalk, metallic sound of cane and swelling out of buds from nodes are the other indicators of the mature crop. The harvesting schedule of early and mid–late maturing varieties under different planting seasons should be followed to regulate the cane supply in the mill. Ratoon of early variety matures first, followed by ratoon of mid–late variety, early variety, and mid–late–maturing varieties. Autumn–planted cane matures earlier than spring, and summer–planted canes in subtropical India. Timely harvesting ensures maximum sugar recovery in the mill and avoids sugar loss through the inversion of sucrose into glucose and fructose. Harvesting of the cane should be delayed by 2–3 days, if rains receive during the period. Cut to crush period should not be more than 72 hr to get maximum cane weight and sugar recovery in the mill. Important sugarcane–production approaches, with expected sugarcane yield, net irrigation water requirement, nutrient–use efficiency and net returns per ha are being given in Table 7. Net returns from sugarcane planting ranges between ₹ 81,700/ha and 224,100/ha in different states of the country. Various factors such as the source of irrigation water, soil type, annual rainfall, planting method, price of sugarcane affect crop yield and net income of the farmers (Table 7).

DRONE APPLICATION IN SUGARCANE

The Drone application in agriculture is a new approach of Precision agriculture for sustainable agricultural management. It allows agronomists, agricultural engineers, and farmers to help streamline their operations, using robust data analytics to gain useful insights into their crops. Crop monitoring is made easier by using drone data for effective planning and making on going improvements, such as the use of ditches and evolving fertilizer applications. Products can be accurately tracked using GPS locations for every point in the journey. Collection of labour–intensive data is avoided. Crucially, the high–resolution nature of drone data can be used to assess the fertility of crops, allowing agricultural professionals to more accurately apply fertilizer, reduce wastage, and plan – and troubleshoot – irrigation systems. The technology can also be particularly effective following natural disasters, such as a flood, to help farmers to assess damage across terrains that may not be readily accessible on foot (Pinguet, 2021).

Drones are commonly used for data collection and analysis for site–specific results. In agriculture, drones have been used for spraying agrochemicals for insect–pest management and chemical fertilizers for site–specific applications (Kurkute, 2018). Besides this, drones can be used to monitor weeds using remote–sensing data. Drones capture the spectral reflectance of crops and other growing objects from above. It reduces the time and application quantity of agrochemicals/ chemical fertilizers resulting in improved crop growth and yield. Drone application in sugarcane is a potential area of research that could open a better platform for crop management.

Table 6. Effect of time of ratoon initiation on ratoon cane yield in Lucknow, Uttar Pradesh

Time of ratoon initiation	Gap (%)	Millable cane (000/ha)	Yield (t/ha)	
			Cane	Sugar
November–December	22–30	78.10	50.10	5.01
February–March	9–17	90.39	60.15	6.02
April–May	10–15	80.14	55.36	5.54

Table 7. Important sugarcane–producing areas, major production approaches, yields, nutrient–use efficiency (NUE), water use efficiency (WUE) and net income

