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Efficiency and Cost-effectiveness Analysis of Developed Embedded System-Controlled Seed and Fertilizer Applicator

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

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ABSTRACT

In maize cultivation, the labour-intensive, time-consuming, and costly nature of manual planting necessitates the exploration of mechanized solutions. This study presents a comprehensive economic evaluation of an embedded system-controlled seed cum fertilizer applicator as a potential answer to these challenges. Precise planting methods offer a multi-pronged approach, aiming to reduce cultivation costs, minimize time requirements, and improve worker comfort during planting operations. By meticulously analyzing both ownership and operational expenses, this study empowers farmers with the knowledge necessary to make informed decisions. These decisions could involve adopting the precise seed cum fertilizer applicator technology, optimizing existing machinery, or exploring alternative methods to achieve enhanced farm productivity and financial gains. The embedded system-controlled seed cum fertilizer applicator was directly compared to traditional manual planting methods. This analysis revealed ownership and operating costs of 9.56 Rs/h and 63 Rs/h, respectively. The compelling findings demonstrated a remarkable 96.87% reduction in planting time and a 55.47% cost decrease when utilizing the embedded system compared to manual methods. These results highlight the significant cost-effectiveness and environmental benefits associated with adopting this precise planting system. This research offers valuable insights to farmers, potentially promoting the integration of advanced agricultural technologies that can optimize resource utilization, improve operational efficiency, and contribute to the implementation of sustainable farming practices.

Keywords: Break-even point; cost economics; embedded system-controlled seed cum fertilizer applicatoroperating cost; ownership cost; payback period.

1. INTRODUCTION

Agriculture forms the backbone of India's economy, with over 58% of its 1.25 billion population reliant on this sector. Despite this significance, Indian agriculture is typified by small landholdings averaging a mere 1.57 hectares [1]. Traditionally, manual practices have dominated seed and fertilizer application; however, technological advancements now offer the potential for transformative change. Historically, manual sowing has faced limitations in achieving uniform seed distribution, leading to uneven crop growth and lower yields. Moreover, this method is time-consuming, requiring a significant investment of labour. Conversely, precision planting, enabled by technologies like embedded-system controlled applicators, offers precise seed and fertilizer placement. This precision minimizes waste, maximizes yields, and allows farmers to optimize seed depth and density – crucial for crop performance. In an era where agriculture faces sustainability challenges, precision planting's enhanced resource efficiency is a major advantage [2]. The transition towards precision agriculture, however, necessitates a thorough financial analysis [3-4]. India's foodgrains production touched a record 315.7 million tones with the help of agricultural mechanization and other factors in 2021-22 despite climate change challenges, the cost of acquiring and maintaining equipment must be weighed against potential gains [5]. Farmers must make informed decisions regarding investments in new technology, factoring in ownership costs, operational expenses (fuel, maintenance, etc.), and potential return on investment. Mechanization, particularly in labour-intensive tasks like planting, carries the promise of increased efficiency and reduced costs. Research demonstrates that robotic planters can address the limitations of manual sowing, leading to uniform crop stands, reduced seed loss, and higher yields. However, in regions reliant on manual methods, particularly in developing nations, a rigorous cost-benefit analysis is crucial for evaluating the feasibility of technological adoption [6]. This research aims to fill this knowledge gap. A thorough examination of the embedded system-controlled seed cum fertilizer applicator, from both a technical and economic standpoint, will be benchmarked against traditional manual sowing methods. Data collection will encompass factors such as: Initial equipment investment Operational costs (labour, fuel, maintenance), Seed and fertilizer usage efficiency, Crop yields, Time savings Potential, impacts on soil health, and long-term sustainability [7].

By comparing the cost-economic profiles of both methods, this study intends to provide a decision-making framework for farmers seeking to optimize their planting practices. Furthermore, it will contribute to the broader discourse on sustainable agricultural intensification in India and similar developing agricultural economies. This research holds the potential to inform policy recommendations and promote the adoption of technologies that simultaneously increase agricultural productivity and the profitability of smallholder farms, which are the foundation of India's rural economy [8]. This research paper undertakes a comprehensive cost-economic analysis of an embedded system-controlled seed cum fertilizer applicator in contrast to the labour-intensive and less efficient practice of manual sowing.

