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Evaluation of different planting methods for sustainable sugarcane production: A comprehensive review

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Abstract

In order to meet the global demand for energy and sweeteners, India, the world's second-largest producer of sugarcane, has gradually improved its output potential over the past 20 years. Planting is the most important and time-consuming stage of sugarcane production. Vegetative propagation of crops such as sugarcane, single-bud to six-bud setts, tissue culture-prepared settling, or single-bud nurseries is a frequent practice. The majority of commercial planting systems employ ring pits, ridges and furrows, or flat planting. The sets with two buds have a better yield and a germination rate of 65 to 70%, according to the researchers. Larger setts do fare better in bad weather, even if single-budded setts also germinate 70% of the time if chemically treated. Partially or fully automated planting devices are used in modern sugarcane planting techniques. Even now, over 80% of the sugarcane planted in Brazil, Australia, India, and other nations is done by hand. These provide an overview of contemporary sugarcane farming methods in India. Adopting the finest planting practices is one of the most important research priorities that may be established to increase the sustainability of sugarcane production and secure its enormous potential, like sugarcane planting techniques.

Keywords

mechanization; planting techniques; soil; sugarcane

Introduction

Sugarcane is a long perennial crop that can reach heights of 5 to 6 meters. It is the primary source of raw materials used in the production of sugar worldwide. Sugarcane accounts for over 80% of global sugar production, with sugar beets accounting for the remaining 20%. The sugar plant, khandsary (brown sugar) mills, and jaggery (gur) businesses use it as raw ingredients. Molasses is utilized in the manufacturing of biofuel, ethanol, and alcoholic beverages. Additionally, molasses is used to produce enzymes, yeast, food, feed, and ferment products like citric, oxalic, and lactic acids. For biofuel and organic manure, respectively, by-products such as bagasses and filter press mud are utilized. Cattle are fed the green tops of sugarcane, and the rise of the sugar industry follows the evolution of human civilization.

The nation's second largest agro-processing sector after cotton and textiles is sugar production. Cultivating sugarcane and its by-products involves about 4 million sugarcane growers and a significant number of agricultural laborers, making up 7.5% of the employment in rural areas. The Polynesians domesticated the plant for its sweet stem (1), but it is now a multipurpose crop that produces not only sugar but also a number of value-added products like paper, ethanol, and other chemicals derived from alcohol, animal feed, particle board, antibiotics, biofertilizer, and raw material for electricity generation (2). Thus, the sugar business serves as a focal point for growth in society in rural areas by mobilizing rural resources, creating jobs and higher earnings, and assisting in the construction of communication and transportation infrastructure.

Because sugarcane is so important to the economies of the regions where it is grown, increasing sugarcane production could have a significant positive impact on the financial well-being of growers and other stakeholders in sugarcane farming (3). Low-quality seed is causing sugarcane yields to decline daily (4, 5). There are a number of potential direct and indirect effects of climate change on agricultural systems, including seasonal variations in temperature and rainfall that may affect agroclimatic conditions; changes to planting and harvesting schedules; water availability; pest, weed, and disease populations; changes to transpiration, photosynthesis, and biomass production; and changes to land suitability (6, 2). Tropical India experiences minimal temperature issues during germination, with low temperatures restricting sugarcane growth during autumn and spring seasons, despite subtropical conditions offering narrow time spans. Sugarcane requires the optimum temperature ranges of 22 to 36°C for germination of setts and 26 to 33°C for sprouting (7). Cane yield was positively impacted by maximum and lowest temperatures of 31.7°C and 14.7°C, respectively, during the germination and tillering stages (8). Drought conditions and scarcity of rainfall due to climate change negatively impact sugar production and post-harvest losses (9).

A significant barrier to the profitable production of sugarcane is disease. Since sugarcane is vegetatively propagated, most illness pathogens tend to accumulate there. Therefore, in addition to seed cane, disease-causing pathogens are also brought to new regions. Over time, the gradual build-up of many pathogens transforms small illnesses into major ones. According to some historical epidemics caused by red rot, smut, wilt, grassy shoots, ratoon stunting, yellow leaves, and leaf scald, disease-infected seeds can play a major role in their emergence and subsequent transmission (10, 3). Sugarcane crops in subtropical regions face biotic stresses like red rot, smut, wilt, and ratoon stunting disease, while insect pests like root borer and scale insect cause Pokkah Boeng (11). Numerous sugarcane research stations produce and release high-yielding sugarcane cultivars. However, there is no seed for these types to be grown on a big scale (12).

Sugarcane has a low seed multiplication rate of 1:6 to 1:10 since it is a vegetatively propagated crop. The lack of high-quality seed material is therefore one of the main issues that farmers in underdeveloped nations deal with. Additionally, the large cane cuttings that are used as seed have a lot of pests and diseases, which significantly reduces cane quality and yield (3). Cane productivity and production on farms must be increased, as must the rate at which sugar is recovered in mills, in order to boost both output and profitability in the industry. The adoption of the most recent technologies is also necessary to increase cultivation efficiency and lower costs to ensure that new, improved sugarcane farmers and the sugar sector preserve sugarcane, which could be used as seed. In order to enhance sugarcane and sugar yields and support the sugar sector, this chapter offers a thorough analysis of the key sugarcane seed production processes and modern methods for seed quality verification through community-based systems.

