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RESEARCH ARTICLE

Design and implementation of a precision sugarcane planter for sustainable agriculture

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ABSTRACT

India is an agricultural country; more than 50% of the population is farmers. The main aim of this research is to fulfill society's needs by the mechanization of the conventional process of sugarcane planting. However, this existing sugarcane planter could be more affordable and lucrative for individual farmers. Also, two or more persons are required to feed the sugarcane to the rotating cutter. Those people need to remain completely attentive during feeding. In order to eliminate these difficulties, we designed a fully automatic rolling feeder that directly feeds the whole sugarcane piece to the cutting unit without any interference from the operator. These roller feeder & cutting units are powered by tractor P.T.O shaft power. After cutting the whole sugarcane piece into the required size for the plantation, it falls into the feeding hopper, which is located below the cutting unit, from which it directly falls into the furrows, which is already made by opening rejer assembly as the tractor moves in forward directions. As soon as the sugarcane pieces fall into the furrows immediately, the soil covers them by using a soil-clogging mechanism. Our project is based on reducing the efforts that occurred during the sugarcane plantation. The scope behind the design and fabrication of this project is to make the simple automatic sugarcane planter available at the lowest possible cost, which will be affordable for individual rural farmers.

Keywords: Sugarcane Planting, sustainable agriculture

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INTRODUCTION

Organic farming is known for being more labor-intensive than conventional farming methods. Sugarcane cultivation in India dates back to the Vedic Period (1400 to 1000 BC), and the country is widely recognized as the original home of various sugarcane species. As the second-largest producer of sugarcane globally, India dedicates about 40 to 50% of its agricultural land to this crop. Despite this, sugarcane farming in India remains heavily labor-dependent, with most operations from planting to harvesting lacking advanced mechanization. Currently, mechanization is largely limited to basic tractor use and land preparation equipment like cultivators and harrows, leading to high cultivation costs and lower yields.

Sugarcane planting methods are adapted based on land slope, soil conditions, wind direction, and water availability. Typically, the ridge and furrows method uses three-eyed (budded) sets, requiring 3.5 to 4 metric tons of seed per hectare, making it a

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labor-intensive and costly approach. Alternatively, the row planting method aims to optimize plant population and yield, using two-eyed sets planted 4 to 6 cm apart, which reduces seed requirements to 2 to 2.5 metric tons per hectare (Ali, 2015).

Traditional sugarcane planting is expensive, time-consuming, and requires significant manual labor and a high volume of stalks per hectare. The common practice involves manually placing whole stalks into furrows created by tractor-drawn ridgers, with 75 cm spacing between furrows. Fifty to sixty quintals of cane are needed to meet seed requirements per hectare, and these are manually laid in the furrows and covered with soil, followed by planking to conserve moisture. Besides land preparation, these steps require 50-60 man-days and 4-5 tractor hours, with costs of Rs 4000-Rs 4500 per hectare, excluding other inputs like seeds, fertilizers, and pesticides (Vasantdada Sugarcane Planter, n.d.; Sendurkar, 2016).

Using a portable mechanized system could significantly cut labor costs, as it can perform all the operations currently done manually, including additional tasks like pesticide application. Incorporating these functions into a single portable machine would save both time and money, making it a one-time investment that offers substantial benefits and increased profitability for farmers . The future food supply of an increasing population will be strained due to climate change, which factors into constraints on water availability, poor soil fertility, and limited agricultural techniques. These challenges require a fundamental restructuring of the agriculture system by incorporating the principles of sustainable agriculture, the holistic approach of agroecology, and economic analysis. As a result, contemporary technology such as precision agriculture is used in a sustainable agriculture system to supply suitable information. Precision agriculture offers solutions to redefine the current sugarcane industry and position it for long-term viability. Consistent, efficient, and effective use of precision agriculture technologies will assist farmers in minimizing cost inputs on the farm, which can have positive long-term sustainability implications for sugarcane production systems. This paper aims to present a 'Design and Implementation of a Precision Sugarcane Planter' to improve sugarcane planting technologies and consequently propose a new approach towards sustainable agriculture for sugar production (Abobatta 2021; Martos et al., 2021)

