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Comprehensive approach to boost sustainability, reliability and safety in sugarcane cultivation

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Abstract

Sugarcane (*Saccharum* spp. hybrid) is cultivated in tropical region as a cash crop. It is one of India's important commercial industrial crops that impact on an average of 50 million sugarcane growers and near about 5 lakh workers of sugar mills. It is grown on an area of nearly fifty lakh hectares with 494.22 MT Production having productivity of 84.01 tones ha⁻¹ in 2022-23. Sugarcane impacts on social, economical and cultural growth of Indian agriculture and GDP of India. Sugarcane is on the top in Indian agriculture scenario because of cultivation in different agro-climatic zones of India. Sugarcane is used as input in sugar mills and near about 25 others processed industries that manufacturing papers, alcohol, chemicals and cattle feed. Considering the potential of sugarcane, there is still an enormous scope to increase sugarcane production by increasing productivity per unit area per unit time. This requires sugarcane-growing farmers to be ready to face new challenges like, soil health, availability of good quality seed material, sufficient irrigation facilities, damage by weed, pest, diseases, aberrant weather situations, global warming and increasing cost of inputs.

To face this challenges the effort have been made to adopt latest and most efficient technologies like use of climate resilient varieties, planting techniques, cropping pattern and management practices, effective use of water by drip system, mechanization, fertilizer management, IPM and IDM, use resource conservation technologies that improve input use efficiency which conserve and protect natural resources. Technological developments pertaining to sugarcane production were carefully considered and deliberated upon in order to guarantee a comprehensive improvement in productivity, social acceptability, commercially feasible sugarcane production and minimal environmental harm.

Keywords: Technology, mechanization, social acceptability, fertigation, IPM, IDM

Introduction

India is the 2nd largest sugarcane producer in the world after Brazil (Resende *et al.* 2023) [71]. Nowadays, sugarcane is used as a food crop as well as a source of renewable energy, bioelectricity, bio fuel and bio materials (Figuerora-Rodriguez *et al.* 2019) [25] and is a sound economic source of farming community of India, leading to socio-economic development in the country. In last 70 years there is a remarkable achievement in sugarcane production from 57.05 Mt (1950-51) to 405.42 MT (2019-20) in India (Sharma *et al.* 2022) [77]. This sugar & allied industry sustains not only the cane growers, sugar millers, manufacturers of sugar machinery and agricultural implements.

The sugarcane grower has facing important sustainability issues. Sugarcane productivity is hampered by huge losses due to several biotic and abiotic stresses like microbes, nematodes, drought, water logging, alkalinity and salinity. Salinity is a significant factor limiting sugarcane yield its effects are shown in changes to many physiological and morphological processes, which inhibit growth. (de Andrade *et al.* 2017) [19]. Besides this, cane cultivation has some other problems as small land holding which is difficult for mechanization, lack of location and situation specific varieties, limited irrigation facilities, imbalanced usage of fertilizers and abundance of pests and diseases are some of the major reasons for low productivity and recovery.

(Singh *et al.* 2019a) [86] reported that sustained efforts and holistic approach is necessary to enhance the productivity of cane and sugar in integration of various sugarcane production technologies are required to be implemented. (Patnaik *et al.* 2016) [64] reported that sugarcane

was planted by bud chip technology showed increase in productivity by 13.86% and decrease 10.24% cost as compared to traditional planting material. In early stage of sugarcane intercropping of short duration crops found most successful practice for efficient utilization of sun light, soil moisture, inter row spacing and other resources without affecting the main crop and increase productivity per unit area per unit time (Kumar *et al.* 2015a) ^[47]. Availability of high-yielding and high-quality sugarcane varieties are plays significant role in increasing farm productivity and farmers' incomes (Singh *et al.* 2019a) ^[86]. Soil fertility is maintained by using organic manures, crop residue and biofertilizers in combination with other plant nutrients. Integrated weed management practice effectively reduced the weed menace during early slow growth period of sugarcane while the hoeing done at 60 and 90 DAP along with herbicide which eradicated residual weed flora from the field (Ghodke *et al.* 2020) ^[27]. A sufficient supply of water is essential for healthy crop growth and high consistent harvests. IPM is the significant strategies to minimize pest infestation sustainably in a non

polluted environment (Sable and Kadam 2012) ^[73]. The IPM techniques involves cultural practices that have been altered an prominence on biological control (predators, parasitoids and entomopathogens), plant extracts, pest monitoring, crop management techniques, and cautious use of insecticides (Khatri *et al.* 2020) ^[42]. Effective sugarcane disease management has changed as a result of novel interventions including continuous disease surveillance, better fungicide distribution, molecular diagnostics in conjunction with a healthy seed nursery, etc. (Viswanathan 2022) ^[104].

This article highlights technological advancement which tackles challenges like deterioration of soil health, infestation of weed, pest and diseases, low sugarcane production and increasing production cost. Technological advancements related to sugarcane production discussed thoroughly and deliberated upon so as to ensure a holistic improvement in the sustainable sugarcane production, productivity, socially acceptable economically viable with minimum damage to the environment.

