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RESEARCH ARTICLE

Assessment and Economic Aspects of Pivoting Arm Intra-Row Weeder

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ABSTRACT

Weeding is a tedious process and labor-intensive task, but it is a challenging task to do weeding in an intra-row zone. Manual weeding demands extensive labour and generates discomfort due to bending posture, time consumption, and the non-availability of labour at the peak stage. Chemical weeding affects human health and crops; though it is costly, it can increase cultivation costs to remove weeds. Mechanical inter-row weeders are available in the market and are working in the field in the row zone only, but for the intra-row, no such type of machinery is available in India. Still, researchers and scientists are working on the intra-row weeding mechanisms and machines to get a permanent solution. To overcome the aforementioned problems, a hydraulic actuated inter and intra row weeder was developed and evaluated in the field conditions. The performance parameters of the developed unit are as follows: actual field capacity, effective field capacity, performance index, time required to do weeding, payback period, break-even point, and the total cost of operation of weeding were calculated as 0.0768 $ha.h^{-1}$, 0.07725 $ha.h^{-1}$, 481.8, 13.1 h. ha^{-1} and 3.17 years, and 3.15 payback period, respectively. In terms of operational efficiency and cost savings, the developed weeder outperforms manual weeding.

Keywords: *Weeder, Intra row, Inter row, Hydraulic, Performance index, Payback period*

INTRODUCTION

Agriculture plays a vital role in the Indian economy, and the total labor force involved in agriculture and allied sectors in our country is 54.6%. Weeding is a crucial agricultural task known for its demanding labor requirements. Notably, a substantial portion, i.e., one-third of cultivation expenses, is incurred for manual weeding. This labor-intensive process requires a significant workforce, accounting for approximately 25% of the overall labor demand, equivalent to 900-1200 person-hours per hectare (Srinivas *et al*., 2023). In India, manual labor undermines the dominant approach to weeding, often involving traditional hand weeding tools such as khurpi, hand hoes, trench hoes & sickels. This practice comes with drawbacks, including the continuous weeding in a bending posture, which causes discomfort and back pain for the laborers. Furthermore, manual weeding is not only a labor-intensive but also time-consuming process. After mechanical weeders like cono weeder, star weeder, cultivator, and rotary weeder are used in the inter-row zone. The next one is chemical weeding, chemicals applied regularly on weeds at the critical

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period of weed growth, but it is harmful to the crop as well as to humans during direct spraying.

Around 92% of the landholding people in the country, who depend on agriculture, are small and marginal farmers. The percentage of small and marginal landholdings is 74.3% of total landholdings in Rajasthan for the year 2023-24 (Anonymous, 2021). Rotary power weeders are specifically designed to cater to this demographic, offering an economical alternative to other weed management approaches. The rising interest in mechanical inter-row weeders can be attributed to concerns surrounding diminishing labor availability, environmental degradation, and the increasing demand for organic food.

The advancement of power and mini tractors, and tractor-operated inter-row weeders, holds promise for controlling weeds and mainly meets both customer and ecological needs. This progress significantly contributes to the safer production of food for the population. The rotary power weeder's very precise operation lies in its ability to pulverize the soil, uproot weeds, and bury them in the same soil (Srinivas and Meena, 2020). Moreover, this process aids in maintaining soil pulverisation, sunlight, and nutrients, and promotes proper aeration for the particular crop. A key advantage of the power weeder is its efficient power utilization for blade operation, resulting in reduced draft and enhanced field performance. The cost of weeding by an engine-operated weeder is about one-third of weeding by manual labour. Intra-row weeding is a challenging and tedious task, which can be done manually in India. However, they still follow traditional methods to remove the weeds in intra-row zones. In some other countries, advanced technologies such as robotic weeders, robotic sprayers, and flame weeders have been developed to remove weeds.

This aims to achieve increased weeding efficiency, reduce labour requirements, minimize plant damage, and finally reduce the economic cost of weeding. Considering all these problems, to overcome the above inter and intra row weeding problems, we have designed and developed an inter and intra row hydraulic actuated system to remove the weeds. The intra-row weeding mechanism is operated with an oblique crank rocker mechanism, which converts the rotary to a reciprocating mechanism. Finally, it forms the sinusoidal pattern in between the plants and reduces the plant damage, increases the weeding efficiency, and in intra-row weeding was done by using duck foot sweeps. This novelty enables the weeding operation to be executed across different crops with varying row spacing. Subsequently, an economic assessment of the hydraulic actuated inter- and intra-row weeder was developed in the field applications.

