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Comparative Analysis on Cost-Economics Evaluation of Robotic Tiller-Planter against Conventional Tillage and Planting Operations

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The labor-intensive, costly, and time-consuming nature of manual tillage and planting in maize cultivation necessitates the integration of mechanized and robotic methods. This study focuses on the economic evaluation of a Robotic tiller-planter as a solution to address these challenges. Precise robotic tilling and planting methods aim to mitigate cultivation costs, reduce time requirements, and enhance worker comfort. Through a thorough assessment of ownership and operational expenses, farmers gain valuable insights to make informed decisions regarding the adoption of precise robotic machinery, optimization of existing equipment, or exploration of alternative methods for improved farm productivity and financial outcomes. The study compares the Robotic tiller-planter with conventional tillage and planting methods, revealing ownership and operating costs of 172.48 Rs/h and 126.44 Rs/h, respectively. The comparative analysis demonstrated a remarkable 61.58% time savings and a 54.72% reduction in costs during tilling and planting when utilizing the Robotic tiller-planter compared to conventional methods. The findings highlight the cost-effectiveness and environmental benefits associated with the robotic system. This research provides farmers with crucial insights, promoting the adoption of advanced agricultural technologies to optimize resource utilization, improve efficiency, and substitute sustainable farming practices.

Keywords: Robotic spot-tiller cum planter; cost economics; operating cost; ownership cost; break-even point; payback period.

1. INTRODUCTION

Historically, agriculture has consumed a large amount of energy, and it continues to do so currently. In the past, energy has been extremely inexpensive, and agricultural products have consumed large amounts of energy [1]. therefore, agricultural production must continue to increase while consuming the minimum possible amount of resources. Moreover, conventional, imprecise mechanized farming demands relatively more petrochemical energy, the majority of which is already consumed by automobiles and other applications [2]. Efficient and high-quality crop production with minimal resource use necessitates precision in all agricultural production operations, from soil tilling to harvesting. Precision agriculture is a modern farm management technique that makes use of computational analysis of observations to monitor and react to agricultural variability [3].

Field operations in agriculture are quite complex, and various issues should be addressed to allow an effective transition towards the robotics era. To build a robotic solution, an overall system analysis of the field operation should be conducted, together with a cost–benefit analysis [4,5]. Such a system should comply with very specific requirements, such as lightweight, small size, autonomy, intelligence, communication, safety, and adaptability, to execute the potential task effectively [4]. Seeding is one of the fundamental tasks in a crop production cycle and contributes significantly to the labor cost. seeding and tilling tasks have issues of proper seed depth and soil coverage further compounding the inefficiencies associated with manual seeding, making it both time-consuming and expensive. Recognizing these challenges, this paper focuses on the Cost-Economic Evaluation of a robotic tiller-planter in comparison to conventional planting methods, offering a scientific and concise exploration of the potential improvements in efficiency and cost-effectiveness associated with the adoption of robotic technologies [4].

Fuel-powered agricultural machinery emits hazardous emissions, including CO and CO_2, significantly impacting climate change. Climate change, in turn, affects agricultural methods and crop output. To mitigate these environmental effects, the adoption of effective and sustainable technologies becomes crucial [6]. The global surge in electric vehicle adoption, driven by their carbon-free nature, aligns with the increasing push for achieving net-zero emissions. Electric vehicles play a pivotal role in combatting climate change, improving public health, and reducing environmental harm. Agricultural machinery and equipment are indispensable for efficient farm operations, albeit at a substantial cost [6]. The recent increase in the cost of farm gear can be attributed to various factors, including the introduction of larger, technologically advanced machines, elevated pricing for replacement components, and increased energy costs.

Despite these rising costs, successful farmers demonstrate efficient management by implementing intelligent procedures and making judicious decisions, keeping expenses per acre under control [2]. The ability to regulate machinery expenses is a crucial aspect of maintaining a prosperous and sustainable farm. One of the challenging decisions for farmers lies in determining the optimal timing for investing in new equipment and selling existing machinery [2].

This encompasses not only the initial investment but also ongoing expenditures related to maintenance, repairs, fuel, and other operational factors. Precise and detailed audits of ownership and operating expenses offer farmers valuable insights, enabling informed decisions regarding new machinery acquisitions, enhancements to existing equipment, or exploration of alternative approaches to augment farm production and profitability. Mechanized agriculture, involving the use of machines in farming tasks, significantly enhances the productivity of farm laborers. The utilization of automated power in agriculture not only alleviates the physical strain associated with manual procedures but also accelerates processes, reduces costs, and ultimately amplifies overall output [7-12].