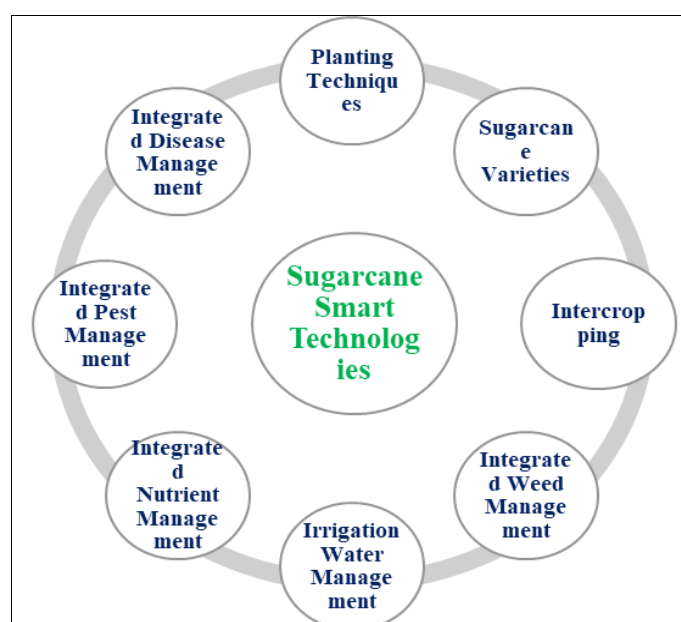


Fig 1: Sugarcane smart technologies

A. Planting Techniques

Sugarcane is vegetatively propagated plant. The growth and yield parameter of sugarcane gives better response to planting layout, planting methods, planting material, bud placement, plant-population etc. Commercially sugarcane setts are used mostly for planting in different layout. Flat planting, ridges and furrows, paired row and ring pit methods are used for planting in all over the world (Nalawade *et al.* 2018) ^[60].

Planting methods and row spacing

Trench methods of planting are mostly adopted in sugarcane among various planting methods. In this method 20-25 cm deep

trenches are opened with ridger, having row to row distance is 75-120 cm. The highest no. of shoot, no. of millable cane, cane weight and yield was found in paired row planting than that of conventional planting (Singh *et al.* 2012) ^[84].

The higher (23.2%) production of cane yield in wide bed planting and paired row methods showed more B: C ratio. (Singh *et al.* 2019b) ^[87]. Tayade *et al.* (2017) ^[96] reported that the 90 cm spacing between rows was more effective for development of tillers, better use of sunlight and its converts it in to the formation of biomass, stalk and CCS yield. Among the planting methods, pit planting recorded highest benefit cost ratio (2.85) (Table 1).

Table 1: Impact of row distance and planting methods on sugarcane production

Treatment	No. of tillers (m ²)	Cane length (cm)	Millable cane (m ²)	Cane Yield (tha ⁻¹)	B:C Ratio	Source
120 cm apart trenches	12.6	223.2 a	12.65	134.12	1.34	Ghaffar <i>et al.</i> (2012) ^[26]
paired row planting method (60:120 cm spacing)	13.35	206.2	9.73	72.3	-	Singh <i>et al.</i> (2012) ^[84]
Small pit (120cmx 60cm spacing 30cm depth with three settlings per pit)	12.99	327.6	11.89	149.5	2.11	Gulati <i>et al.</i> (2015) ^[29]
180 cm spaced trenches with triple row strips.	-	224	12.80	15.11 A	-	Ullah <i>et al.</i> (2016) ^[100]
Sowing in 120 cm apart trenches	15.92 A	2.36	13.51 A	104.4 A	-	Chattha <i>et al.</i> (2007) ^[14]
Pit planting	12.09	-	8.45	96.70	2.85	Sidar <i>et al.</i> (2020) ^[82]

Planting Material

Yield, productivity and quality of produce is depends on seed material used. Well swollen eye buded, healthy, pest and disease free setts are used for planting of sugarcane. In pit planting the pre- germinated cane settlings can be an ideal source of planting material particularly in areas where there is problem of poor germination to ensure optimum plant population (Chand *et al.*

2011) [12]. As compared to bud chip settling micropropagated plantlets showed maximum number of millable cane ($89.47 \times 10^3 \text{ ha}^{-1}$) and cane produce (91.0 t ha^{-1}). Tissue culture or bud chip planting material should be applicable and cost saving alternative. Among various researches the scientists found that bud chip planting material recorded highest yield parameter than other planting materials (Table 2).

Table 2: Effect of planting material on sugarcane yield

Treatment	Germination (%)	Cane length (cm)	No. of tillers (m^{-2})	Millable cane (m^{-2})	Cane yield (t ha^{-1})	B:C Ratio	Source
Planting single chip bud seedlings	-	190.00	270.7	-	101.85	-	Bhanupriya <i>et al.</i> (2014) [8]
Bud chip method	93.2	-	173.00	14.2	129.2	3.86	Samant (2017) [74]
Chip budded seedlings;	87.01	229.46	113.01	-	98.32	2.63	Sugeerthi <i>et al.</i> (2018) [94]
Bud chip method	92.6	-	231.00	14.1	122.6	3.94	Mishra (2019) [58]
Transplanting of chip budded seedlings with 5 x 1 ft spacing in a double row	85.7	453.00	168.14	12.3	-	-	Sathiya <i>et al.</i> (2024) [75]

B. Sugarcane Varieties

The introduction of new sugarcane varieties stands out as a pivotal moment, ushering in a new era of production, productivity and economic growth for farmers across the state. The CSRS, Padegaon (MH), India, was first established in 1890 at Pune. In 1930 it was relocate to Padegaon, Dist. Satara. This CSRS has releasing 12 varieties of sugarcane which were high yielding, pest and disease resistant, water and nutrient

responsive characters and make positive impact on economic development of farmers so these varieties become popular among the farmers

(<https://iisr.icar.gov.in/iisr/aicrp/pages/padegaon>).