MATERIALS AND METHODS

The pivot arm working principle

The hydraulic system comprises several components that work together to generate a reciprocating motion in the intra-row weeding tool. The system includes a hydraulic motor (EPRM-25) that is directly connected to a chain drive with a 3:1 ratio. This chain drive is then connected to a flywheel. The flywheel receives rotational energy from the chain drive, which is driven by the hydraulic motor. A specially designed oblique crank is set at an angle relative to the rocker arm and connecting rod. This crank produces oblique motion rather than standard rotational motion. As the hydraulic motor drives the chain drive, it transfers rotational motion to the flywheel connected with the oblique crank. This imparts a reciprocating motion to the connecting rod, causing it to move back and forth instead of in a simple circular motion. The connecting rod's other end is attached to the rocker, a rigid lever that pivots around a fixed point called the rocker pivot. This transfers the reciprocating motion to the rocker, which oscillates around its pivot. The motion of the rocker is then transmitted to the reciprocating arm, a mechanical linkage designed to convert the back-and-forth motion. Finally, the reciprocating arm is connected to the intra-row weeding tool, which is specially designed for efficient weed removal within crop rows.

The assessment of the developed hydraulic actuated inter and intra row weeder was accomplished at AEC&RI (TNAU), Coimbatore. Detailed specifications of the weeder are represented in Table 1. The components of this weeder comprise the hydraulic motor, flywheel, crank, lever, oscillating weeding blade, flow check hydraulic analyzer, and pressure relief valve. The total expenditure for the developed weeder was Rs. 40,600/-.

Assessment of the developed unit and weeder performance and evaluation were conducted in vegetable crops. Before the evaluation, a preliminary operation of the machine was carried out within the plants and in rows for each crop to confirm its effective functioning. Specifically, the machine testing focused on vegetable crops, including tomato and chilli, both of which featured an 800 mm working width. These crops were selected with consideration of their row-to-row spacing of 600 mm and plant-to-plant spacing of about 450 mm.

Weeding efficiency

Weeding efficiency is the proportion of weeds eliminated by a weeder relative to the total number of weeds in a given area, expressed as a percentage. The number of weeds was counted before and after each test, and the procedure was repeated three times. The resulting averages were computed for various forward speeds: 0.84, 0.96, and 1.09 km. h^{-1}at different operating depths (D_1, D_2, and D_3) for chili, tomato, and cotton crops.

Weeding efficiency (%) $= \frac{W_1 - W_2}{W_1} \times 100$ (Kumar *et al.*, 2014)......... (1)

where,

W_1 = Number of weeds before weeding

W_2 = Number of weeds after weeding

Plant damage

It represents the proportion of plants in a row that have been damaged, relative to the total number of plants present, expressed as a percentage. The number of plants in a 30 m field was recorded before and after the operation, replicated thrice, and the

Table 1. Specifications of inter and intra weeder

S. No.	Particular	Specification
1.	Name of machine	Inter and Intra Row Weeder
2.	Make	TNAU
3.	Model	Prototype
4.	Type of machine	tractor operated
6.	Overall width of machine, mm	850
7.	Overall length of machine, mm	850
7.	Overall height of machine, mm	550
8.	No. of rows covered	1 (intra) 2 (inter)
9.	Type of transmission system	The hydraulic system of the tractor
10.	No. of pillow block bearings	6
11.	No. of flange bearings	1
12.	width of weeding tool, mm	58, 78, and 98mm
13.	Type of linkage system	3