More demand for greater sugarcane yield per hectare carries with it a cost of establishing the crop. Consequently, the planting of sugarcane is a critical management activity, and yet, in comparison to activities that take place when a crop is growing, remarkably little is known about gains in the management system for the planting of farmers (Bhange et al., 2016). This method of planting also needs to be sustainable in other ways, such as being driven by environmental considerations when modern farming contains tools and components that can carry out such sealing, silt applications, and zero-tillage technology when addressing environmental concerns and global warming. The potential of ancient plows is quite evident in addressing the sustainability of our farming futures. Although sugarcane is planted at increasing costs, new low-cost per-cane planting methods are required because of pressure due to global economic competition. Yet, such methods need to be accurate to ensure the timely harvest of land. If established, automatic control features may reduce direct costs at a reasonable price. In order to meet this need for precision farming, a modern mechatronic sugarcane planting mechanism prototype for a dual mapping subsystem is proposed.

MATERIALS AND METHODS

Methodology flowchart

The development of the Precision Sugarcane Planter involved several key stages: design conceptualization, component selection, prototype development, testing, and performance evaluation.In this planting machine design, the sugarcane plant is helped by centrifugal force generated by a rotating shaft on which blades are mounted. The tractor's PTO shaft provides the required power for the machine (Ali, 2015). The planting of sugarcane is fully automatic.

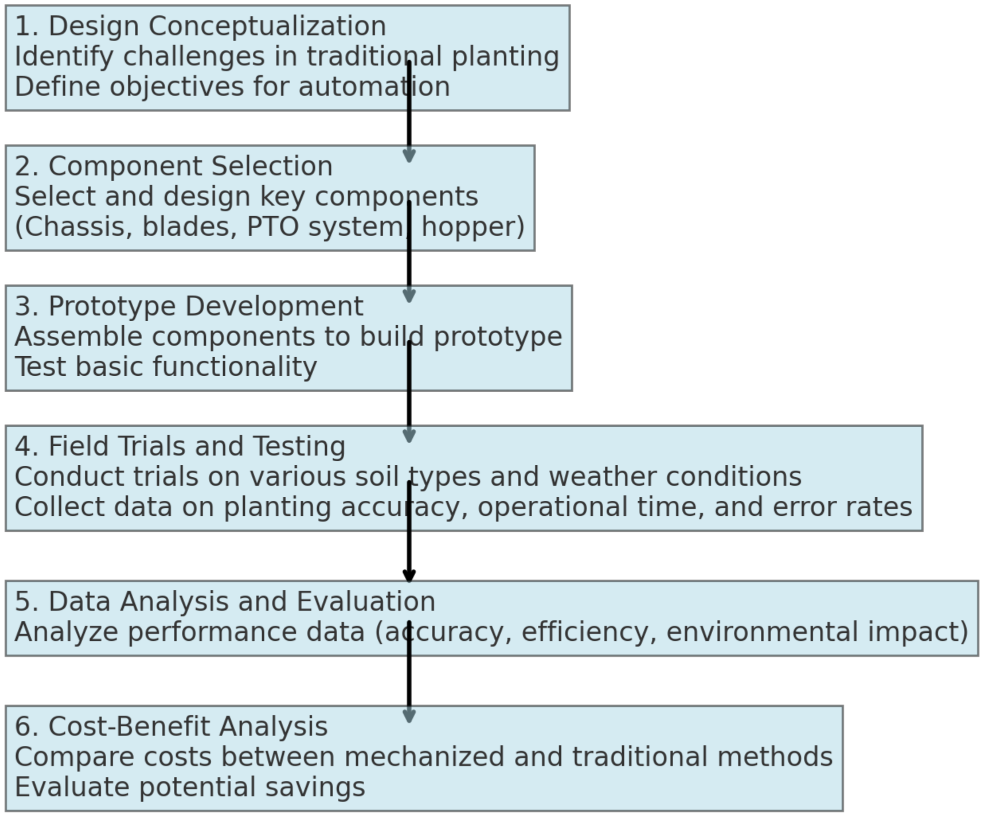


Figure 1: Methodology Flowchart

OBJECTIVES

The primary objective of this research is to design, develop, and implement a fully automated precision sugarcane planter aimed at enhancing sustainable agriculture practices. The specific objectives include:

1. **Automation of Sugarcane Planting:** To design a sugarcane planter that eliminates the need for manual intervention during the planting process, thereby reducing labour demand and ensuring consistency in planting depth and spacing.
2. **Cost Reduction:** To minimize the cost associated with traditional sugarcane planting methods by reducing the required labour and time for planting. The goal is to decrease the cost per acre from Rs 6000-8000 (as in conventional methods) to Rs 500-700 through mechanization.
3. **Time Efficiency:** To significantly cut down the time required for planting sugarcane. The conventional method requires 6 to 8 hours per acre, while the proposed planter aims to reduce this time to just 2 hours.
4. **Improved sugarcane planting technology:** To boost crop yields by ensuring precise spacing and depth, promoting higher productivity. The planter's design prioritizes uniformity and accuracy to enhance planting effectiveness.
5. **Sustainability:** Developing a planting machine that is eco-friendly, leading to decreased fuel usage, reduced emissions, and soil compaction, ultimately promoting sustainable agricultural methods.

SYNTHESIS OF MACHINE

While developing the precision sugarcane planter, several experiments were conducted to improve multiple prototypes. The focus was on enhancing the mechanism that feeds sugarcane stalks into the cutting unit efficiently and automatically. The primary challenge was to ensure that sugarcane pieces could smoothly pass through the upper hopper without any blockages or manual intervention. To address this, the hopper's design was meticulously crafted with a specific angle between two flat feeder plates to facilitate controlled feeding and prevent clogging. Furthermore, adjustments were made to the hopper's dimensions and the roller mechanism to accommodate varying sizes of sugarcane stalks. The optimized design of the roller and inclined feeder system aimed to ensure consistent feeding and reduce the need for operator supervision. These design improvements were crucial in the development of the final version of the machine, which boasts fully automatic feeding and cutting mechanisms. By precisely feeding sugarcane pieces into the cutting unit, the machine guarantees consistent placement of the pieces in the prepared furrows for soil coverage. (Guo et al., 2022) (El Shal et al., 2021) (Punkkinen, 2021).

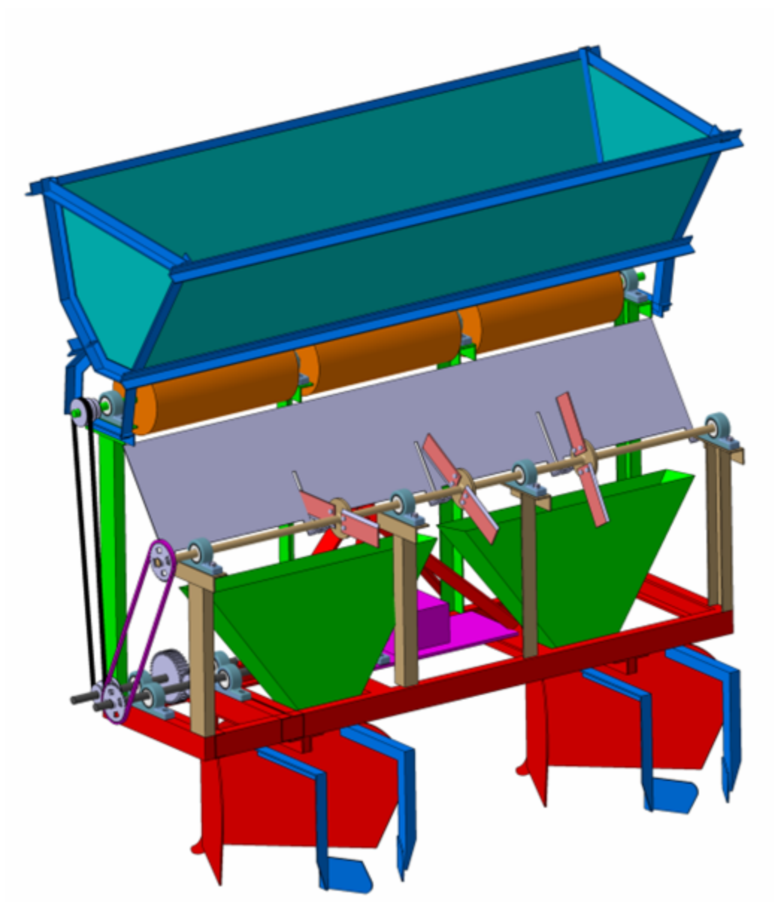
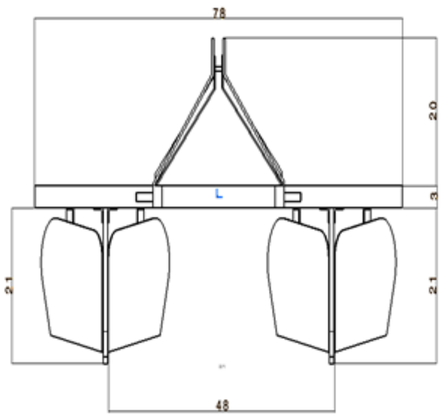