These efforts led to the release of several commercially successful cultivars, significantly boosting sugarcane production in many regions including western Maharashtra, Marthwada and Vidarbha region.

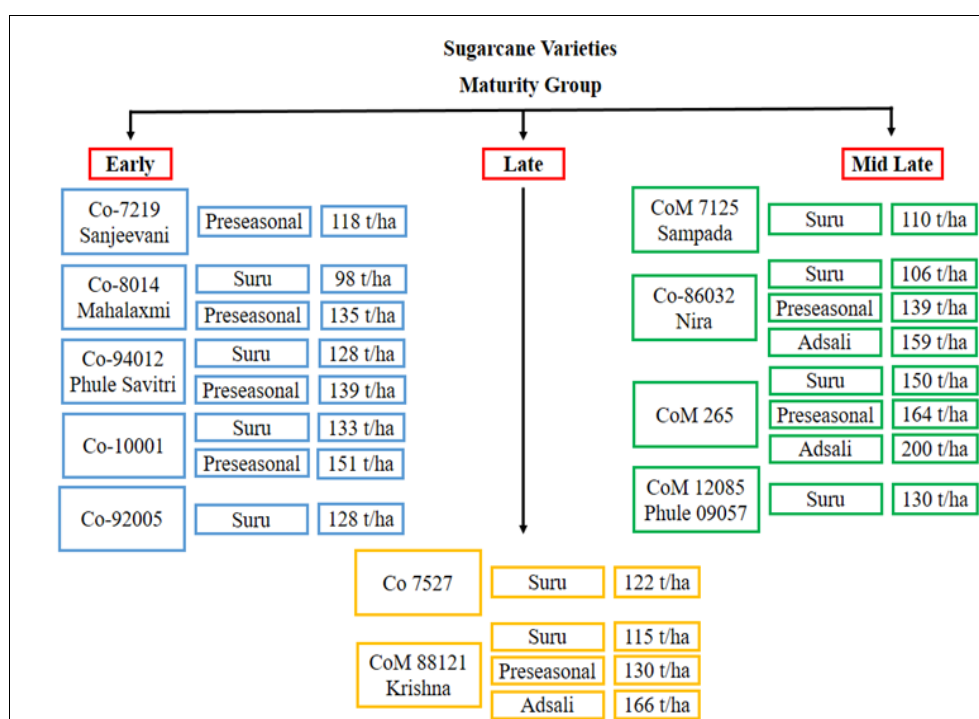


Fig 2: <https://iisr.icar.gov.in/iisr/aicrp/pages/padegaon>

From above (Fig. 2) it is evident that, the Mahatma Phule Krishi Vidyapeeth, Rahuri released varieties viz., Co 419, Co 740 were very old varieties released in 1936 and 1956 respectively. These varieties were very popular amongst the farmers in earlier period. In between 1980 to 1990 three varieties viz., Co 7219, Co 7125, and Co 7527 were released which occupied major area of sugarcane.

Co 86032 is largely accepted by farmers because of overcoming biotic and abiotic stresses. The area under these two varieties Co 86032 and CoM-0265 increased tremendously from the release

year of the respective varieties. After release of these two varieties the productivity of sugarcane was above 90 t ha^{-1} in Western Maharashtra.

The CO 86032 sugarcane variety is known for its elite characteristics, particularly for sugar recovery, cane production and resilient to varied environments. Research done on this shown that it performs well regarding cane production, sugar yield and sucrose content, with notable improvements over other standard varieties (Srinivasan *et al.* 2022) [93]. Physiological parameters such as internodes length, stalk height and single

cane weight have been highlighted as superior in it as compared to other varieties.

Moreover, the enhanced productivity of these varieties has proven to be a game-changer for farmers, empowering them to maximize their land's yield potential while minimizing input costs. The results further revealed that the cultivation of Co 86032 improves the economic condition of farmers of Maharashtra from last 22 years (Gulave *et al.* 2020) [30].

In conclusion, the impact of sugarcane varieties released in Maharashtra on production, productivity and the economy of farmers cannot be overstated. Through their adoption, farmers have not only increased their yields and incomes but have also contributed to the overall growth and prosperity of the state's agricultural sector. As Maharashtra continues to embrace innovation and sustainable practices, the future looks sweeter than ever for its farming community.

C. Intercropping

Intercropping is a promising approach to boost the production of short-term crops. like pulses, oilseed crops, maize, vegetables and spices. Sugarcane is a wide distance (60 to 180 cm) and take 12 to 18 months for harvesting so it require 30 to 45 days for sprouting because of slow growth in initial stage so there is a great opportunity to take small duration crops as a intercrop in sugarcane cultivation. Intercropping in sugarcane utilizes light, space and moisture in initial stage of sugarcane also minimizes weed infestation.