In regions where manual planting with different is prevalent, particularly in underdeveloped countries, the traditional method proves to be time-consuming and labor-intensive [13-15]. Transitioning to robotic planters can effectively address these challenges, yielding substantial benefits for the agriculture sector. Research indicates that agricultural mechanization profoundly influences the attainment of high-quality agricultural growth. Robotic planting and management techniques contribute to more uniform crop distributions and development. Additionally, the adoption of agricultural machinery has been proven to mitigate seed losses while concurrently increasing yield [16-18].

2. METHODOLOGY

In this research, the methodology employed for evaluating the cost-economic aspects of the designed robotic tiller-planter stands as a critical component. The total expense of the designed robotic tiller-planter is computed based on the bill of materials and manufacturing costs, overhead charges constituting 25% of the overall cost, resulting in a total expenditure of ₹2,45,000/-. Assumptions for calculating the operational cost of the robotic tiller-planter for maize crops include:

i. Useful life hours of the machine per year (H): 250 hours
ii. Useful life years of the machine (L): 10 years
iii. Salvage value (S): 10% of the initial cost
iv. Interest rate (i): 12% of the initial cost
v. Shelter and insurance: 2% of the initial cost
vi. Price of electricity: ₹0.615/h
vii. Labour wages: ₹300/day-1 (8 hours)

The chosen method for depreciation is the straight-line method, ensuring a systematic and approach to the evaluation of the robotic tiller-planter's operational costs.

2.1 Machinery Cost

There are two primary cost categories associated with farm equipment: ownership costs and operational expenses. Annual ownership fees are incurred irrespective of equipment utilization, while operational costs fluctuate directly with usage. Calculating the true cost of these expenses is contingent upon factors such as equipment lifespan, annual usage, and fuel and labor rates. Despite the challenges in accurately determining costs before equipment disposal or wear-out, approximations can be made by leveraging assumptions. This document provides a spreadsheet for estimating costs related to specific equipment or processes. Ownership expenditures, categorized as fixed costs, encompass depreciation, interest (also termed opportunity cost), taxes, insurance, and housing. Additionally, repairs and maintenance contribute to the operational expenses [16].

2.1.1 Ownership cost

Ownership costs, commonly referred to as fixed costs, represent regular expenses incurred by owners for the possession of a particular asset. Examples of these expenses include depreciation, interest (opportunity cost), taxes, insurance, and the housing of the item or property.

2.1.1.1 Depreciation (D)

Depreciation constitutes an expense associated with the wear, deterioration, and aging of a machine. The actual value of a machine during exchange or sale is contingent upon its mechanical wear, potentially deviating from the average market prices for similar equipment. Technological advancements or significant design changes may also render older equipment obsolete, leading to a rapid decline in residual value. Nevertheless, age and total operational hours typically serve as the primary factors in estimating a machine's remaining worth. To generate an annual depreciation estimate, the economic lifespan of the machinery and the salvage value at the end of its commercial lifespan must be determined. The economic life of a machine is the number of years for which expenses are estimated, often shorter than the machine's service life due to equipment replacement before complete wear-out. Farm equipment generally has a usable life of 10 to 12 years, with tractors lasting around 10 years, while the robotic system in this case has a useful life of 6 years. Salvage value is an estimated monetary worth assigned to a machine at the conclusion of its economic life, representing potential trade-in allowance, resale value, or zero if retained until complete depreciation and functional obsolescence.

The annual depreciation value (D) for the developed robotic tiller-planter can be calculated using the expression [16]: D= $\frac{P-S}{L\times H}$.

Where, P represents the initial cost. For the given scenario, the salvage value (S) is determined as 10% of the initial cost, translating to ₹24,500/-.

Substituting these values into the formula, the depreciation per hour (Rs h^{-1}) is computed as

$$\mathrm{D} = \frac{\mathrm{P}245000-24500}{10\times 250} = 88.20\ \mathrm{Rs./h} \qquad \ldots(1)$$

Where, D = Depreciation (Rs. h-1) and P = Initial cost (Rs.).

Therefore, the depreciation of the developed robotic tiller-planter is calculated to be ₹88.20 per hour, as per Equation (1). This calculation serves as a crucial component in assessing the overall ownership costs and economic viability of the robotic tiller-planter in agricultural operations.