Figure 2: Synthesis of Machine

COMPONENTS OF VERSATILE SUGARCANE PLANTER

Chassis-

The chassis is made of plain carbon steel; it is made of C-channel. The dimensions of the rectangular chassis are 8.5ft × 1.75ft. The ridge is attached to the lower portion of the chassis to make the furrows. All the units are mounted on the chassis. The total cost of the chassis is Rs.4000.



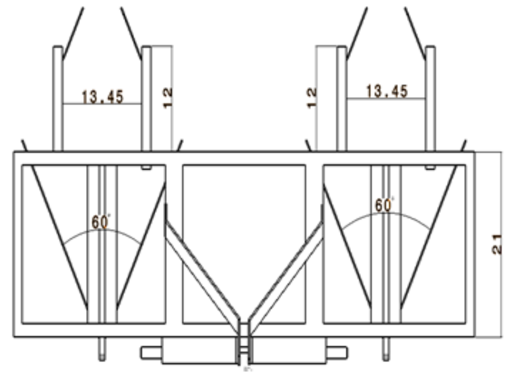


Figure 3: Front view of chassis

Figure 4: Top view of chassis

Solid shaft with cutting blades

A solid shaft is used to transmit rotary motion to the set of blades mounted on it and offer the required torque for cutting the sugarcane piece. The total length of the solid shaft is about 7ft and a diameter of 25mm. Three sets of blades at a distance of 1.5ft are mounted on the solid shaft, each set consisting of two blades. The blades are mounted on a supporting plate with the help of nuts and bolts. The solid shaft is supported on the chassis by four journal bearings. The cost of a solid shaft is Rs. 400, and the cost of all cutting blades is Rs.300.