Intercropping with sugarcane alters the physical, chemical, and biological qualities of the soil. This could attributed the variation in growth habit, rhizodeposition, intake of nutrient and plant debris, etc. (Theirfelder and Wall 2012) [97]. Intercropping of soybean in sugarcane found ideal for enhancing production and income over unit area and time by efficient utilization of light, reducing N-leaching and stability in yield (Yang *et al.* 2013) [108]. While in sugarcane wheat, mustard and maize take as an intercrop helps to increase organic carbon and microbial respiration in soil (Suman *et al.* 2006) [95]. Under an intercropping system, plant roots directly interact with one another; consequently, root exudation may change microbial heterogeneity, activity of various enzymes and productivity of crop (Lian *et al.* 2019) [54].

Various intercropping systems have been developed due to its beneficial effect over monoculture regarding soil health, crop growth, yield and crop production per unit area (Hossain *et al.* 2003) [34]. Pulses are best suited in intercropping with sugarcane and helps microbial activities, yield and net return (Li *et al.* 2013) [53]. Potato + sugarcane cropping system increases production as well income than any other intercropping because maximum utilization of phosphorous, potassium and adequate use of nitrogen (Rehman *et al.* 2014) [70] followed by sugarcane + fenugreek (Singh *et al.* 2020) [83] (Table 3). There is negative effect of sugarcane monoculture on health of soil (Cherubin *et al.* 2016) [16]. Hence intercropping of different crops in sugarcane plays important role to improve health of soil and crop yield.

Table 3: Economic performance of sugarcane intercropping

Intercropping	S. cane Yield	Intercrop yield	Yield advantage compare to sole crop (t/ha)	B:C ratio	References
S. cane + Cowpea	86.8	-	118.4	2.06	Kumar <i>et al.</i> (2006) [49]
S. cane + Maize	131.0	-	200.6	1.90	Rana <i>et al.</i> (2006) [68]
S. cane + Potato	99.3	-	-	5.36	Rehman <i>et al.</i> (2014) [70]
S. cane +Bhendi	97.2	-	116.0	2.03	Gouri <i>et al.</i> (2015) [28]
S. cane + Palak	99.65	-	116.8	2.05	Gouri <i>et al.</i> (2015) [28]
S. cane + Cabbage	69.52	1.52	87.95	1.75	Kumar <i>et al.</i> (2015a) [47]
S. cane + Groundnut	106.67	1.37	131.61	2.74	Ombase <i>et al.</i> (2018) [62]
S. cane + Potato	102.30	24.50	179.44	1.97	Singh <i>et al.</i> (2018) [89]
S. cane + Fenugreek	97.2	-	246.45	4.77	Singh <i>et al.</i> (2020) [83]

D. Integrated Weed Management

Effect of weed infestation on growth of sugarcane plant and its production depends on its density and the age of the sugarcane (Mehra *et al.* 1990) [57]. According to Singh and Kumar (2013) [85] sugarcane is wide spacing crop which is favorable for growing wide range of weeds in initial stage. Application of fertilizers and repeated irrigations helps weeds to grow fast and compete with sugarcane plant at initial stage (Singh *et al.* 2008) [88] for water, nutrients, light and area increases weed density results in loss of cane yield (Zafar *et al.* 2010) [109].

In India, almost 150 weed species found in sugarcane cultivated area (Rathika *et al.* 2023) [69]. The prime species of weeds are *B. articularis*, *C. pilosus*, *A. haustonianum*, *Commelina* spp., *Axonopus compressus*, *M. invisa*, *C. arvensis*, *S. bifolia*, *D. annulatum*, *B. amosa*, *M. corchorifolia*, and *S. palmifolia* spp., From these weed species, the problem of *A. haustonianum*, *D. retroflexa*, *M. invisa*, *B. articularis*, *E. indica*, *D. horizontalis*, *C. dactylon*, *C. bengalensis*, *C. rotundus*, *B. pilosa*, *S. barbata*, *A. conyzoides*, *P. conjugatum*, *P. urvillei*, *P. foetida*, *P. oleraceae*,

S. nigrum, *T. portulacastrum*, *S. halepense*, *D. aegyptium*, *P. maximum* and *C. album* which accounts around 70% overall weed population (Begum and Bordoloi 2016) [7]. The weeds are not controlled in early growth stage of sugarcane found reduction in sugarcane yield from 10-70 percent (Rathika *et al.* 2023) [69]. Chauhan and Srivastava (2002) [15] reported that 40-67% heavy yield loss in sugarcane due to weed infestation.

There are four methods of weed control in sugarcane i.e. Cultural (Field preparation, Maintenance of plant population, Irrigation and drainage, Crop rotation, Mulching, Inter cultivation and Intercrops), Mechanical (Tillage, Hoeing, Hand Weeding), Biological and Chemical (Pre and post emergence of Herbicides).

Cultural and mechanical practices became cumbersome, time consuming, labourious and costly (Ramesh and Rathika 2016) [67]. Application of herbicides is widely used for effective check of weeds in sugarcane. Herbicides are sprayed before and after the emergence of sugarcane plant to avoid sugarcane weed competition (Ghodke *et al.* 2020) [27].

Table 4: Impact of weed management techniques on sugarcane production.