Global sugarcane production status

The attractive and guaranteed pricing, along with advances in yield and recovery, continue to entice farmers to plant sugarcane despite the market's glut and declining sugar prices. It wouldn't be an exaggeration to say that the country has structurally changed into a nation with a surplus of sugar. The sector is highly consolidated, with the highest possible ten manufacturers in the world accounting for over 83 percent of the total revenue during the triennial ending (TE) 2020. The world's largest producer of sugarcane, accounting for 39.2% of global production in TE 2020, is Brazil, which is followed by India (20.1%), Thailand (4.95%), China (5.65%), Pakistan (3.72%), Mexico (2.95%), and Australia (1.67%). According to the Food and Agricultural Organization, which is part (13), sugarcane production worldwide reached 1920 million tonnes (MT) in 2020, a 2.7% rise over the previous year. The dynamic picture of sugarcane production over the past forty years in the leading producing countries shows that Brazil's industrial position has stabilized and that its share has grown from 18.2% in TE 1980 to 39.2% in TE 2020. India's share of global sugarcane production has decreased from 23% in TE 2000 to 20% in TE 2020. The output of sugarcane has increased in China, Thailand, and Pakistan. Over the forty years, sugarcane production has decreased in the United States, Australia, the Republic of the Philippines, the nation of Mexico, and Cuba (14).

Recent Indian sugarcane production status

India has a flourishing sugar industry, supported by the 6.5–7.7 million farmers who grow sugarcane and other related industries. With an average production of 494.22 million tons of sugarcane and a productivity of 82 tonnes per hectare, this crop is grown on around 5.88 million hectares, or 3.52% of the net planted area (15, 16). Table 1 shows that sugarcane average production and productivity increased in India between 2017 and 2022. While the national average has remained about 84.01 t/ha, tropical states show superior yield, ranging from 80 to 105 t/ha. The sugarcane crop was abundant across the country. In 2021-2022, the sugarcane crop increased by 22 lakh hectares in Maharastra, the country's main sugar source, thanks to the abundant monsoon. The state is expected to generate 138 lakh tonnes of sugar, a 30% rise from the previous year. India's sugar production is expected to reach a record-breaking 35.5 MT, up 14% from the current marketing year 2021-2022. The nation produced 31.1 MT of sugar in 2020-21 compared to 27.21 MT in 2019-20, 33.30 MT in 2018-19, and 22.45 MT in the 2017-18 marketing year. The first estimate of sugarcane production for 2022-23 is 4650.49 lakh tons (17).

Table 1. Sugarcane area, production, yield and sugar production in India

Year	Area (million ha)	Production (million tonnes)	Yield (tonnes/ha)	Sugar Production (million tonnes)
2017-18	4.732	379.90	79.6	22.45
2018-19	5.114	400.16	78.24	33.30
2019-20	4.867	377.77	77.61	27.21
2020-21	5.010	397.770	79.42	31.10
2021-22	5.080	414.700	81.20	35.00

Source: (15).

An estimated 35 MT of sugar were produced during the 2021-2022 sugar season, out of which, Maharashtra, Uttar Pradesh and Karnataka altogether contributed 80% of sugar production.

Cultivation of sugarcane

Sugarcane germinates at 25–32 °C, with optimal conditions in North Indian settings in October and February-March. Spring planting occurs in February and March, with March being the best month in Punjab and Haryana. Eastward planting starts in December-February, lasting 15–18 months. A year after it is sown in January and February, the crop is harvested (18). In addition to having enough levels of potassium, phosphorus, and nitrogen, the soil should be sodic, or alkaline and non-acidic. In sugarcane farming, controlling fertility through the use of environmentally friendly, sustainable agronomic practices like residue management and the addition of organic carbon-rich manure is a better method for recycling nutrients. Long-lasting and nutrient-depleting sugarcane is sometimes called a heavy feeder crop because it drastically lowers soil fertility. A higher proportion of sucrose is accumulated when nitrogen administration is limited to six to eight weeks before sugarcane harvest (19). Nitrogen is the main nutrient that promotes development, affects crop canopy area, and increases the absorption of solar radiation. It must be optimized, though, as too much nitrogen application can also lower the quality of the sugar. The largest amount of sugar yield and stripped cane was linked to a nitrogen application of 252 kg per hectare spread across two equal splits (20).

Planting techniques

There are a variety of techniques for planting sugarcane depending on the soil and climate conditions, labour availability, degree of mechanization, and moisture content (21–23).

System of Ridges and Furrows

Nepali farmers use a method where fields are divided into ridges and furrows using a tractor or bullock. The spacing is typically 90 cm, with closer spacing for early and short-duration varieties and wider spacing for longer maturities and higher tillering rates. Furrow length depends on slope and slope, with loosening the bottom for directed irrigation. Proper drainage and irrigation channels are installed. The top part of the furrows is left empty when setts are planted end to end or eye to eye in them and covered with 8–10 cm of soil (Fig. 1).