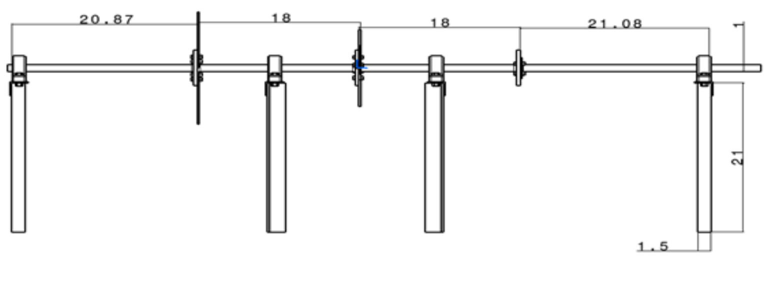


Figure 5. Front view of cutting blade unit

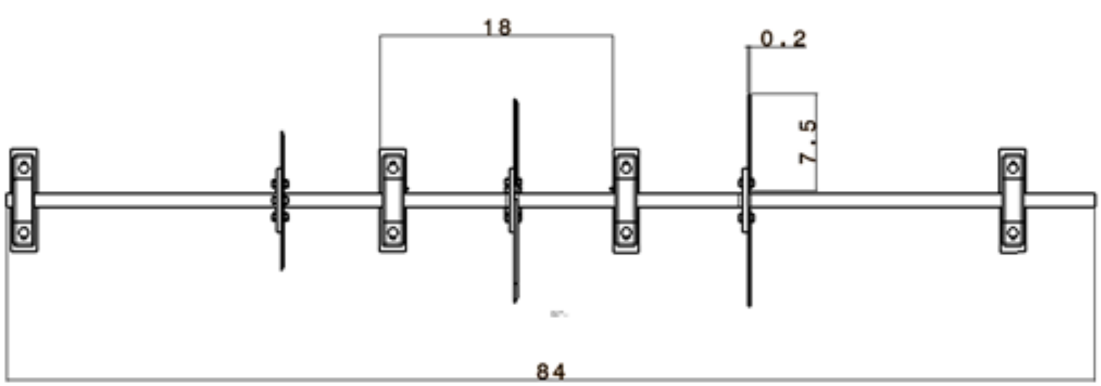


Figure 6. Top view of cutting blade unit

Bevel gear pair

A straight bevel gear pair of ratio 1.8:1 is used. The pinion gear has 10 teeth and is mounted on an input solid shaft, and the driven gear has 18 teeth and is mounted on a solid transmission shaft. Bevel gears are used for power transmission in 90˚.

Spur gear drive

A spur gear pair mounted on a transmission solid shaft, with a gear ratio of 2:1, is used for reducing the speed of the roller up to 30 rpm. The total number of teeth on the spur pinion is 15, and on the gear, 30.

Chain drive

A pair of sprockets with 14 and 10 teeth is used to transmit the power from the driver transmission solid shaft to the driven solid transmission shaft at the mentioned assembly with the help of a chain.

Splined solid shaft

A splined solid shaft with 6 splines is used to take power from the tractor's P.T.O. solid shaft with the help of a double-end universal joint. This power is taken as input power for the chain drive. This splined solid shaft is held by two journal bearings. The cost of the splined solid shaft is Rs.400.

Upper hopper with a roller-

The upper hopper is made of sheet metal and has a narrow hollow cross section in which the whole sugarcane pieces are kept. One side of the hopper is slightly straight to give proper allowance for sugarcane feeding. At the narrow portion of the upper hopper, there is one roller that feeds the sugarcane towards the inclined feeder plates. The length of the roller is 6.5ft, and the diameter is 6", and the total cost of the unit is Rs.2000.