Treatment	WCE (%)	Millable cane (10 ³ /ha)	Cane yield (tha ⁻¹)	B:C Ratio	Source
Metribuzin @ 0.50 kg a.i.ha ⁻¹ + 2, 4-D @ 1.00 kg a.i. ha ⁻¹ at 25 DAP fb hoeing at 60 and 90 DAP	75.99	80.8	155.51	3.13	Ghodke <i>et al.</i> (2020) [27]
PE Pendimethalin + Sesbania (BM) + hand hoeing at 90DAP	82.3	128.0	100.5	2.72	Fanish and Ragavan (2020) [24]
Three hoeing at 30, 60, 90 DAP	57.1	119.2	88.8	3.35	Ballyan <i>et al.</i> (2015) [6]
Metribuzin 1.4 kg ha ⁻¹ PE fb 2,4-D 1.6 kgha ⁻¹ at 45 DARI	70.3	105.0	74.3	1.57	Kumar <i>et al.</i> (2014) [46]

A range of studies have demonstrated the positive impact of integrated weed management on sugarcane yield and quality. Post-emergence application of metribuzin + 2, 4-D followed by hoeing at 60 and 90 DAP was the most effective integrated weed management practice for pre-seasonal sugarcane (Table 4).

The combination of chemical and mechanical weed management strategy found most successful method in reducing weed competition during the growth of sugarcane and also controlling residual weed flora.

E. Irrigation Water Management

Due to global climate change, heat waves and droughts may combine to harm field crops (Jaldhani *et al.* 2022) [37]. In sugarcane producing countries such as Brazil, Cuba, Myanmar, Pakistan, Philippines, China, Thailand and India drought or early drought stress is a common issue. It inhibits the yield of photosystem II efficiency, physiological activity of plant which reduces biomass, sugar recovery and cane production up to 60 per cent (Leanasawat *et al.* 2021) [51]. Therefore, additional water from an appropriate watering system may be needed for the sufficient moisture in the soil during the life cycle of plant in order to reap greater benefits with high yield and an extended ratooning time. Sugarcane crops have been irrigated using various micro irrigation systems (Mahesh *et al.* 2016) [56].

1. Water requirement and iWUE

The crop coefficient (Kc) and potential evapotranspiration (ET_o) were major factors used for calculating requirement of water for sugarcane crop which meant that it depended on the climate and growth stages. The average annual water need was 1212 mm (Wonprasaid *et al.* 2023) [105]. Kaushal *et al.* (2012) [40] estimated that the production of sugarcane required a lot of water, between 1100 and 2200 mm every season.

The iWUE of subsurface drip irrigation was 1.2 times higher than that of surface drip irrigation (Hanafy *et al.* 2008) [32]. Various research were revealed that subsurface drip irrigation conserve maximum moisture than surface drip irrigation because of avoiding loss of water from soil (Mahesh *et al.* 2016) [56].

2. Soil Moisture Status

Amount of moisture in the soil plays crucial impact in sugarcane cultivation, affecting various parameter of the crop growth, development and yield. Proper soil moisture is major requisite for germination of sugarcane setts and the establishment of sugarcane seedlings. Root development, plant growth and biomass production, photosynthesis and transpiration, sugar accumulation and yield, nutrient uptake and stress resistance.

During the growth season, average moisture in the soil under drip system was 24.3% which was greater than under rainfed situation (19.1%). Before the irrigation, moisture in the soil progressively dropped up to 19–20% in drip irrigation however, it increased up to 25–26% after drip irrigation and nearly equal to field capacity of soil (26.4%) (Wonprasaid *et al.* 2023) [105]. 25 to 30 per cent moisture boost the germination (71–95%) of

sugarcane setts (Moreira and Cardoso, 1998) [59]. Development of sugarcane root and availability of nutrients particularly Ca and P₂O₅ was maximum at 20 to 40 cm depth in the soil because of drip irrigation system (Ohashi *et al.* 2015) [61].

3. Yield Components

The application drip method in sugarcane cultivation improves quality of produce, production (7–25%) and water use efficiency (60–200%) (Kaushal *et al.* 2012) [40]. Yield of sugarcane was increased when the availability of water was as per the demand of sugarcane plant (Da Silva *et al.* 2013). Drip irrigation is used instead of floods, border, furrow, sprinkler or micro-sprinkler irrigation maximizes the production of cane by 28.92%, 14.55%, 8.03%, 2.32% and 5.17% respectively (Yang *et al.* 2023) [107].

F. Integrated Nutrient Management

Plant nutrients regulate growth and development of sugarcane plant and its management is important for higher sugarcane yield. Nitrogen, phosphorus, potassium and micronutrients are essential nutrients that are vital to the growth and metabolism of sugarcane plants (Singh *et al.* 2019a) [86].

There is a great scope for utilization of agricultural waste from the sugarcane industry to lower the use of fertilizers (Dotaniya *et al.* 2016) [21]. Shukla *et al.* (2019) [80] recommended to apply composted 5 tons press mud or well-prepared 10–15 tons FYM/compost in one hector area. Incorporation of bio-compost and farmyards which increase available nitrogen and enhances the multiplication of microbes (Sinha *et al.* 2014) [91]. Press mud contains 10–15% N, 1.4–4.0% P₂O₅, 0.5–2.0% K₂O and variety of elements like Mg, S, Zn, Cu, Fe and Phospho Rich Organic Manure (PROM) was prepared using liquid inoculants in 30 days containing 8.84% organic carbon, 2.5%N, 10.55% P₂ O₅ and 0.62% K using windrow method (Shukla 2024) [79]. Press mud is rich source of Ca, Mg, Si, P₂ O₅, Fe and Mn (Yadav and Solomon 2006) [106]. Bagasse is a byproduct of sugar factories; it includes nutrients that can be utilized to produce biofertilizers in large quantities. (Rocha *et al.* 2011) [72].