Important sugarcane–producing states*	Major production approaches	Expected sugarcane yield (t/ha)	Nutrient–use efficiency (kg cane produced/ kg of N.P.K. applied)	**Net irrigation water requirement (mm/year)	*Net returns (₹)/ ha
	Subtropical region				
Uttar Pradesh (45.8%)	Improved varieties, trench method of planting, intercropping in autumn–planted sugarcane, mechanization, use of biofertilizers, integrated nutrients and disease management; IPM	100	370	1,283	155,000
Bihar (3.3%)	Improved varieties, integrated nutrients and disease management; intercropping in autumn–planted cane	80	296	985	129,600
Haryana (2.3%)	Improved varieties, summer–planted cane; planting wheat and sugarcane in FIRBS; trench method of planting, mechanization, use of biofertilizers, integrated nutrients and disease management.	90	333	1,752	224,100
Punjab (2.0%)	Improved varieties, trench method of planting, crop diversification, sett treatment, mechanization, integrated nutrients and disease management	95	351	1,555	190,000
	Tropical region				
Maharashtra (21.5%)	Improved varieties, dry and wet planting methods, crop diversification, sequential/ intercropping, application of recommended manures/ fertilizers/ in–organics/ micro–nutrients/ bio–fertilizers/ bio–agents, mechanization and drip irrigation; wide row planting; IPM	130	288	1,296	137,800
Karnataka (9.8%)	Improved varieties, crop diversification, mechanization, use of biofertilizers and integrated disease management; IPM	140	311	1,127	211,400
Tamil Nadu (2.9%)	Improved varieties, transplanting young chip bud seedlings, integrated nutrients/ weeds/ diseases/ insect–pests management, use of biofertilizers, mechanization, and drip irrigation; IPM	150	333	1,339	139,500
Gujarat (2.9%)	Improved varieties, use of bioagents, mechanization, integrated nutrients and disease management; I.P.M.	80	177	1,226	120,000
Andhra Pradesh (2.2%)	Improved varieties, mechanization, integrated nutrients and disease management; I.P.M.	95	211	1,342	81,700

IPM, Integrated pest management; FIRBS, furrow–irrigated raised bed system; *Percentage area compared to national level.
Source: * C.A.C.P. (2020); **Shukla *et al*., (2017a); Price of sugarcane was considered as per FRP/SAP.

FUTURE RESEARCH THRUSTS

Irrigation water has become a major constraint for growing sugarcane crop. Emphasis on evaluation of breeding stocks tolerant under biotic and abiotic stress conditions is required besides the resource–management techniques to improve the input–use efficiency. Suitable crop and product diversification options in the various sugarcane growing regions are required to be identified. Inclusion of high value (medicinal, aromatic and vegetable crops/ varieties) and low volume crops in the sugarcane–based system and identifying suitable integrated farming systems have great potential in improving farmers' income. Organic production of sugarcane integrating microbial consortium to sustain soil fertility and long–term crop productivity should be standardized. Identification of suitable microbes for nutrient supply in various sugarcane growing zones to reduce the chemical demand of the crop and sustain soil organic carbon for a longer period is required. The nanotechnology approach to reduce the requirement of fertilizer, pesticide, and herbicide has great potential in sustaining crop yield and improving farmers' profitability. Application of artificial intelligence viz., drone technology, and identifying pests and diseases in fields must be explored to provide the immediate solution to sugarcane–growers/ sugar mill development personnel.

CONCLUSIONS

The small interventions of improved technologies will certainly provide benefits to the farmers. Comprehensive approaches including micro–irrigation techniques, bio–fertilizers, and crop–residue recycling to minimize the use of chemical fertilizers and improve soil health are 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/ byproducts are being managed well in soil–sugarcane–sugar production system. In this scenario, trash, press mud cake, vinasse, composted bagasse, rhizodeposition of stubble play a great role in sustaining soil fertility and increasing crop productivity. The viable options are to be intercropped green manuring through dual–purpose legume crops such as cowpea, greengram and blackgram. Integrated weed–management in ratoon through trash mulching, one hoeing and a single atrazine application @ 2 kg ai/ha during ratoon initiation minimizes crop–weed competition. Adoption of skip furrow/ alternate furrow techniques affected water saving up to 35–40% without yield reduction. Planting in the furrow irrigated raised bed method, particularly in the sugarcane–wheat system improves the sugarcane yield besides improving water use efficiency and nutrient–use efficiency. Adoption of integrated pest management reduces the burden of chemicals on the soil and crop besides increasing the population of beneficial insects. The use of organic bio–fertilizers reduces the number of chemical fertilizers and improves the nitrogen–use efficiency and crop response to nutrients. Besides, increased water–holding capacity and nutrients availability provide sustainability to the sugarcane–based system. Maturity–based harvesting and minimizing cut–to–crush delays are crucial for higher sucrose recovery. Sugarcane productivity in India has increased > 80 t/ha. However, keeping in view the achievable potential of the crop, there is immense scope to double the productivity and farmers income while safe guarding the environment (soil, water and air) through established technologies.

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