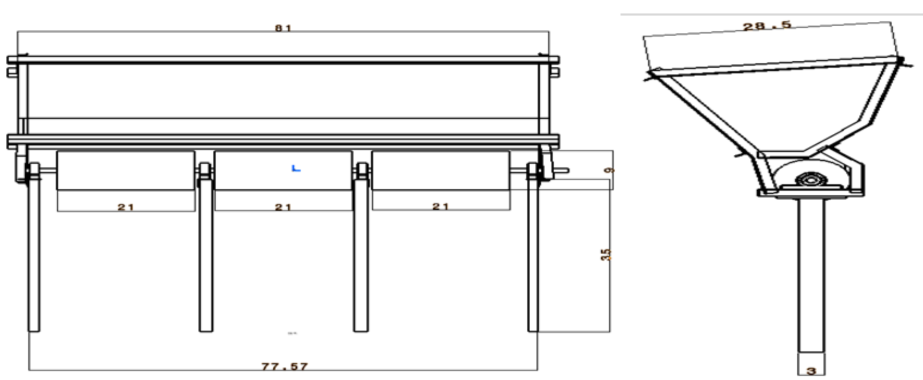


Figure 7. View of upper hopper with roller

CONSTRUCTION AND WORKING

Construction

The precision sugarcane planter's construction starts with the chassis, which serves as the primary support structure for all other parts. Made of durable plain carbon steel, the chassis is designed to accommodate various units, including the cutting blade mechanism, sugarcane feeder, and hopper system. At the core is the solid shaft with blade assembly, crucial for power transmission and cutting. A narrow, hollow upper hopper holds the sugarcane pieces horizontally on the chassis. A roller system at the lower section of the hopper feeds the sugarcane pieces one at a time into the cutting blades, arranged in sets for even and efficient cutting. Once cut, the sugarcane pieces fall into furrows prepared by the ridger mechanism, also mounted on the chassis. Integrated soil burrowers then cover the sugarcane pieces with soil to complete the planting process. The machine is powered by a tractor's Power Take Off (PTO) system, rotating at 540 RPM, with power transmitted through a double universal joint to the solid transmission shaft, which further distributes power to the various mechanisms using chain and sprocket drives. The transmission shaft and cutting blade assembly are made of mild steel, providing the necessary strength and durability, while the blades themselves are made from High-Speed Steel (HSS) for hardness and sharpness. The intricate system of gears, sprockets, and shafts ensures smooth and efficient operation of the machine, allowing for precise and automated sugarcane planting (Silva et al., 2013).

WORKING

The sugarcane planting machine is powered by the 540 RPM Power Take Off (PTO) shaft of the tractor, which is then transferred through a double-end universal joint to the solid shaft of the machine. This solid transmission shaft powers the chain sprocket, driving the cutting blade assembly and the roller shaft. The roller rotates to feed sugarcane pieces into the cutting mechanism, where they are cut into four pieces and deposited into furrows by the machine. Soil burrowers then cover the sugarcane pieces with soil, completing the planting process accurately and effectively (JukgolJun et al. 2023; Gelana, 2020)

Figure 8. Actual Fabricated Model of Sugarcane Planter

RESULT AND DISCUSSION

The outcome of planting sugarcane setts in the furrows created by the plow mechanism was determined through numerous experiments and adjustments to an actual model of the planter . Once all the mechanisms were properly aligned, a trial was conducted at the farm to observe the results of the plantation and analyze the planted sets. This allowed for the assessment of the number of sets that could be planted in the shortest possible time, as well as the orientation of their buds. This data is crucial for estimating the yield after the sugarcane is harvested, which typically occurs 12-14 months after planting (Sendurkar, 2016). Additionally, it enables us to observe the length of the cut sugarcane sets and determine the exact distance between two planted sets. The trial also helps to approximate the tractor speed (approximately 2-2.5 km/hr) required for proper sugarcane plantation. Automation plays a significant role in this process, as it allows one person to handle the entire plantation operation, with only two additional workers needed to transport the sugarcane from the cutting area to the planting area, along with one person to drive the tractor. Therefore, a total of three individuals are sufficient for the plantation process..

Cost of plantation by Versatile Sugarcane Planer:

Table 1. Cost of plantation by Versatile Sugarcane Planer

Operations (Rs/Ha)	Versatile Sugarcane Planter
Opening of Furrows	0
Field Channel and Layout Preparation	0
Sugarcane Plot Cutting for Seed	1500
Seed Treatment	0
Planting (Detrashing of seed cane)	3150 (15F&3M/Ha)
TOTAL	4650/-

This cost estimation is taken by taking the reference of Vasantdada Sugarcane Planter and also by doing the survey of various sugarcane producing farmers and by taking into consideration current labor rates. And hence the cost of plantation is obtained (Padilla-Fernandez & Nuthall, 2009)(Vasantdada Sugarcane Planter, n.d.).

Analysis of Results:

- **Planting Accuracy:** The precision planter consistently showed higher planting accuracy compared to traditional methods across all soil and weather conditions. The improvement ranged from 10% to 12%, demonstrating the planter's effectiveness in maintaining uniform spacing and depth (Gelana, 2020).
- **Error Rates:** The error rates were significantly lower with the precision planter, especially in drier conditions, indicating better control over seed placement. This reduction in misses and incorrect placements directly contributes to higher yield potential.
- **Operational Time:** The planter reduced the time required to plant a hectare by approximately 40%, highlighting the efficiency gains due to automation.
- **Fuel Consumption:** A modest reduction in fuel consumption was observed, contributing to lower operational costs. The lower fuel consumption is primarily due to the optimized operation of the planter compared to manual or less efficient mechanical methods.
- **Yield Comparison:** Yields from fields planted using the precision planter were consistently higher, with an average increase of 10%. This yield improvement can be attributed to better planting accuracy, reduced error rates, and consistent planting depth, which promotes better growth conditions for the sugarcane.