Glucanacetobacter is an endophytic nitrogen-fixing bacterium particular to sugarcane. Also 10 kg Azotobacter /Azospirillum applied in one hector area two times in first 60 days saves 25 per cent nitrogen (Shukla *et al.* 2019) [80]. Babar *et al.* (2011) [4] found that 50% Bio-fertilizer + 50% RDF of chemical fertilizer increases the sugarcane yield and reduces environmental pollution. Arbuscular Mycorrhizal Fungi protect the plant from salt stress condition by increasing nutrient uptake, accumulation of an osmoregulators, an increase in rate of osmolytes and water-use efficiency (Evelin *et al.* 2009) [23]. Acetobacter and PSB (@ 1000 ml ha⁻¹ each) is applied as sets treatment, soil application (2000 ml ha⁻¹ each at each time), at sowing and at earthing up gives higher cane yield and cost effective too by 50 per cent reduction of chemical nitrogen and phosphorous (Mahatma *et al.* 2016) [55].

Sesbania aculeate taken as green manure in asugarcane cultivation resulted additional 10 t ha⁻¹ yield and net return of Rs.

25000ha⁻¹. Because of this green manuring, soil become rich in organic matter and nitrogen also lowers soil pH by 0.17. Kammar *et al.* (2023) ^[43] found that sugarcane ratoon was benefited by application of sugarcane trash and green manure and also helps nutrient status, microbial counts, soil microbial

biomass, carbon and Dehydrogenase in soil as compared to burning or removal of sugarcane trash. Higher sugarcane yields were obtained from the integration of inorganic fertilizer and green manuring (Table 5 & 6).

Table 5: Impact of different organic fertilizer inputs on sugarcane yield

Organic fertilizer inputs	Cane yield (t ha ⁻¹)				Source
	Without organic manures	With organic manures	Increase/decrease		
			(tha ⁻¹)	(%)	
<i>S. aculeate</i>	104.9	144.5	39.6	37.75	Chandra <i>et al.</i> (2008) ^[13]
Vermicompost	87.42	93.88	6.46	7.38	Lakshmi <i>et al.</i> (2011) ^[50]
Bio methanated distillery effluent	58.50	72.13	13.63	23.29	Sinha <i>et al.</i> (2014) ^[91]
Bio compost	58.70	74.14	15.44	26.30	Sinha <i>et al.</i> (2016) ^[92]
<i>C. juncea</i>	59.11	91.87	32.76	55.42	Kabiraj <i>et al.</i> (2017) ^[39]
Bio gas slurry	57.0	70.2	13.2	23.15	Umesh <i>et al.</i> (2018) ^[101]
Sugarcane trash	47.0	59.3	12.3	26.17	Umesh <i>et al.</i> (2018) ^[101]

Table 6: Impact of different fertilizer level on sugarcane

Sr. No.	Treatment Details	Remark	Reference
1	N ₂₄₀ K ₂ O ₁₂₀	High yield with quality. An increase inN, P ₂ O ₅ , and K ₂ Oavailability by maintaining soil health.	Kumar <i>et al.</i> (2019a) ^[44]
2	25% RDF+75% effluent	Highest cane yield, sugar yield and nutrient uptake	Sharma, (2014) ^[78]
3	100% of RDF	Higher cane yield and monetary benefit	Shivashenkaramurthy <i>et al.</i> (2021) ^[76]

G. Integrated Pest Management

Since the green revolution, crop pest conditions have drastically changed. The species of insects, frequency of their outbreaks and introduction of new pests have all contributed to the worsening of pest problems (Dubey *et al.* 2022) ^[22]. It is predicted that when global warming increases, losses from diseases and insect pests would rise (Deutsch *et al.* 2018) ^[20]. Networking, global cooperation, AI techniques, diagnosis and data analytics are necessary for the isolation and pest surveillance. (Dubey *et al.* 2022) ^[22].

Bio-intensive IPM is based on holistic agro-ecosystem interactions. This involves combining knowledge about insects, their symbionts, pathogens, natural enemies, plants and endophytes (Arshad *et al.* 2022) ^[3].

Major Pests of Sugarcane

Insect pests, nematode and diseases can all have an impact on sugarcane (Leslie, 2004) ^[52]. Certain pests have detrimental effects on the economy, bringing crops value down to below profitability. Approximately 1300 insect pest species are known to harm sugarcane crops worldwide (Qamar *et al.*, 2021) ^[65].

Insects from the order Lepidoptera, Homoptera, Coleoptera, Hemiptera, Orthoptera and Isoptera damage the sugarcane worldwide. There are three types of pest in sugarcane viz, Borer pests, Sucking pests and Subterranean pests (Table 7).