2.1.1.2 Interest (I)

When contemplating the acquisition of a planter, a farmer faces two financing options: borrowing funds from a lender or utilizing personal cash. If opting for borrowing, the lender determines the interest rate based on creditworthiness and market conditions. In the case of utilizing personal funds, the interest rate is computed considering the opportunity cost of capital in alternative farm business investments. A weighted average of the two interest rates is recommended for situations involving both borrowing and using personal capital. Assuming a 12-percent average interest rate for financing the proposed planters, the formula used to calculate annual interest on an average investment with the current interest rate is as follows [16]:

$$\mathrm{I} = \frac{P+S}{2}\times\frac{i}{H}$$

Where, P represents the initial cost and S is the salvage value. By substituting these values into the formula, to calculate annual interest (I):

$$\mathrm{I} = \frac{245000+24500}{2}\times\frac{12}{100\times 250} = 64.68\ \mathrm{Rs/h} \quad \ldots(2)$$

This calculation provides valuable insights into the annual interest costs associated with financing the planter, taking into account both the initial cost and the salvage value, and is essential for a comprehensive assessment of the economic viability and financial considerations related to the acquisition of the planter.

2.1.1.3 Taxes, housing, and insurance

These supplementary expenditures, encompassing sales tax, road tax, insurance, and shelter charges, though comparatively lower than depreciation and interest, are integral in determining the overall ownership cost of farm machinery such as a planter. Sales and road taxes can be prudently distributed over the machine's lifespan to accurately reflect their impact on annual costs. Insurance assumes a critical role in safeguarding machinery against catastrophes, theft, and damage, enabling timely replacement or repairs as necessary [7].

Ensuring adequate coverage, tools, and maintenance equipment for the machinery obviate the necessity for frequent field repairs, concurrently shielding it from weather-induced wear and tear. This not only enhances reliability during operations but also preserves a higher trade-in value. Calculating the total annual expenses for taxes, insurance, and housing typically amounts to approximately 2% of the average machine cost. Specifically, insurance and shelter costs generally constitute around 1%

of the machinery's initial purchase cost. This meticulous consideration of these additional costs contributes to a scientifically informed assessment of the comprehensive ownership expenses associated with farm machinery, such as a planter.

Taxes, housing, and insurance collectively account for 2% of the initial cost (P) and are calculated as (2 % of P)/H

$$= 0.02 \times \frac{245000}{250} = 19.6\frac{Rs}{h} \qquad ...(3)$$

Combining this with the previously computed depreciation and interest costs (Equations 1 and 2), the total ownership cost is determined as [17]:

Total ownership cost = (1) + (2) + (3)
= 88.20 + 64.68 **+** 19.6
= 172.48 Rs. /h ..(4)

This computation provides a scientifically derived insight into the holistic expenses associated with owning and maintaining the developed robotic system, facilitating informed decision-making for farmers regarding the economic viability of this agricultural machinery.

2.1.2 Operating cost

Variable costs are those that vary directly with the level of machine operation, being incurred only during active use. Such expenses, directly linked to consumption volume, encompass repairs, lubricants, service, and labour.

2.1.2.1 Repair and maintenance costs

Farm machinery repair expenses arise from routine maintenance, parts wear and tear, and the potential for accidents. The amount allocated for maintenance varies significantly based on factors such as farm location, soil type, presence of rocks, weather conditions, and machinery operation practices. Repair costs may also differ among neighbouring farms, contingent upon their maintenance practices and the proficiency of machine operators. Monitoring and recording previous repair bills provide an effective means to gauge a machine's maintenance history and anticipate potential major overhauls. This data aids in assessing the effectiveness of the maintenance program and the operator's skill in addressing issues. In the absence of such records, estimating repair costs based on average experiences is still possible, although results may be less precise for individual circumstances. Repair and maintenance expenditures, constituting an integral facet of machinery ownership, are calculated at 4% of the machine's purchase price annually [18].

Repair and maintenance cost = (0.04 × 245000)/250 = 21.56 Rs/h (5)

2.1.2.2 Labour wages

Planting activities involve variable labour requirements, necessitating the inclusion of labour expenses in machinery evaluations. In the comparison between ownership and customized hiring, labour costs emerge as a crucial factor. The labour wages were determined based on the prevailing rates in the research region, with the robotic tiller-planter operator receiving Rs. 300/day. Additionally, a singular labourer was engaged for harvesting operations at Rs. 300/day for 8 hours daily. This data provides a scientifically grounded assessment of labour costs associated with both the operation of the robotic tiller-planter and manual harvesting activities.