Fig. 1. Ridges and Furrows planting techniques.

The Flat Bed technique

The land is prepared for planting after ploughing, harrowing, planking, and leveling the terrain. Repeated ploughing helps conserve soil moisture, and the soil is mixed with manures and fertilizers. Planting of cane setts is done on level terrain by placing them 75–90 cm apart. The setts are covered with dirt or using a country plough. Sugarcane setts are planted using end-to-end planting techniques in furrows (Fig. 2). Compared to other approaches, this method requires a higher amount of seed (75000 three-bud setts/ha).

Fig. 2. Deep trench planting techniques.

System of trenches

This method is mostly used in coastal areas and other areas with heavy clay soil where cane lodges due to strong winds during the rainy season. U-shaped trenches or furrows with a depth of 25 to 30 cm are created by hand by piling clods manually and using spades spaced 75 to 120 cm apart. The width and depth of the trench are 20–30 cm, with the majority of the trenches being loosened once they are initially 30 cm and then another 10–15 cm below. After planting, setts are covered with 8–10 cm of dirt and arranged end or eye to eye in the furrows. The excavations have been filled with soil during the earthing-up procedure after 85–100 days of planting, when the freshly sprouting shoots are well grown.

Deep Trench method

Under this technique, two neighboring trench enters are spaced 120 cm apart, meaning that there is a 60 cm interval between each deep trench. The trenches have a depth of 30–45 cm and a width of 60 cm. On both sides of the trench bottom, sugarcane setts are planted and only partially covered with dirt (Fig. 3). With each manuring, the ditch fills with soil as the cane grows. In order to evacuate extra water during the monsoon, a tiny trench is finally created between two sets of paired rows. It is discovered that this technique works best in early drought and late waterlogged circumstances. This system requires a lot of labour. But, balancing planting provides good basal anchorage, preventing lodging early, saving 15% in irrigation water, and enhancing yield by 5–10 t/ha compared to flat planting (23).

Fig. 3. Ring or pit planting techniques.

Ring or Pit method

The ring pit method is a cost-effective and efficient method for sugarcane farming, compared to traditional row-to-row planting. This method stimulates mother shoot growth and can triple the current average production. The Haryana government selected this method as the most effective among existing cultivation systems. Sugarcane setts are planted in circular pits with a 180 cm gap between rows and a 150 cm gap between each pit within a row. Power tillers are used to dig the pits, which are filled with topsoil, 5 kg of farmyard manure (FYM), 100 grams of gypsum, and 125 grams of superphosphate. They are also well watered. Pit depth is maintained between 1.25 and 1.75 kg each before planting. This method improves nutrient use efficiency and water usage, saving labor and machining costs. The ring pit method of planting can increase cane yield by 1.5–2.0 times and save 20-40% of irrigated water (24), with the optimal nitrogen dosage being less than the conventional method. This method requires less nitrogen for 1 tonne of cane yield (25).

Techniques for ring preparation

About 90 cm diameter circular pits are excavated to a 45 cm depth, leaving 30 cm between each pit's neighbor. However, it would not be possible to have a 30 cm gap since it would be impossible to insert the dugout dirt in irrigation and into gaps (Fig. 4). As a result, a revised layout was created. It is determined that there is a spacing of 60 cm on one side and a 90 cm gap at this spacing. It is possible to build 4000 pits per acre at the same time. Mix 5-8 kg of FYM or compost with soil in each pit. FYM is able to fill the pit's bottom by 10 cm. Compost, or FYM, is combined with 5 g or 5% Aldrin to protect the crop from attack. Additionally, each pit receives 10 g of urea, diammonium phosphate, and muriate of potash. 20 gm of urea have to be applied to each pit thirty days after germination. Once more, each pit should have 20 g of urea top-dressed at the time of earthing. Each pit should have 20 horizontally positioned, well-budded, pre-treated setts, three of each kind. 2.5-5 cm of soil cover covers these. Dug soil is gradually added to pits as plants grow after germination. It is simple to achieve a millable cane yield of 150-180 t/ha. A drawback is that the procedure requires a lot of labor.

Fig. 4. Rayungan planting techniques.

Benefits

- In both the subtropics and the tropics, this technique has produced exceptionally high yields, with yields that are 25% greater.
- Provide superior rations.
- It performs better under saline irrigation conditions and on saline soils.
- A drip irrigation system works better.

Rayungan technique or IISR8626

At the Indian Institute of Sugarcane Research (IISR), Luck-

Fig. 5. TJEBLOCK planting techniques.

now, Dr. R. R. Panje and colleagues devised this technique. The terms Consociation of Auxin Action" and "Extension of Growth and Unhindered Utilization of Soil" allude to the methods used in the "CAEGUS" system (Fig. 5).

It is a technique from Indonesian farmers that refers to the process of preparing a field for planting cane, which involves removing the topmost internode tip and green leaves before sowing. This process allows buds to develop and side shoots to form. To prepare the field, trenches are dug 90 cm apart, and loose dirt and fertilizer are added. Sets are harvested from topped cane, and rayungans are used for planting. Approximately 20000 rayungans are needed per hectare.