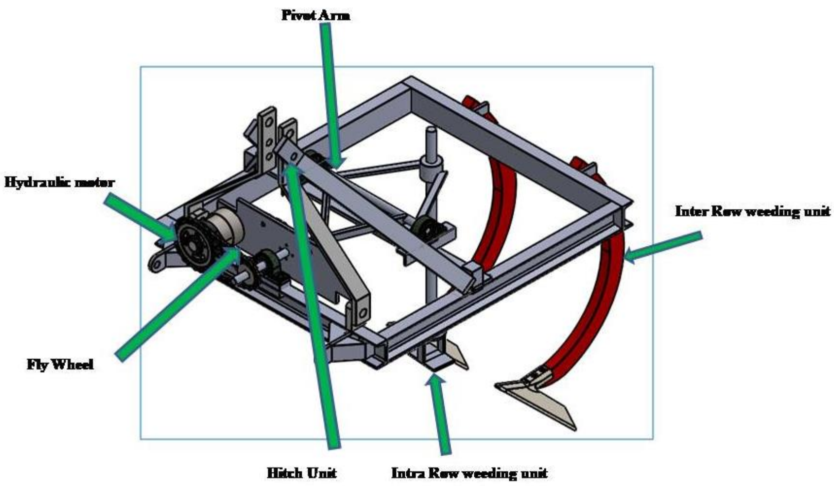

Fig.1. Isometric view of intra-row weeder pivot arm

Fig.2. Measurement of weeding efficacy in the field Plant damage

average plant damage percentage was calculated at all forward speeds of 0.84, 0.96, and 1.09 km. h^{-1}at D_1, D_2 and D_3 depth of operation levels for chilli, tomato, and cotton crops (Shakya *et al.*, 2016).

Plant damage, (%) = x 100
(Khan and Khan; Khan *et al.*, 2023) (2)

where,

q = Number of plants left in a 30 m length after weeding

p = Number of plants in a 30 m length before weeding

Theoretical field capacity

Theoretical field capacity refers to the maximum capacity or rate at which a machine, such as an inter and intra row weeder, is theoretically capable of covering a field under ideal conditions without considering any operational constraints or interruptions. (Kiran *et al.*, 2014).

$$\text{Theoretical field capacity, ha.h}^{-1} = \frac{S \times W}{10} \quad (3)$$

Where,

TFC = Theoretical field capacity, ha. h^{-1}

S = forward speed, km. h^{-1}

W = width of coverage, m

Effective field capacity

Adequate field capacity is the practical average speed at which the weeder covers the field, taking into account the total time spent operating, and is expressed as (Hossen *et al.*, 2014).

$$C_{eff} = \frac{A}{T} \quad (4)$$

Where,

C_{eff} = effective field capacity, ha. h^{-1}
A = Field coverage, ha
T = Actual time of operation, hr

Field efficiency

Field efficiency is calculated as the ratio of the effective field capacity to the theoretical field capacity. The field capacity is determined using the following formula (Ragesh *et al.*, 2018).

$$\text{Field efficiency } E_f = \frac{EFC}{TFC} \times 100 \quad (5)$$

Where,

E_f= Field efficiency, %

EFC = Effective field capacity, ha. h^{-1}

TFC = Theoretical field capacity, ha. h^{-1}

Performance Index

The weeder's performance was evaluated using the Performance Index (PI), employing the following relationship as proposed by the Performance Index (Srinivas *et al.*, 2010).

$$PI = \frac{FC \times (100 - PD) \times WE}{P} \quad (7)$$

Where,

FC = Field capacity, ha/hr

PD = Plant damage, %

WE= Weeding efficiency, %

P = Power, hp.

Cost economics of inter and intra-weeder

In the realm of agricultural equipment design, cost-effectiveness is a paramount consideration. The objective is to create machinery that not only exhibits optimal field performance but also minimizes expenditure. Hence, the economic viability of both inter-row and intra-row weeders was evaluated using the straight-line method. The operational expenses of the newly against those of the developed inter-row and intra-row weeders, which were compared with those of the manual weeding approach. Fixed and variable

Fig.3. Assessment of pivot arm in field conditions

costs associated with utilizing the prototype weeder per hour were determined following the procedure outlined in IS: 9164-1979. By extrapolating the field capacity of the inter-row and intra-row weeders, the operational cost per hectare was computed. This figure was then contrasted with the cost incurred through manual weeding. The cost-effectiveness of the weeder, compared to manual weeding, was quantified as the amount saved.

Determination of break-even point

Conducted to determine the point at which profit and loss balance out, the break-even analysis gauges the required duration of work at a given price to cover all costs and expenditures. The break-even point is marked by the juncture where the total cost line intersects the custom hiring cost line. If the break-even point falls below the machinery's annual utility time, owning the equipment proves advantageous for the farmer. Conversely, if the break-even point exceeds the machinery's annual utility time, machinery ownership could result in losses; in such cases, opting for custom hiring becomes a more viable choice for the farmer.