Losses by Pest

Insect pest attacks on every part of sugarcane plant from planting to harvesting, which decreases sugar recovery and 20-25% production (Kumar *et al.* 2019b) ^[45] the identical outcome was discovered by (Shyamrao and Kumar 2020) ^[81]. The major pest of sugarcane is borer, which reduces sugarcane yield by 8–10% in the field and by 10–15% in sugar industry (Jasmine *et al.* 2012) ^[38].

Table 7: Sugarcane pests and yield reduction (%)

Name of pest	Khanzada (1993)	Kumar <i>et al.</i> (2019b) ^[45]	Qamar <i>et al.</i> (2021) ^[65]
Early shoot borer	22–33	-	-
Top shoot borer	21–37	-	10-15
Stalk borer	Upto33	20	15-36
Gurdaspur borer	70–75	-	20
Root borer	Upto10	-	10-20
Scale insect	32.60	-	-
<i>Pyrilla</i>	35	-	-
Whitefly	86	24	-
White grub	80-100	-	-
Termite	30–33	-	-
Woolly Aphid	-	26	-
Leaf hopper	-	28	25

1. Control Measures

Knowledge-based integration of Integrated Pest Management (IPM) methods reduces pest levels in crops (Conlong & Rutherford 2009 and Das and Lala 2024) ^[11, 18] to minimize the impact of pests on yield and quality of sugarcane (Campbell *et al.* 2009) ^[11]. IPM reduces pest population sustainably to a satisfactory level without harmful effect on environment (Sable and Kadam, 2012) ^[73].

Modified cultural techniques, focus on biological control (predators, parasitoids and entomopathogens), plant extracts, pest monitoring, crop management techniques and the cautious application of pesticides are all included in IPM (Khatri *et al.* 2020) ^[42]. Jaipal (2000) ^[36] suggested to use six ecology-based techniques were used such as use of urea, time of irrigation, management of crop residue, earthing up operation, propping of stalk, application nitrogen spray, release of different egg parasitoids (*T. chilonis*) and destruction of pests at their damaging stages.

Table 8: Practices carried out in IPM for sucking pests. (Das and Lala 2024) ^[18]

Sucking Pests: Leaf Hopper, Whitefly, Woolly Aphid, Scale Insect and Mealy bug	
Methods	Treatments
Cultural	Use drip irrigation, use RDF, Keep the cultivated area along with bund free from weed and avoid repeated ratooning, use resistance varieties.
Mechanical	Trimming and disposing of affected leaves (Bhavani & Rao, 2013) ^[9] . Detrashing of sugarcane.
Biological	Releasing <i>Chilocorus nigritus</i> or <i>Pharoscyrnus horni</i> egg cards. The release of <i>hymenopteran parasitoids</i> and predatory mites <i>Saniosulus nudus</i> which feed on scale insects, Encourage natural predators (<i>Diapha aphidivora</i> , <i>Chrysopa</i> spp., <i>Cheilomenes sexmaculata</i> , <i>Coccinella septempunctata</i>) and pathogens (<i>C. oxysporum</i> , <i>M. anisopliae</i> , <i>V. lecanii</i> , <i>B. bassiana</i>) for effective control of sugarcane woolly aphid.
Chemical	- Sprays 0.1% of malathion (50 EC), or 0.15%acephate (75% SP). Spray 1 ml l⁻¹dimethoate 30 EC, mixed with fish oil resin soap at 2.5 ml l⁻¹. - Apply 2 l ha⁻¹fenitrothion 50 EC. Also, use of 125 g ha⁻¹thiamethoxam 25 WG. Additionally, spray 2 g l⁻¹acephate. Repeat the spray after one month.

H) Integrated Disease Management

In India near about 60 diseases have been identified to infect this crop. From these diseases some are of major and economically important (Tiwari *et al.* 2017) ^[99]. Diseases like smut, red rot, ratoon stunting disease (RSD), wilt, leaf scald (LSD), yellow leaf disease (YLD) and grassy shoot are epidemics which affected sugarcane cultivation during different decades in India (Viswanathan, 2018) ^[102]. Recently, some are recognized as minor diseases, viz, twisted top (Pokkahboeng), leaf fleck, brown spot, rusts, mosaic, yellow spot, etc. have affected sugarcane yield in different parts of country (Viswanathan, 2022) ^[104]. Generally 15 to 30% loss of sugarcane production due to infestation caused by fungal diseases (Tiwari *et al.* 2010) ^[98]. According to Ali *et al.* (2023) ^[2] sugarcane smut decreases yield by 9%-75% and 3%-7% sugar recovery. The yield loss due to Red rot (sugarcane cancer) was observed up to 100% (Viswanathan, 2021) ^[103]. Grisham reported 24-50% yield loss due to infestation of ratoon stunting disease (RSD) in sugarcane. 40.2-50.1% reduction in sett germinability caused by sugarcane wilt, millable canes (39.9-50.9%), tillers (40.0-49.0%) and cane production (45.2-51.2%) (Kumar *et al.* 2015b) ^[48]. According to Parameswari *et al.* (2021) ^[63] grassy shoot disease

reported 5 to 70% yield losses in plant crops and up to 100% in ratoon sugarcane. Singh *et.al.* (2021) ^[90] recorded 40 per cent yield loss in sugarcane after incidence of pokkahboeng. Sugarcane mosaic disease decrease yield 17% to 50% in susceptible varieties (Bagyalakshmi and Viswanathan, 2021) ^[5]. IDM in agriculture helps sustainable and resilient farming systems that can better withstand disease outbreaks and other environmental challenges. The major components of IDM are crop rotation, rouging, sanitation, disease-escaping varieties, soil solarization and use of bio agents such as predatory insects, parasitic nematodes and microbial antagonists.