TJEBLOCK technique

Better than the Rayungan method since it ensures that all of the buds have access to nutrients and energy. Stalks are chopped in half here, and they are planted vertically with one node below the surface for roots (Fig. 6). There is sufficient irrigation and fertilization for both the mother stalks and the planted ones.The upper buds of the mother cane and the block are now planted in rayungan by cutting them into setts as they sprout throughout the season.

Fig. 6. Single-bud vertical planting techniques.

Single-bud vertical seed multiplication

In terms of sugarcane seed multiplication, this method is more incentive than the Rayungan and Tjeblock methods. A bundle of five to ten cane stalks is formed here by harvesting the standing stalks, and the upper green leaves are severed from the top node. So that two nodes of the lower portion of the bundles are under the soil for roots, the bundles should be planted vertically. It is recommended to apply restricted nutrients after planting, with at least five days of regular irrigation between treatments.

The vertical seed multiplication technique at SRI, Pusa campus, has been successful in producing plantlets with three to five leaves in twenty to thirty days. Over 95% of buds sprout from the higher to lower direction, depending on nutrient needs. The technique has been ongoing for three years, with single-bud plantlets making outstanding progress. The goal is to produce 500 plants, including tillers, and growers for future growth. However, single-bud planting in plastic trays has drawbacks, including reduced production and transportation costs.

Method of Sablang /Sprouting

This method involves planting setts in rich soil, according to minimum planting depth requirements. Broad plant-to-plant spacing, a sufficient amount of fertilizer, and regular irrigation. Not long after its own roots begin to emerge, the healthy tillers are split off the mother plant. It can be sown in the main field separately. More tillers are removed in the same manner as before, split off from their mother plants, and planted in the main field. Cuba and Java both use this technique successfully.

Algin technique

After every four rows of wheat measuring 90 cm by 50 cm, the uppermost nodes are gathered during the cane stripping process in preparation for crunching. The Allahabad Agriculture Institute in Prayagraj, Uttar Pradesh, developed it (U.P.-70). Settling on the field is done in many ways from end to end:

- This approach has a low sett rate.
- Observational approach
- The double-row method is used for off-season and thicker planting.
- Planting single buds: they are setts that contain just one bud.

Settling in the Partha technique

When there is waterlogging from July rains, this approach is for employees to solve the seed germination issues (Tamil Nadu). Three bud sets are planted at a 45-degree angle on the ridge, leaving at least one bud above the soil. (26) created this planting method. The field is separated into ridge and furrow. Following another 5–6 weeks, when the plant reaches a height of 20–25 cm, the setts are forced horizontally. After that, a branch emerges from the bud.

Spaced transplanting procedure techniques

The IISR in Lucknow developed spaced transplanting procedures (STP) (Fig. 7). The standard planting approach for cane crops results in lower stalk density per unit area, a higher percentage of shoot death, and an inability to harvest solar radiation. For this purpose, STP was created. This method uses single bud setts to raise settling in a nursery bed (Fig. 8).

Paired row method

This method involves bringing two canes together, leaving a large space between them, and then starting with another set of two rows. The paired row may have a spacing of 120 cm and be 60 cm. This technique has the benefit of allowing for a large gap between any two sets of paired rows, which can be used to grow intercrops. In order to check the accommodations, a good earthing up is possi-

Fig. 7. Spaced transplanting techniques.

Fig. 8. Furrow irrigated raised bed planting techniques.

ble. Additionally, it enables the crop to better intercept light, which might result in a larger yield.

Furrow Irrigated Raised Bed (FIRB) technique

This method was created by the Lucknow-based Indian Institute of Sugarcane Research, or ICAR. This method entails growing wheat in elevated beds and sugarcane in furrows (Fig. 8). This method works better in the western parts of Uttar Pradesh, where sugarcane is grown after wheat. The usual sugarcane-based cropping pattern in the northwest of subtropical India is wheat-sugarcane-ratoon-wheat (Fig. 9). According to estimates, this technology is used to grow sugarcane on 14% of the nation's land, with over two-thirds of that area located in Uttar Pradesh. In the furrows, sugarcane is planted 90 cm apart, and on a raised bed that is roughly 60 cm broad between two cane furrows, wheat is planted in three rows, 15–17 cm apart. The Institute created a tractor-operated "raised bed seeder" machine to plant wheat and sugarcane using this technique. The machine plants the crops on an elevated bed (27). This approach is used in two ways. If wheat is planted in November, sugarcane setts are pushed with the foot in the moist furrows following the initial irrigation of the wheat. For this reason, it is also known as the wet approach. Approximately 50000 sugarcane three-eyed setts are needed for the existing wheat crop in February. This method involves burying the sugarcane setts at the exact same time or the following day when the soil is moist or before irrigation, crushing the setts by hand while they remain fresh.