2. METHODOLOGY

A crucial aspect of this research is the methodology used to assess the economic viability of the designed embedded system-controlled seed cum fertilizer applicator. The total cost of the applicator is meticulously calculated by considering the bill of materials, manufacturing expenses, and a 25% overhead charge to account for unforeseen costs. This comprehensive approach yields a total expenditure of ₹11254. To determine the operational cost of the applicator for maize crops, the researchers are currently formulating a set of assumptions:

i. Useful life hours of the machine per year (H): 300 hours
ii. Useful life years of the machine (L): 5 years
iii. Salvage value (S): 10% of the initial cost
iv. Interest rate (i): 10% of the initial cost
v. Shelter and insurance: 2% of the initial cost
vi. Labour wages: ₹400/day-1 (8 hours)

2.1 Machinery Cost

The financial analysis of farm equipment requires a clear understanding of the two fundamental cost categories: ownership costs and operational costs. Ownership costs, also termed fixed costs, represent expenses incurred annually regardless of the equipment's usage frequency. These include depreciation (the decline in value due to wear and tear or obsolescence), interest (opportunity cost of capital invested), taxes, insurance, and housing expenses. Operational costs, or variable costs, directly fluctuate with the degree of machine utilization. Key components within operational costs include repairs and maintenance, fuel consumption, lubrication, and labor expenses. It's important to note that the precise values of both ownership and operational costs can be difficult to determine before the eventual sale or deterioration of the equipment. However, by employing informed assumptions about the equipment's lifespan, expected annual usage patterns, fuel prices, and labor rates, it is possible to arrive at reasonable cost estimates. This process is essential for making sound financial decisions regarding the acquisition and operation of farm machinery, allowing for budgeting, cost-benefit analyses, and operational optimization [9].

2.2 Ownership Cost

Ownership costs, also known as fixed costs, are the recurring expenses you pay just for owning an asset, regardless of how much you use it. These costs include factors like depreciation (loss of value over time), interest (the potential earnings you miss out on by buying the asset), taxes, insurance, and any costs related to storing or housing the asset.

2.3 Depreciation (D)

Depreciation is a critical cost associated with machinery, representing the loss of value due to wear and tear, age, and potential obsolescence. While the exact resale or trade-in value of a machine can fluctuate based on its condition and market forces, the most significant factors dictating its remaining value are its age and total usage hours. To calculate annual depreciation, we need to first determine the machine's economic lifespan and its salvage value. Economic lifespan represents the number of years over which the machine's costs are amortized and is often shorter than its physical lifespan, as farmers tend to trade equipment before it's completely worn out. As a general guideline, most farm equipment has a lifespan of 10-12 years, with tractors at around 10 years; in the specific case of a seed cum fertilizer applicator, a 5-year lifespan is assumed. Salvage value is the estimated worth of the machine at the end of its economic life. It might reflect a trade-in allowance, expected secondhand market value, or simply zero if the machine will be used until it's fully depreciated with no functional value. Understanding how depreciation works is crucial because it lets farmers allocate a portion of the machine's initial cost to each year it's used, providing a realistic assessment of expenses. This knowledge enables informed decision-making related to equipment purchases, replacements, and long-term operational costs within the farm. The annual depreciation value can be calculated by the following expression [9]:

Depreciation (D), Rs/h= $\frac{(C-S)}{(L\times H)}$

(Salvage value (S) of the machines as the 10% of the purchase value (IS 9164:1979))

Salvage value (S) =10 percent of the initial cost
=0.10×11254
=1126 Rs

Where,

D = Depreciation (Rs h^{-1})
C = Initial cost (Rs)

$$D, (Rs/h) = \frac{(11254-1126)}{(5\times 300)} = 6.75 \quad (1)$$

The determination of the seed cum fertilizer applicator's depreciation, calculated at ₹6.75 per hour using Equation (1), represents a vital step in quantifying ownership costs and evaluating the overall economic feasibility of the seed cum fertilizer applicator for agricultural use. This particular calculation highlights the progressive decline in the applicator's value over time, providing a realistic framework for cost analysis and facilitating informed decision-making regarding the long-term financial implications of deploying this technology.