Table 2: Testing Results

Parameter	Soil Type	Weather Condition	Speed (km/h)	Planter Performance	Traditional Method Performance	Improvement (%)
Planting Accuracy (%)	Sandy	Dry	2	95	85	11.8
	Loamy	Moist	2	92	83	10.8
	Clayey	Wet	2	88	80	10
Error Rate (misses per 100 m)	Sandy	Dry	1.5	3	7	-57.1
	Loamy	Moist	2.5	5	10	-50
Operational Time (hours/ha)	Loamy	Dry	2	1.8	3	-40
Fuel Consumption (L/ha)	Clayey	Moist	2	12.5	16	-21.9
Yield (tonnes/ha)	Sandy	Wet	2	75	68	10.3

The precision sugarcane planter demonstrates significant environmental benefits compared to traditional planting methods.

Table 3: Environmental Impact

Impact Category	Precision Sugarcane Planter	Traditional Methods	Improvement (%)
Fuel Consumption	Lower due to integrated operations, reducing the number of passes.	Higher due to multiple operations requiring separate machinery (7).	20-25%
Emissions (CO_2, NOx)	Reduced emissions due to lower fuel use.	Higher emissions due to increased fuel consumption.	20-25%
Soil Compaction	Minimal compaction due to fewer passes over the field.	Significant compaction from repeated machinery use.	Up to 30%
Sustainability Contribution	Enhances soil health, reduces energy needs, and aligns with sustainable practices.	Degrades soil structure, increases operational costs, and emissions.	Significant improvement in overall sustainability.

Table 4. Operation cost comparative

Sr. No	Operations (Rs/Ha)	Conventional Planting (Manually)	Existing Sugarcane Planter (VSI)	Versatile Sugarcane Planter
1.	Opening of Furrows	1900	0	0
2.	Field Channel and Layout Preparation	1680	0	0
3.	Sugarcane Plot Cutting for Seed	1500	1500	1500
4.	Seed Treatment	500	0	0
5.	Planting (Detrashing of seed cane)	5700 (30 F@ Rs150/- &4 M@ Rs300/- Ha)	3750 (15 F&5 M/Ha)	3150 (15F&3M/Ha)
TOTAL		11280/-	5250/-	4650/-
Net Savings (Rs /Ha)		0/-	6030/-	6630/-
Cost of Saving Under Mechanized Planting		0%	53.46%	58.78%
Net % Saving in Cost by 'VERSATILE SUGARCANE PLANTER'			**21.61 %**	

CONCLUSION

The overall performance of the prototype, as per the technological requirements, was investigated. Individual yields and all associated results were based on data collected from biophysical assessments conducted in different locations. The research demonstrates that the Versatile Sugarcane Planter (VSP) offers several advantages over traditional and existing mechanized planting methods. After thorough examination of operational costs, it is evident that the VSP significantly decreases expenses associated with sugarcane planting. This reduction in cost is mainly due to its fully automated and integrated design, which consolidates multiple planting tasks into one efficient process, ultimately reducing both labor requirements and fuel usage. The affordability of the VSP is also essential in making it accessible to small-scale and rural farmers. Its lower cost allows individual farmers to purchase it, or for groups of farmers to collectively own and share the planter, thereby increasing its utilization and effectiveness. Furthermore, sugar factories could offer the VSP on a rental basis, spreading its benefits further across the farming community and supporting economic sustainability. The VSP also contributes positively to sustainable farming practices, achieving lower fuel consumption, reducing emissions, and minimizing soil compaction—essential factors for maintaining healthy soil and reducing the environmental impact of sugarcane cultivation. When these environmental benefits are combined with the financial savings, the VSP emerges as a highly effective tool for advancing sugarcane planting in a more sustainable and modern manner.

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