Benefits of the FIRB approach

- Separate pre-planting irrigation is not required for the growing of wheat and sugarcane.
- The farmer receives extra money because there is no negative impact on the wheat output when compared to the nearly typical sugarcane yield.
- Improves the efficiency of water use. Irrigation water and nutrients are re-

Fig. 9. SSI method of planting techniques. (**A**, **B**) Machines for chip bud cutting and treating the chip bud with bio inoculants, (**C,D,E &F**) SSI method of raising sugarcane seedlings.

duced by about 25%.

- Weed infestation is lower in crops.
- The amount of wheat seed needed per hectare has been lowered from between 100 to 120 kg to 75 to 80 kg.

Techniques for winter nursery

In December, three budded setts are placed closely together in the nursery bed at IISR, Lucknow. Water covers setts, which are covered with a thin layer of soil. No longer than two or three hours should be spent submerged. The floating sets are eliminated. The nursery is then covered with polythene sheets that let in sunlight but keep out air. In a few hours, dew forms on the polythene sheet underside and starts to fall over the setts on the cane. Such setts are referred to as “slip setts” until they have sprouted (the polythene covers are removed) after 5–6 weeks. For three bud-thick varieties, the setts rate is 70 quintals per hectare, while for thin varieties, it is 50 quintals per hectare.

Methods for sugarcane seed multiplication

Utilizing Rapid Multiplication Techniques (RMTS) to enhance high grade sugarcane planting material

Sugarcane yields are steadily declining due to a shortage of high-quality seed. A low rate of seed replenishment and a lack of high-quality seed for new sugarcane varieties have a negative impact on the varieties prospective cane output. The availability of true-to-type planting material free of pests and diseases is a crucial precondition for attaining the intended increase in sugarcane output. In order to strengthen and multiply high-quality sugarcane planting material quickly, several research organizations have created several novel procedures over the past 25 years that must be combined. The following sections of this chapter provide further detail on these methods and how they are integrated with advanced biotechnological technologies in comparison to traditional systems.

Sustainably increasing sugarcane production through SSI techniques

Sugarcane used for commercial seed production is often overlooked, leading to insufficient quality. To ensure high-quality, disease-free seed cane, growers should cultivate the crop independently and conduct continuous field counts. The Sustainable Sugarcane Initiative (SSI), funded by the Worldwide Fund for Nature (WWF) and the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT), aims to "produce more with less" by reducing cultivation expenses and increasing crop yields. This strategy, based on the System of Rice Intensification (SRI), has shown positive results with other crops (Fig. 10).

Components of SSI

- Make use of tiny chips from the sugarcane, each containing a single bud, to raise new sugarcane seedlings in a nursery before letting them grow out separately in cups. This makes it possible to harvest sugar from the cane itself instead of planting it in the ground to sprout, as is now done.
- After these seedlings have sprouted and established, they should be transplanted while still young (25–35 days old).
- When transplanting, make sure to provide a 4-by-2-foot gap between plants in the main field.
- Enough moisture should be given to the crop, not flooding it.
- Through providing organic substances to the soil for nutrient improvement, protection of plants, and other intercultural practices, we can promote soil fertility and health. Higher germination of 66.93% was observed when coir pith + Vermicompost @ 3:1 ratio was used as a nurdery media (28). Application of 0.5 g urea/bud along with foliar spraying of 1% urea at 15 DAP recorded the higher vigour index of chip budded seedlings of sugarcane at 30 DAP (29).
- For a more efficient use of land, intercropping using various crops, including lady fingers, cabbage, garlic, and onions, improve the fertility and health of the soil.
- By making the best use of fertilizers and land, this approach to improved management methods in sugarcane farming uses fewer seeds and less water.
- It can increase yields and revenues for both millers and farmers.
- The traditional seed, water, and space-intensive sugarcane farming methods currently used by millions of farmers nationwide can be replaced with SSI.
- Treating the setts with aerated steam at 50°C for one hour with *Trichoderma viride* at 4 g/L or *Pseudomonas fluorescens* or *Bacillus substilis* at 10 g/L of water for 10 min is recommended for the management of red rot and primary infection of grassy shoot disease.

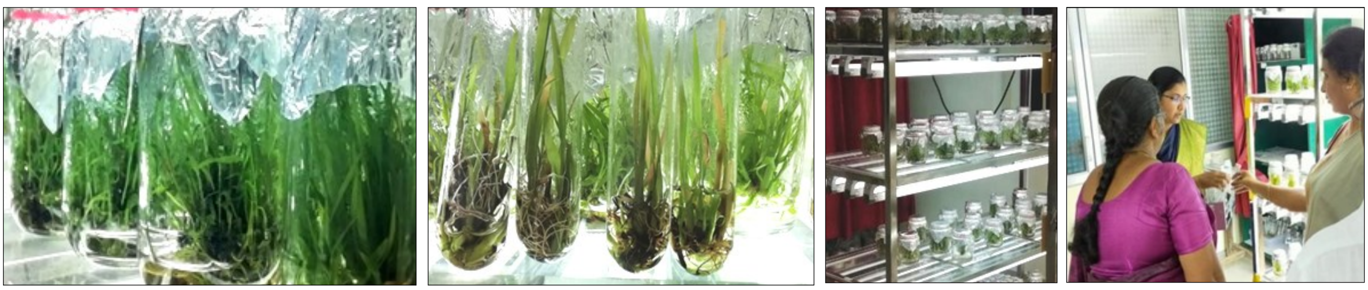

Fig. 10. Micro-propagation planting techniques.