2.4 Interest (I)

Farmers considering the purchase of a planter have two primary financing avenues: obtaining a loan or investing their own capital. With a loan, the interest rate is set by the lender based on the farmer's creditworthiness and prevailing market conditions. Alternatively, if personal funds are used, an opportunity cost arises – the potential return those funds could have generated in different farm investments. For scenarios involving a mix of borrowed and personal funds, a weighted average of the two interest rates is the most accurate approach. In this case, assuming a 12% average interest rate for financing the proposed planters, the annual interest on an average investment is calculated using the following formula [9]:

Interest at 10 % (i), Rs/h

$$Rs/h = \left[\frac{(C+S)}{2}\right] \times \left[\frac{i}{(100\times H)}\right]$$

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

$$Rs/h = \left[\frac{(11254+1126)}{2}\right] \times \left[\frac{10}{(100\times 300)}\right] = 2.06 \quad (2)$$

The calculated annual interest expense takes a holistic approach by factoring in both the planter's initial cost and its anticipated salvage value. This approach offers crucial insights into the actual financing costs associated with ownership. By understanding this expense, farmers gain a comprehensive perspective on the economic viability of acquiring the planter, enabling them to make well-informed decisions that align with their financial goals and long-term operational strategies.

2.5 Taxes, Housing, and Insurance

Beyond the primary expenses of depreciation and interest, a thorough assessment of ownership costs for farm machinery like a planter must also account for ancillary expenditures such as sales tax, road tax, insurance, and shelter. While these supplementary costs may individually be lower, their collective impact is significant over the machine's lifespan. By prudently distributing sales and road taxes across the anticipated operating years, farmers gain a realistic understanding of their annual financial contribution. Moreover, insurance serves as a crucial safeguard against unforeseen events like damage, theft, or catastrophes, ensuring that the planter can be promptly repaired or replaced, minimizing operational disruptions and mitigating financial risks [10].

Strategic investments in proper coverage, tools, and maintenance facilities substantially enhance farm machinery longevity and operational efficiency. These measures minimize the need for costly field repairs and protect equipment from weather-related deterioration, ensuring reliable performance and preserving a higher resale or trade-in value down the line. As a general guideline, annual costs for taxes, insurance, and housing collectively represent approximately 2% of the machine's average cost, with insurance and shelter expenses typically accounting for 1% of the initial purchase price. This diligent accounting of supplementary costs contributes to a rigorous, scientifically-grounded evaluation of the total ownership expenses associated with acquiring and maintaining 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

$$\mathrm{Rs/h} = \left[\frac{(\mathrm{C} \times 2)}{100 \times \mathrm{H}}\right]$$

(Insurance and taxes were 2 % of the purchase price of the machine (IS 9164:1979))

$$= 0.02 \times \frac{11254}{250} = 0.75 \frac{Rs}{h} \quad (3)$$

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)
= 6.75 + 2.06 + 0.75
= 9.56 Rs. /h (4)

The calculated total ownership cost offers a meticulously derived, scientifically informed understanding of the comprehensive expenses associated with acquiring and operating the developed robotic system. This analysis empowers farmers to make well-reasoned decisions grounded in economic viability when considering the adoption of this agricultural machinery.

2.6 Variable Cost

Variable costs, also known as operating costs, are expenses that fluctuate directly in proportion to the amount a machine is used. Unlike fixed costs, variable costs are only incurred when the machine is actively in operation. These costs are tied to factors that increase with usage, such as repairs, lubrication, maintenance, and the labor needed to operate the machine.

2.7 Repair and Maintenance Costs

Repair expenses for farm machinery stem from the need for routine maintenance, wear and tear on components, and the potential for unforeseen breakdowns. These costs can fluctuate widely depending on environmental factors (like soil type and weather), operational practices, and the skill of machine operators. Ideally, historical repair records provide the most accurate insight into a machine's maintenance needs and help predict major overhauls. This data also reflects the effectiveness of maintenance protocols and an operator's ability to troubleshoot. In the absence of such records, repair costs can be estimated based on industry averages, but may lack the precision of personalized historical data. As a significant component of ownership, repair and maintenance expenses are often calculated at approximately 4% of the machine's initial purchase price on an annual basis. (19).