The labour wages were calculated at Rs. 37.5 per hour, resulting in operator wages for the developed Robotic tiller-planter amounting to 37.5 Rs/h .. (6).

2.1.2.3 Electricity

India benefits from relatively lower electricity rates compared to many affluent nations. The cost of electricity is computed by multiplying charging power with the charging time, where charging power is the product of charging voltage and current. A standardized rate of power consumption per unit is applied, and the total electricity charges are derived by recording the total units utilized by various components [16].

The power consumption cost for battery charging in the developed Robotic tiller-planter, considering six 12V 26 Ah batteries, amounts to 67.38 Rs/h.

This calculation involves a battery capacity of 1872 watts, a cost of Rs. 6 per unit of power, and a total power consumption of 11.23 kilowatt-hours for full battery charging.

Battery capacity: = 6×12×26 = 1872 watts

(1 unit of power = 1000 watts or 1-kilowatt hour)

Time taken to full discharging of battery = 360 min
Power consumption for full charging of battery is = 1872 ×6 = 7488 watts =11.23 U
Power consumption cost = Rs. 11.23 ×6= 67.38 Rs/h
Therefore, total electricity charges = 67.38 Rs/h … (7)

The total operating cost, encompassing labour wages, operator wages, and electricity charges, equals 126.44 Rs/h. Consequently, the total cost of the developed Robotic tiller-planter, including ownership and operating costs, is 298.92 Rs/h.

Total operating cost = (5) + (6) + (7) = 21.56 + 37.5+ 67.38 = 126.44 Rs/h
The total cost of the developed Robotic tiller-planter= Total ownership cost+ Total operating cost = 172.48 + 126.44 = 298.92 Rs/h

2.2 Planter Cost of Operation/ha

The field capacity of the developed Robotic tiller-planter is 0.12 ha/h, resulting in a cost of operation per hectare of 2491 Rs/ha, calculated by dividing the total cost of 298.92 Rs/h by the field capacity.

Cost of operation/ha = 298.92 /0.12 =2491 Rs/ha … (9)

Additionally, overhead charges, representing 25% of the total cost, amount to 74.73 Rs/h. The profit margin is then determined by adding the overhead charges to 25% of the overhead charges, resulting in a profit of 93.41 Rs/h.

Overhead charges @25% of total cost = 298.92×0.25 =74.73 Rs/h
Profit = Overhead charges + 25% of overhead charges = 74.73 + 18.68 = 93.41 Rs/h

2.3 Custom Hiring Charges (CHC)

Custom hiring costs for agricultural machinery encompass personalized and formal charges associated with renting specific farm equipment, tailored to the unique needs of farmers utilizing machinery for agricultural tasks. These fees are influenced by various factors, such as the type of machine required (e.g., tractors, planters, or ploughs), the duration of the hire, additional services required, and the geographical area of use. Each leasing agreement is distinctly crafted, with fees adjusted to establish a fair and official arrangement aligned with the specific requirements of the farmer [18].

The custom hiring charges for agricultural machinery are determined by combining the total cost, overhead charges, and profit.

Custom hiring charges = Total cost + Overhead charges + Profit

= 298.92 +74.73 + 93.41

= 467.06 Rs/h

In this case, the custom hiring charges amount to 467.06 Rs/h, calculated as the sum of 298.92 Rs/h (total cost), 74.73 Rs/h (overhead charges), and 93.41 Rs/h (profit).

2.4 Breakeven Point

The break-even point of a planter represents the operational or production level where the planter's total operating expenditures precisely match the income generated from its use. At this juncture, neither profit nor loss is incurred, indicating that the company covers all expenses without generating additional profits. The break-even point is a pivotal concept in business, frequently employed to evaluate the financial viability of investments and activities. For a planter, the break-even threshold is attained when the revenue generated from planted crops (or any other service provided by the planter) fully offsets all costs associated with ownership, maintenance, and operation of the machine.

The break-even point, denoted in hours, [16] is calculated using the formula:

Breakeven point (h) =annual fixed cost/year/costom hiring charges-operating cost

$$= \frac{172.48 \times 250}{467.06 - 126.44}$$

= 127 h/ year

The average net annual profit in rupees is computed using the formula:

Average net annual profit (Rs) = (Custom hiring charges- Operating cost) × Annual use

= (467.06-126.44) ×250

=85,155 Rs

2.5 Payback Period

The payback period of a planter represents the duration required for the cumulative cash inflows generated through planter utilization to equal the initial investment cost of acquiring the machine. Essentially, it signifies the timeframe in which the planter "pays back" the expenditure incurred on its purchase through generated revenue. The payback period serves as a vital financial metric for assessing the risk and return associated with an investment. Generally, a shorter payback time is favoured as it indicates a swifter return on investment, minimizing the likelihood of an extended recovery period.