- The sugarcane varieties CoSi(Sc) 6 and CoC 24 performed better in sandy clay loam soils under SSI (30). This method enables intercropping in-situ incorporation of sunnhemp on 45th DAS which inturn, increased the nutrient availability and maintained soil fertility (31, 32).

Micro-propagation

The persistent issue of low seed multiplication can be resolved using this alternative method. Sugarcane is propagated using cloning, which allows planting material to grow quickly without compromising genetic integrity. Shoot tip culture is a superior method of micropropagation because plants derived from mother plants have similar phenotypic characteristics (33). Numerous other advantages of employing this technique for cane development have also been demonstrated by studies, including increased rates of multiplication of newly released varieties (34), improved cane stalk health, disease-free plants, and the use of this technique specifically for cane germplasm storage (5, 35). Micropropagation is the most practical and effective technique for producing pathogen-free seed material, in addition to being a common means of clonal multiplication (36). This method can be used to rejuvenate exceptional old varieties and to produce freshly released sugarcane varieties on a wide scale, which will speed up the breeding process (37). Several micropropagation methods have been documented that are appropriate for commercial sugarcane seed production. Apical meristem culture could be used to produce sugarcane mosaic virus-free plants (38, 39). Axillary bud culture was successfully used to create true-to-type clones in a variety of sugarcane types (40). The apical meristem culture method was standardized (41) for the quick growth of plants of variety Co740 that are devoid of mosaic viruses. Apical meristem with a couple of leaves primordial (meristem tip) as the explants is the basis of the standardized micropropagation technique developed (42). The steps listed below are typically used for this approach (Fig. 11).

- Step 1: First cultivation of the meristem or shoot tip

Fig. 11. Polythene bag method of planting techniques.

- Step 2: Proliferation stage of auxiliary buds (repeated 6–8)
- Step 3: The stage of root initiation
- Step 4: The hardening or acclimatization phase
- Step 5: Establishing the field and transplanting

Consideration of quality control in micro-propagation

In sugarcane, tissue culture can be utilized to rejuvenate exceptional cultivars and quickly multiply newly created, high-yielding, disease-resistant varieties. Quality control is necessary to guarantee that the right starting material is utilized for micropropagation, that the culture conditions are adequate, and that the cultivar identity is preserved throughout the culture phase. To preserve the quality of sugarcane plants grown in tissue culture, the following factors have been highlighted (43).

Source material genetic purity

The breeder or research group responsible for the variety's upkeep shall certify the genetic quality of that variety to be micropropagated.

Source material

The source material should be an explant from a healthy, vigorously developing plant that was developed using heat-treated setts and given the right amount of moisture and nutrients. The crop grown from seedlings that were micropropagated shouldn't be used as a source.

Micropropagation laboratory accreditation

To guarantee technical proficiency and adequate infrastructure, a micropropagation process lab should be accredited by the relevant authority.

Micropropagation protocol

This technique should guarantee that there are only mirror genetic alterations. Limiting shoot multiplication cycles will prevent morphological variation.

Establishment of seedlings

When supplied to user agencies, the seedlings should have four to five green leaves and a strong root system in the soil mixture.

Disease indexing

Using ELISA and molecular techniques, the plants grown by micropropagation should be checked for the absence of viruses and virus-like illness. To evaluate the genetic purity of plants, standard molecular techniques can be employed.

Production of seed

The seedling propagated by micropropagation needs to be considered the principal seed of breeders. Using vegetative cuttings, this seed should be further multiplied to provide foundation [secondary] seed followed by commercial seed. During the breeding stage of seed development, the field must be inspected to eliminate any off varieties.

Commercial seed

This type of seed should be used within four years of production

Technology using polythene bags or spaced transplants

Settlings are cane setts that have roots and shoots. Either polythene bags can be used to raise seedlings. When growing sugarcane using the spaced transplanting technique, individual node settlings are used as planting material. The Spaced Transplanting Technique (STP) is a planting method developed by the Indian Institute of Sugarcane Research, Lucknow (44, 45). About a month prior to being transplanted onto the main field, single bud settlings are produced in a nursery. It takes about 50 m^2 of land and two tons of seed cane to transplant one hectare of field. With a consistent crop stand and a greater average cane weight, this method guarantees a large stalk population (>1.2 lakh canes ha^{-1}), decreased disease and pest prevalence, as well as decreased crop lodging. The percentage of cane seeds in production is improved from 1:10 to 1:40. 4 t/ha of seed cane is saved using this method (Fig. 12). Nowadays, the main frontier seed multiplication method for sugarcane is the bud chip/single bud technique for raising seedlings (46).