Repair and maintenance cost = (0.04 × 11254)/300 = 1.5 Rs/h (5)

2.8 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 tractor operator receiving Rs. 400/day. This data provides a scientifically grounded assessment of labour costs associated with both the operation of the seed cum fertilizer applicator and manual sowing activities.

Labor costs associated with operating the developed embedded system-controlled seed cum fertilizer applicator have been established at a rate of Rs. 51.37 per hour. This precise calculation allows for accurate budgeting and forecasting of operational expenses related to human resources. Total over cost is also included the tractor operation cost

Labour cost = 51.37 (6)

Total variable cost = (5) + (6)
= 1.5 + 51.37
52.87 Rs./h

Overall total cost = fixed cost + variable cost + tractor operation cost

= 9.56+52.87+ 650 = 712.43 Rs./h

The comprehensive cost calculation offers a scientifically grounded understanding of the total expenses involved in acquiring and operating the developed embedded system-controlled seed cum fertilizer applicator. This analysis provides farmers with the necessary financial knowledge to make well-informed decisions regarding the economic feasibility of implementing this innovative machinery within their operations.

2.9 Planter Cost of Operation (/ha)

The total cost of operation is the summation of tractor operation cost and the field capacity of the seed cum fertilizer applicator.

The field capacity of the developed seed cum fertilizer applicator = 0.32 ha/h

Cost of operation/ha = 712.43/0.32 =2226.34 Rs/ha (7)

Overhead charges @25% of total cost = 712.43×0.25 =178.10 Rs/h

Profit = Overhead charges + 25% of overhead charges
= 178.10 + 44.52
= 222.62 Rs/h

The profit margin is then determined by adding the overhead charges to 25% of the overhead charges, resulting in a profit of 222.62 Rs/h.
The field capacity of the developed seed cum fertilizer applicator is 0.32 ha/h, resulting in a cost of operation per hectare of 2226.32 Rs/ha.

2.10 Custom Hiring Charges (CHC)

Custom hiring costs in agriculture represent the formalized and individualized fees associated with farmers renting specialized farm equipment to address their specific operational needs. These costs are dynamic, influenced by factors like the type of machinery required (e.g., tractors, planters, ploughs), the duration of rental, ancillary services included, and the geographical region. Each custom hiring agreement is uniquely structured, with fees negotiated to establish a fair and transparent arrangement that aligns with the farmer's particular requirements (19).

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

= 712.43 +178.10 + 222.62
= 1113.15 Rs/h

In this case, the custom hiring charges amount to 1113.15 Rs/h, calculated as the sum of 712.43 Rs/h (total cost), 178.10 Rs/h (overhead charges), and 222.62 Rs/h (profit).

2.11 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, [9] is calculated using the formula:

$$\text{BEP} = \frac{Annual\ fixed\ cost}{(Custom\ fee, Rs./h - operating\ cost, Rs./h)} \quad (8)$$

Custom fee = (operating cost/h + operating cost/h × 25% of overhead charges) + 25 % profit over new cost

= (63+63×0.25) ×1.25
= 98.5

$$\text{BEP} = \frac{3000}{(98.5-54)}$$

BEP (h/year) = 67.41

2.12 Payback Period

In the context of farm machinery, the payback period of a planter refers to the amount of time necessary for the accumulated cash inflows generated by its use to offset the initial investment cost. It serves as a crucial metric for evaluating the financial feasibility of the investment, as it indicates how quickly the planter 'pays for itself' through operational returns. A shorter payback period is generally preferred, demonstrating a faster return on investment and mitigating the risk of a prolonged recovery period. This metric plays a significant role in scientifically informed decision-making when farmers are considering the acquisition of new agricultural machinery. The Payback period, denoted in years, [9] is calculated using the formula:

Payback Period (year) = (Initial cost of the machine)/((Custom fee,Rs./h-operating cost,Rs./h)×Annual utility) (9)

$$\text{Year} = \left[\frac{(11254)}{(98.5-63)\times 300}\right] = 1.1$$

2.13 Conventional Methods vs Embedded system-controlled Seed cum Fertilizer Applicator

The rise of labor scarcity during peak planting seasons in India has propelled planters to the forefront of agricultural machinery [11]. Traditional manual sowing and planting methods, often relying on manual ploughs or animal-drawn and tractor-drawn implements, are becoming increasingly inefficient. These methods require significant manpower or fuel consumption, leading to higher operational costs. Furthermore, the manual approach is susceptible to delays in sowing and planting, resulting in substantial losses for farmers. Additionally, the current system necessitates uncomfortable squatting positions for workers, potentially causing long-term health problems. To address these challenges and improve maize cultivation efficiency, automation in this domain is paramount. The adoption of autonomous technologies has the potential to reduce operational time and costs, while also mitigating worker discomfort and strain [12]. Embedded system-controlled seed cum fertilizer applicator not only holds promise for increased farmer productivity and profitability but also fosters improved working conditions, ultimately contributing to the long-term sustainability and growth of the agricultural industry.

While manual and mechanical planting has its limitations, a successful new planting system must tackle two crucial concerns: field preparation, and the associated costs and time required for planting. The effectiveness of novel technology can be strategically demonstrated by addressing these primary variables, emphasizing its potential to streamline operations and attract farmers. To rigorously evaluate the advantages of the proposed technology, it's essential to conduct a comparative analysis against both manual planting and conventional methods, quantifying the time and cost savings offered by the new solution, 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 planting/ha = 100 h
iii. The field capacity of the developed planter = 0.32 ha/h
iv. Man, hours with planting/ha = 3.12 h

Save in time % = $\frac{100-3.12}{100}$ ×100= 96.87%

b) Saving in cost

i. Man, hours in the manual method of tillage and planting /ha = 100h
ii. Labour wages = 400 Rs/day (8 hours)
iii. Total cost in the manual method of tillage and planting/ha = (400/8)×235 = 5000 Rs/ha
iv. The total cost of operation with a developed embedded system-controlled seed cum fertilizer applicator =2226.32 Rs/h

Saving in cost with comparison to manual method (%) = $\frac{5000-2226.32}{5000}\times 100$
=55.47%

3. RESULTS AND DISCUSSION

A deep understanding of the cost economics surrounding a developed embedded system-controlled seed cum fertilizer applicator is critical for farmers and stakeholders in the agricultural sector. When considering investments in tillage and planting machinery, a comprehensive analysis of both acquisition and operational costs is essential. This analysis allows farmers and agricultural businesses to determine the financial feasibility of the investment and evaluate the payback period. Additionally, a thorough grasp of operating costs – including fuel consumption, maintenance, labor, and spare parts – empowers farmers to optimize equipment utilization and operational practices, ultimately leading to improved efficiency and cost reductions [13]. A comparative cost analysis of various tilling equipment and planters equips farmers with the knowledge necessary for data-driven decision-making. By meticulously evaluating factors like operational efficiency, labor demands, maintenance costs, and potential productivity increases, farmers can strategically select the most cost-effective option that aligns perfectly with their unique operational requirements and financial constraints. This scientific approach empowers them to optimize their agricultural investments and maximize profitability [8]. Furthermore, the cost economics of an embedded system-controlled seed cum fertilizer applicator exert a profound impact on the profitability of agricultural operations. By meticulously managing costs and optimizing resource allocation, farmers can drive profitability and attain long-term financial sustainability. A thorough analysis of the time-saving capabilities offered by robotic spot tiller-planters is particularly crucial, as reductions in operational time directly translate into enhanced productivity and the potential for increased planting cycles – ultimately boosting agricultural yields. This understanding is essential for making scientifically informed decisions that lead to improved financial outcomes for farmers (10).

Field trials using the developed embedded system-controlled seed cum fertilizer applicator for maize cultivation revealed significant cost and time reductions compared to established manual and conventional methods. These findings align with similar trends observed in studies evaluating sensor-based autonomous seed-sowing machines, further underscoring the potential of these innovative technologies to transform agricultural practices and enhance operational efficiency. The presented diagram provides compelling evidence of the efficacy of the advanced technology, showcasing its superiority over manual methods in agricultural practices. The developed technology demonstrates remarkable enhancements, significantly reducing planting durations by 96.87% and decreasing overall costs by 55.47%. These findings underscore the tangible benefits of integrating innovative techniques into agricultural processes, resulting in heightened efficiency and cost-effectiveness in crop tilling and planting methodologies [14].