The Payback period, denoted in years, (7) is calculated using the formula:

Payback period = (initial cost of machine)/(avarage net annual profit)

= 2,45,000/85,155

= 2.877 years

2.6 Conventional Methods vs Robotic Tilling and Planting

Planters have gained prominence as the predominant agricultural machinery in India, primarily due to labor constraints during the peak planting season [19]. Traditional manual methods of sowing and planting, involving manual ploughs or animal-drawn and tractor-drawn implements, have become increasingly cumbersome, demanding substantial manpower or fuel usage and resulting in elevated operational costs. This manual approach, however, poses challenges, with delays in sowing and planting leading to significant losses for farmers. Additionally, the current system requires workers to adopt uncomfortable squatting positions, contributing to potential health issues over time. Addressing these challenges and enhancing maize cultivation efficiency necessitate urgent automation in this domain. The implementation of autonomous techniques holds the potential to reduce time and expenses associated with operations, as well as alleviate worker discomfort and strain [13]. The automation of robotic tiller cum planters not only promises increased farmer productivity and profitability but also fosters improved working conditions, contributing to the long-term growth of the agricultural industry.

Despite the drawbacks of mechanical planting, any novel system must address two pivotal issues: field preparation and planting cost and time. The efficacy of the new technology can be demonstrated by focusing on the elimination of these variables, showcasing its potential to attract farmers. To assess the time and cost savings offered by the proposed technology compared to manual planting and conventional methods, the following estimates are provided below.

a) Saving in time:

i. Area covered by man in the conventional method of planting = 0.01 ha/h
ii. Man, hours in the conventional method of tillage/ha = 135 h
iii. Man, hours in the conventional method of planting/ha = 100 h
iv. The field capacity of the developed planter = 0.12 ha/h
v. Man, hours with the robotic spot tilling and planting/ha = 90.27 h

$$\text{Saving in time (\%)} = \frac{235 - 90.27}{235} \times 100 = 61.58\%$$

b) Saving in cost

i. Man, hours in the manual method of tillage and planting /ha = 235 h
ii. Labour wages = 350 Rs/day (8 hours)
iii. Total cost in the manual method of tillage and planting/ha = (350/8)×235 = 10281 Rs/ha
iv. Total cost in the conventional method of tillage and planting/ha=5500 Rs/ha
v. The total cost of operation with a developed robotic spot tiller cum planter=2491 Rs/ha

Saving in cost with comparison to manual method (%) = 10281-2491/10281× 100

= 75.78%

Saving in cost with comparison to the conventional method (%) = 5500-2491/5500× 100

= 54.72%

3. RESULTS AND DISCUSSION

The cost economics of a robotic tiller-planter holds paramount importance for various stakeholders involved in agriculture and farming. Informed decision-making regarding the acquisition, operation, and maintenance of tillage and planting equipment relies on a comprehensive understanding of its cost dynamics. Farmers and agricultural businesses face significant capital investments when procuring tillage and planting equipment. Through a detailed analysis of cost economics, they can ascertain the financial viability of the investment, gauging the time required to recover the initial outlay through enhanced tilling and planting efficiency and increased productivity. A thorough comprehension of operating costs, encompassing elements like fuel consumption, maintenance, labor, and spare parts, is crucial for optimizing equipment efficiency. Armed with this knowledge, farmers can fine-tune operational practices to maximize efficiency and minimize costs [18]. The comparative analysis of costs among different tilling equipment and planters empowers farmers to make well-founded choices.

Evaluating factors such as efficiency, labor requirements, maintenance expenses, and potential productivity gains allows farmers to select the most cost-effective option tailored to their specific needs [9]. Furthermore, the cost economics of a robotic tiller-planter directly influences the overall profitability of agricultural operations. Keeping costs in check and optimizing resource utilization enables farmers to enhance overall profits and achieve financial sustainability. Assessing tilling and planting operations, particularly the time-saving potential of robotic spot tiller cum planters, is crucial. Time reduction not only enhances overall productivity but also facilitates increased planting cycles, ultimately resulting in improved agricultural output [17].