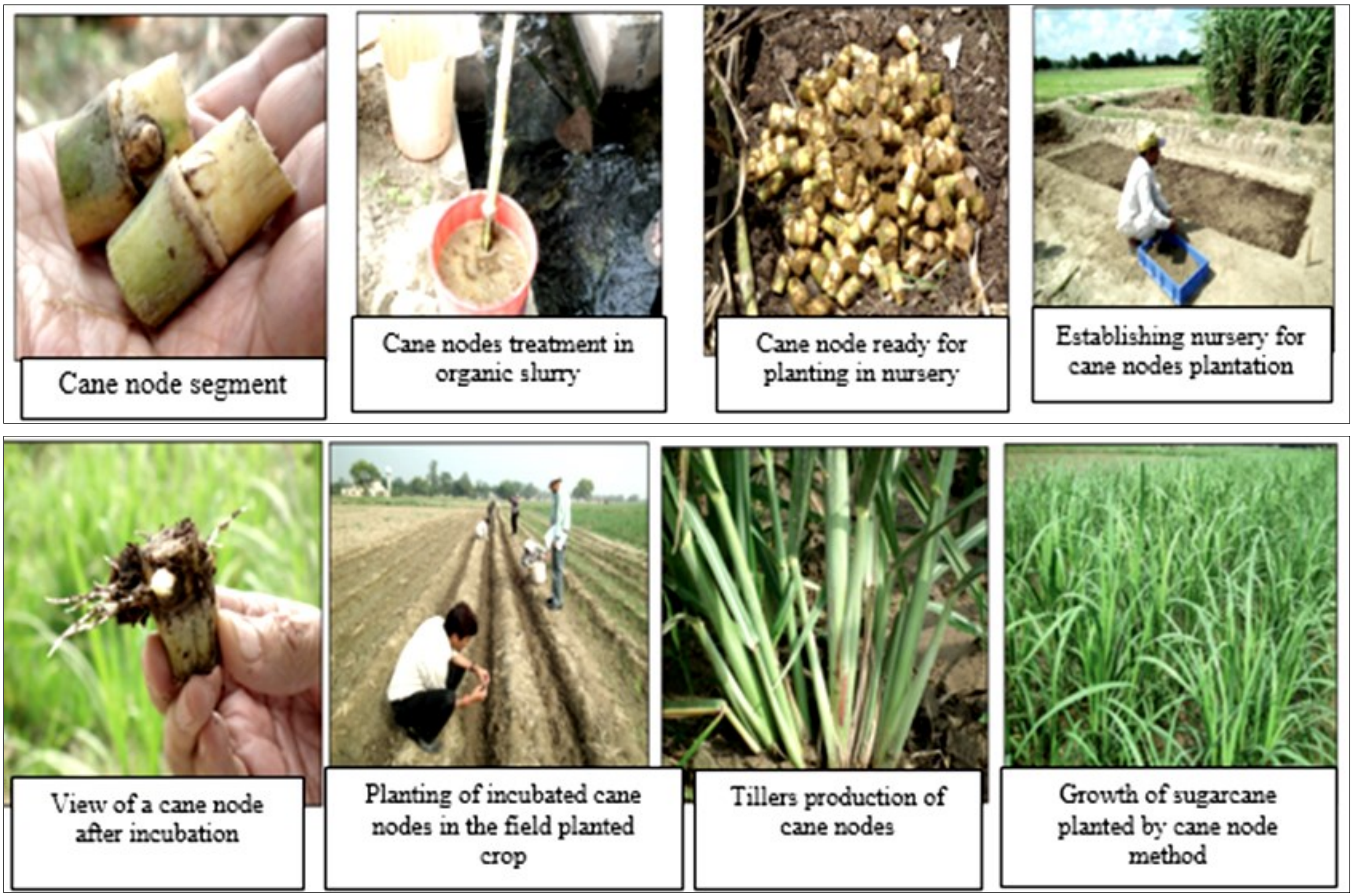

Fig. 12. Sequential methodology of cane node technology of sugarcane growing.

Cane-node technique

Seed cane is primed using a stem cutting with a bud and root band, one inch of internode attached on both sides. A 0.10–0.75% liquid carbendazim solution is applied to the planting material (Fig. 13), followed by 15–20 min of treatment in a liquid organic formulation of cattle dung to cattle urine. This organic composition is made into a natural sludge for priming the seedlings by diluting it five– to ten–fold with water and stirring it for five to ten min.

Cane nodes are submerged in the slurry for 15–20 min, followed by germinating in a solid organic mixture of soil and decomposed farmyard manure. The planting material is incubated in layers with a 2–5 cm thick solid organic formulation, and three layers of dry soil are planted in different locations. To protect against termites, a 10 ml/ L water solution of chlorpyriphos is sprayed on top.

Bud swelling begins after covering and can be observed in the field with a temperature range of 25–350 °C after 5 to 7 days. Seed cane material can be transported from the nursery site to the actual planting site if cane node segments are to be planted in different fields or locations.

Fig. 13. Mechanization of sett planting techniques.