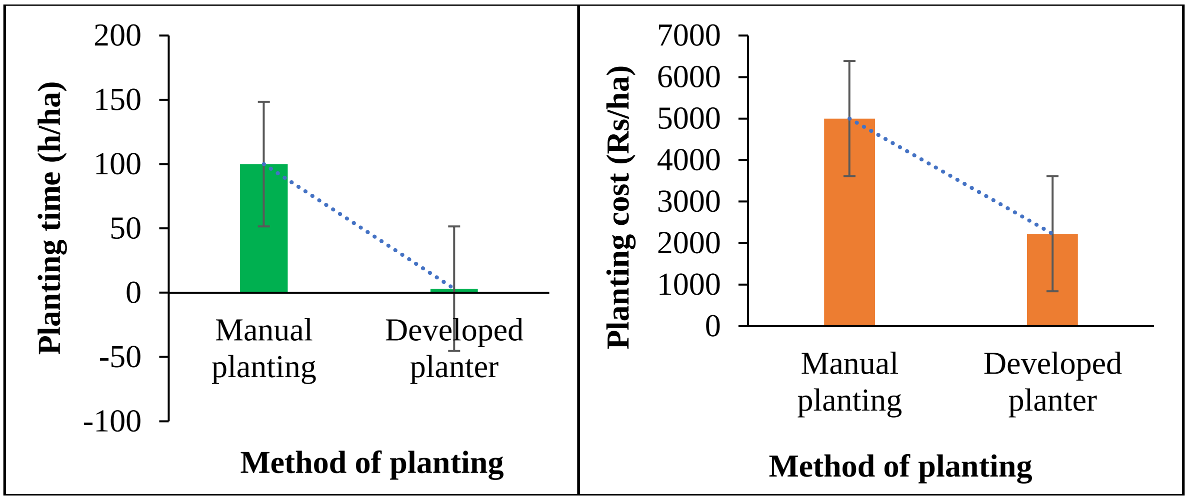

Fig. 1. Comparing the time and cost of seed planting between manual methods and a developed planting machine

Table 1. Results for cost economics of developed seed cum fertilizer applicator

The total cost of machine (with labour costs), Rs 11254							
Sl. No.	**Fixed cost**				**Variable cost**		
1.	Depreciation, Rs/y	:	6.75		Labor cost, Rs/h	:	52.87
2.	Interest, Rs/y	:	2.06		Repair and maintenance, Rs/h	:	1.5
3.	Housing, shelter, Rs/y	:	0.75		Total Rs/h	:	54.37
4.	Total Rs/h	:	9.56		Total Rs/h	:	54.37
5.	Operating cost, Rs/h			:	63		
6.	Field capacity, ha/h			:	0.32		
7.	Cost of operation, Rs/ha			:	2226.32		
8.	Overhead charges, Rs/h			:	178.10		
9.	Profit, Rs/h			:	222.62		
10.	Custom hiring charges, Rs/h			:	1113.15		
11.	Breakeven point, h/year			:	67.41		
12.	Payback period, years			:	1.1		

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 [9], 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.

4. CONCLUSION

The developed embedded system-controlled seed cum fertilizer applicator boasts a notable operational cost of 2226.32 Rs/ha, with custom hiring available at 1113.15 Rs/h. It reaches its financial break-even point after 67.41 hours of annual use and offers an impressive 1.1-year payback period, demonstrating its financial viability. Compared to traditional methods, this technology achieves a remarkable 96.87% reduction in operational time and a 55.47% cost reduction during spot tilling cum planting. Moreover, the tiller-planter's ability to perform two operations simultaneously reduces labor requirements, while its autonomous and eco-friendly design aligns with sustainable precision agriculture principles. Overall, the robotic tiller-planter presents itself as a time-saving, cost-efficient, labor-reducing, and environmentally conscious innovation that holds significant value for modern agricultural practices.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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