Different component of IDM

1. Cultural practices a) Crop rotation b) sanitation c) Disease escaping varieties d) rouging e) Mixed cropping (Gupta *et al.* 2023) ^[31].
2. Biological Control
Biological disease management in sugarcane involves integrated approaches to combat various pathogens with combination of cultural practices, resistant varieties, and biocontrol methods.

A. Biological control of diseases

Sr. No.	Name of Disease	Causal Organism	Bio agent
1	Smut	<i>S. scitamineum</i>	<i>P. Aeruginosa</i>
2	Red rot	<i>C. falcatum</i>	<i>B. velezensis</i>
3	Pokkahboeng	<i>F. sacchari</i>	<i>T. harzianum</i> , <i>P. fluorescens</i> and <i>Bacillus</i> sp.
4	Wilt	<i>F. sacchari</i>	<i>T. harzianum</i>
5	Pineapple	<i>C. paradoxa</i>	<i>T. harzianum</i>
6	Red stripe	<i>A. subsp. avenae</i>	<i>A. strain</i>
7	Ratoon stunting	<i>L. xyli</i>	<i>Diazotrophic</i>
8	Leaf Scald	<i>X. albilineans</i>	<i>G. diazotrophicus</i>
9	Sugarcane mosaic	<i>Mosaic virus</i>	<i>T. harzianum</i> and <i>M. anisopliae</i>

B. Botanical Control

It has been demonstrated that the leaf extracts of *Azadirchta indica* (5%) and *Eucalyptus globosus* (5%) have stronger antifungal properties. Garlic, Ginger, Turmeric, Tobacco, Neem and essential oils of Nettle, Thyme, Lemon grass, Eucalyptus, Rue and Tea tree commercially used for preparation of extract against various diseases (Gupta *et al.*2023) ^[31].

3. Chemical Control
For effective control of twisted top and mealy bug attack in sugarcane, spray of imidacloprid (1ml l⁻¹) and propiconazole (1 ml l⁻¹) or carbendazim (1 g l⁻¹) is suggested (Viswanathan, 2022) ^[104]. Triazole fungicide, such as Propiconazole, Triadimefon and Cyproconazole and the Strobilurin fungicide Azoxystrobin were effective against smut disease (Bhuiyan *et al.* 2021) ^[10]. Various

pests like aphids, jassids, thrips, mites, mealy bugs are act as vector to transmit viral diseases therefore it is prime need to control the attack of these pests so Holkaret *al.* (2020) ^[30] reported that spraying of dimethoate 30 EC @ 0.05% was showed against *M. sacchari* to minimize 83.3% population of sugarcane aphids. Whereas, population of aphids also minimize up to 77.5% by application of chlorpyriphos 20 EC at 0.05%.

4. Genetic Resistance

A number of biotechnological approaches, such as the utilization of molecular markers associated with resistant sources, *in vitro* culture of apical meristems, molecular diagnostic techniques and the use of byproducts are being successfully used for the sustainable management of sugarcane diseases in Tucumán, Argentina (Racedo *et al.* 2023) ^[66].

Disease resistant varieties of sugarcane

CoM 7125 (Sampada), CoM 88121 (CoM7714) (Krishna), Co 86032 (Nira), Phule 265 these varieties are Moderately resistant to smut, Co 94012 (Phule Savitri) is Moderately resistant to smut and red rot, Co 92005, MS 10001 are resistant to smut, red rot and wilt and CoM 12085 (Phule 09057) is resistant to smut and moderately resistant to wilt also resistant to foliar diseases (Rust, brown spot, Pokkahboeing) under field conditions.

(<https://iisr.icar.gov.in/iisr/aicrp/pages/padegaon>)

Adopting these innovative ways is expected to solve the increased problems arises by sugarcane diseases for sustaining sugarcane production and productivity.

Conclusion

Sugarcane is annual crop grown in three season and utmost to environmental factors such as temperature, rainfall, frost, etc. and is also susceptible to various insect pests, diseases, weeds and soil health. Application of different advance crop management technologies from selection of planting material to harvesting, helps in minimizing the adverse effect of biotic and abiotic stress by proper application of water, fertilizers, chemicals and reducing the carbon while improving the health of soil, qualitative and quantitative parameters and hence sustainability of sugarcane farming. Further, integrated approach and judicious use of various technologies such as planting techniques, cropping system, nutrient management, water management through micro irrigation, integrated pest, disease and weed management, etc. are plays important role in efficient utilization of inputs and resources for sustainable sugarcane production. This technological management helps for sustainable sugarcane production by maintaining soil health, avoiding harm to man, animal and environment.

Thus technological advancements related to sugarcane agriculture and sugar industry shall be thoroughly discussed and deliberated upon so as to ensure a holistic improvement in the sugarcane production, productivity, quality of produce and socio economic standard of sugarcane grower.

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Compliance with Ethical Standards

Conflict of Interest: The authors declare that they have no conflicts of interest.

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