Priming buds with visible roots on a conjoined roots band are placed in furrows as soon as the packed planting material arrives at its destination. Shoots emerge from these priming buds in 7–10 days, resulting in a total time needed for shoot emergence of 12–16 days, compared to 35–45% with traditional planting techniques. The germination rate is over 90%, compared to 35–45% with traditional planting techniques.

Constrains and potential directions for cane node technology

The cane node method is unquestionably helpful in lowering the amount of seed cane material needed for planting and quickly growing the recently introduced sugarcane types, in addition to increasing cane production. This method of planting sugarcane reduces the amount of seed cane material needed and increases cane production. The optimal seasons for planting are autumn and early spring in subtropical climates due to less soil moisture loss. However, planting past February can cause soil moisture to evaporate quickly, hindering cane node germination and plantlet establishment. Nutrition and soil moisture constraints are crucial for increased germination and plant growth.

Traditional methods of stalk cutting are expensive, time-consuming, and labour-intensive, requiring large amounts of sugarcane stalks per hectare. To reduce human labour and improve efficiency, an automated node-cutting machine is needed. This machine should have adequate control over cutting locations and cut as many nodes as possible in the shortest time.

Mechanization and planting techniques for sugarcane

Sugarcane planting techniques are mostly determined by the kind of planting material that is used and second, by how the planting material is positioned. The three main categories are settling transplanters, entire cane planters and sett planters.

Sett planting for sugarcane

Planting comprises the opening of the furrow, applying fertilizer, distributing the setts in the furrow and closing the furrow; harvesting; sett cutting; seed treatment and transportation to the planting area. Partially or fully, this planting process is automated.

Manual planting of sugarcane

Fig. 14. Settling transplanting. **(A)** Chain sugarcane transplanter, **(B)** Cup type sugarcane transplanter.

The majority of sugarcane cultivation involves a semi mechanized approach, where seeds are harvested and dispersed manually in a furrow, with uniform spacing between them. This process involves harvesting plant cane, de-trashing, cutting setts (Fig. 14), treating them with fungicides and pesticides, plowing the field, creating ridges and furrows, and placing setts at the bottom of the furrow. This process requires 30 to 35 labour days per hectare (5, 47). An additional five workers are needed for fertilizer application (48).

Using manually fed sugarcane cutter planters for planting

A semi-automatic bullock-drawn sugarcane planter was developed for light to medium soil types, allowing for manual planting, fertilization, and soil compacting. This single process, requiring feeding employees, has led to numerous device developments in India and globally. Major contributors to these developments include the Tamil Nadu Agricultural University in Coimbatore, the Punjab Agricultural University (PAU) in Ludhiana, the Indian Institute of Sugarcane Research (IISR) in Lucknow, and the Vasantdada Sugar Institute (VSI) in Pune. These machines transport the entire sugarcane stalk to the cutters. Planting ranged in depth from 12 to 25 cm. Sett length ranged from 30 to 50 cm, and less than 5% of buds only were damaged. The equipment could be used to plant with a field capacity of 0.2 ha h^{-1} with furrow spacing of 0.90, 1.20, and 1.50 m, as well as paired row spacing of 0.90–1.80 m (49, 50). In contrast to conventional sugarcane planting in India, which costs Rs. 7721/- per hectare, the operational cost was Rs. 4010/- per hectare (51).

Settling transplanting

Nursery-developed sets are used in transplanting machines. Sugarcane settlings were made using some modifications to the machinery created for vegetable transplanting. In order to adapt existing semi-automated technology for sugarcane, researchers attempted to (52) create a single-row machine that uses a ground wheel to mechanically transplant sugarcane. Workers fed seedlings from the tray were placed in funnels at the bottom of the furrow. For settlings grown from sugarcane bud chips, (53) created a 35-horsepower tractor-mounted mechanical transplanter. Furrow openers, soil openers, furrow closers, an operator's seat, and a metering mechanism were all on the main frame of the two-row machine. With the hills missing, the field capacity was 2.33%, and it was attained at a speed of 1.4 km/h.

Conclusion

India's sugarcane industry, which operates with 50000 employees, mostly coming from rural regions and largely reliant on conventional methods, faces limitations in productivity and profitability. To meet rising domestic sugar demand of 33 million tonnes by 2030, research and development should focus on mechanization to improve efficiency and revenues. Multidisciplinary initiatives from the sugar sector, state agricultural research institutions, and research centers are needed to adopt machine-driven sugarcane production. Sugarcane cultivation is the most planned sector of agriculture, which is directly associated with the sugar industry and plays a distinguished role in the Indian economy. Overcoming challenges in material handling systems, furrow opening, sett distribution, and seed treatment can optimize mechanized planting performance, enabling high-quality and cost-effective sugarcane production. Future studies should focus on the safe production, transportation, and planting of chip buds and tissue culture-based propagules for area expansion in sugarcane to increase productivity and production to meet the demand for sugar in the near future.

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Authors' contributions

RBC has written an original manuscript. RV, BT, NR and AR have contributed to writing a part of the manuscript. MP and SJR have reviewed and corrected the entire manuscript. NR & AR designed the entire idea for making a review paper, contributed to writing, review and correction. All authors have read and approved the final manuscript.

Compliance with ethical standards

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