The utilization of the developed technology for spot tiller cum planter in maize cultivation demonstrated substantial cost and time savings in comparison to traditional manual and conventional methods. Similar trends were observed in the assessment of sensor-based autonomous seed-sowing machines [3,13]. The accompanying figure illustrates compelling evidence of the technology's benefits, with the developed technology surpassing conventional methods by reducing tilling and planting time by an impressive 61.78% and lowering overall costs by 54.72%. These findings highlight the tangible advantages of incorporating advanced techniques in agricultural practices, leading to more efficient and cost-effective crop tilling and planting processes.

Ownership costs, encompassing factors such as depreciation, interest, taxes, shelter, and insurance, are associated with machine ownership and are determined by the duration of ownership rather than the extent of usage. Conversely, operating costs, also known as operational costs, fluctuate based on the level of machine usage. Variable costs, including repair and maintenance, fuel, oil or lubrication, and labor costs [16], contribute to operational costs. The operational cost, break-even point, and payback period were computed using the BIS code 9164-1979. The obtained results in cost economics are presented in the following Table 1.

Table 1. Results for cost economics of robotic spot tiller cum planter

Total cost of machine (with labor costs), Rs 245000						
Sl. No.	**Fixed cost**			**Variable cost**		
1.	Depreciation, Rs/y	:	22050	Labor cost, Rs/h	:	37.5
2.	Interest, Rs/y	:	16170	Electricity, Rs/h	:	67.38
3.	Housing, shelter, Rs/y	:	4716.5	Repair and maintenance, Rs/h	:	21.56
4.	Total Rs/h	:	171.7	Total Rs/h	:	126.44
5.	Operating cost, Rs/h		:	298		
6.	Field capacity, ha/h		:	0.012		
7.	Cost of operation, Rs/ha		:	2483		
8.	Overhead charges, Rs/h		:	89.4		
9.	Profit, Rs/h		:	26.82		
10.	Custom hiring charges, Rs/h		:	414.22		
11.	Breakeven point, h/year		:	369.34		
12.	Payback period, years		:	8.26		

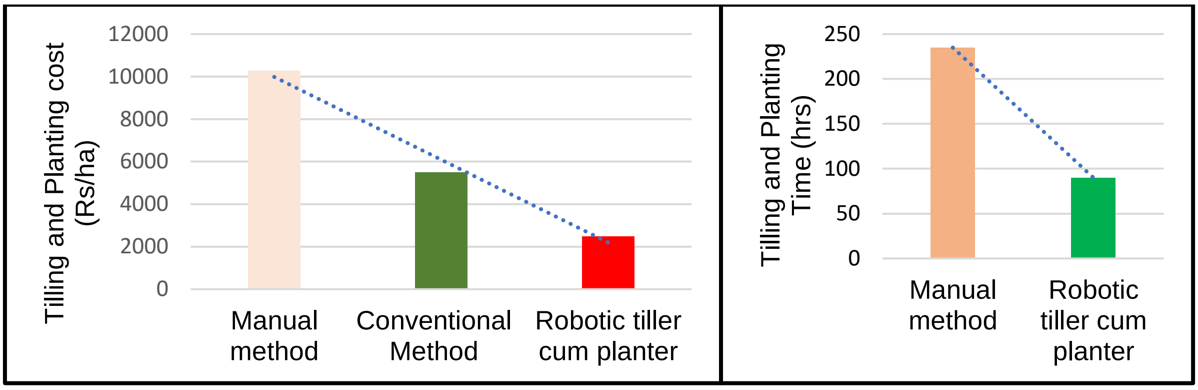

Fig. 1. Comparison of tilling and planting time and cost with the conventional methods

4. CONCLUSION

The autonomous operation of the robotic tiller-planter comes with a cost of 2491 Rs/ha, available for customer hire at 467.06 Rs/h, and attains a break-even point at 127 h/year. With a commendable payback period of 2.87 years, the investment in this tiller-planter proves to be financially lucrative. In comparison to conventional methods, it significantly reduces time requirements by 61.58% and cuts costs by 54.72% during spot tilling cum planting. Moreover, the tiller-planter executes two operations simultaneously, diminishing the need for manual labor. The autonomous and eco-friendly design of the robotic tiller-planter aligns with sustainable precision agriculture practices. In summary, the robotic tiller-planter emerges as a time-saving, cost-efficient, labor-reducing, and environmentally responsible innovation, positioning it as a valuable asset for modern agriculture.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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