Payback period

The payback period is the time required for an investment to recover its initial cost through annual cash inflows. The calculation of the payback period involves the following formula. Typically, this period is expressed in years for farm machinery (Venkat *et al.*, 2021).

$$\text{Payback period} = \frac{\text{Initial investment}}{\text{Average net annual benefit}} \qquad (8)$$

Where,

The average net annual benefit, Rs = (CHC−TOP) × Annual utility

CHC = Custom hiring charge, Rs.h^{-1} = (25 % over total cost of operation Rs.h^{-1})

TOP = Total operating cost

Theoretical field capacity

The interrelationship between forward speed and theoretical field capacity in weeding operations is evident in Fig. 4. As forward speed increases, the theoretical field capacity also tends to rise. This relationship is intuitive: higher speeds enable the machine to cover more ground in the same amount of time, thereby increasing theoretical field capacity. For instance, when the forward speed increases from 0.84 km.h^{-1} to 0.96 km.h^{-1}, the field capacity goes up from 0.0672 ha.h^{-1} to 0.0768 ha.h^{-1}, and further increases to 0.0872 ha.h^{-1}at 1.09 km.h^{-1}. This connection underscores the importance of selecting an appropriate forward speed to optimize productivity and efficiency during weeding,, as it directly affects the weeding operation's ability to complete work within a given time frame.

Effective field capacity

The connection between forward speed and adequate field capacity in weeding operations becomes apparent when examining Fig.5. As the forward speed accelerates, the adequate field capacity shows a corresponding increase. This correlation is quite intuitive: higher speeds allow the machine to cover a larger area in the same time frame, resulting in a noticeable boost in practical field capacity. For instance, when the forward speed rises from 0.84 km.h^{-1} to 0.96 km.h^{-1}, the field capacity increases from 0.063 ha.h^{-1}(Olaoye and Adekanye, 2006) to 0.0695 ha.h^{-1}, and it continues to climb, reaching 0.07725 ha.h^{-1} at a speed of 1.09 km.h^{-1}. This relationship underscores the pivotal role of selecting an appropriate forward speed to optimize efficiency and productivity during weeding operations, as it directly impacts the amount of work that can be completed within a given time frame.

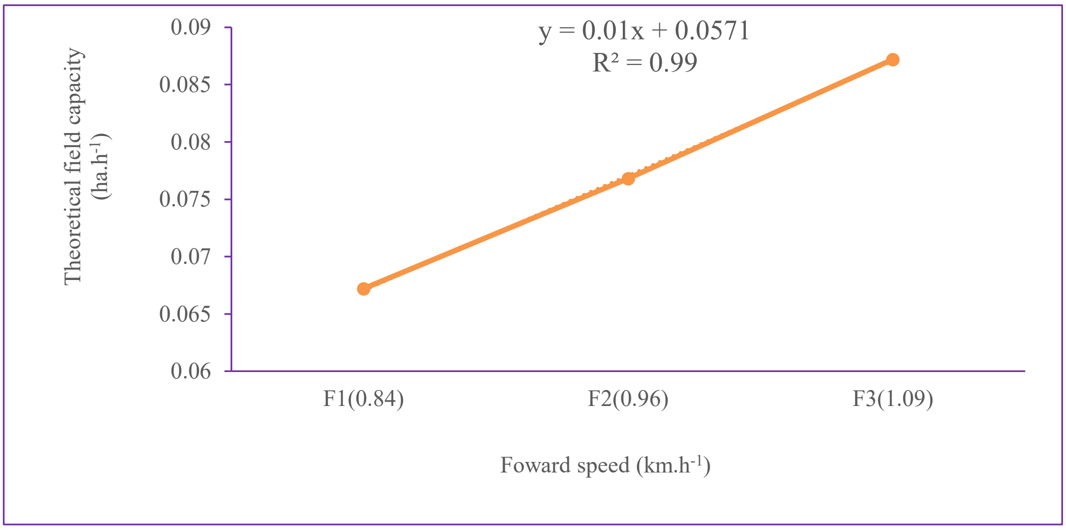

Fig.4.Effect of forward speed on theoretical field capacity

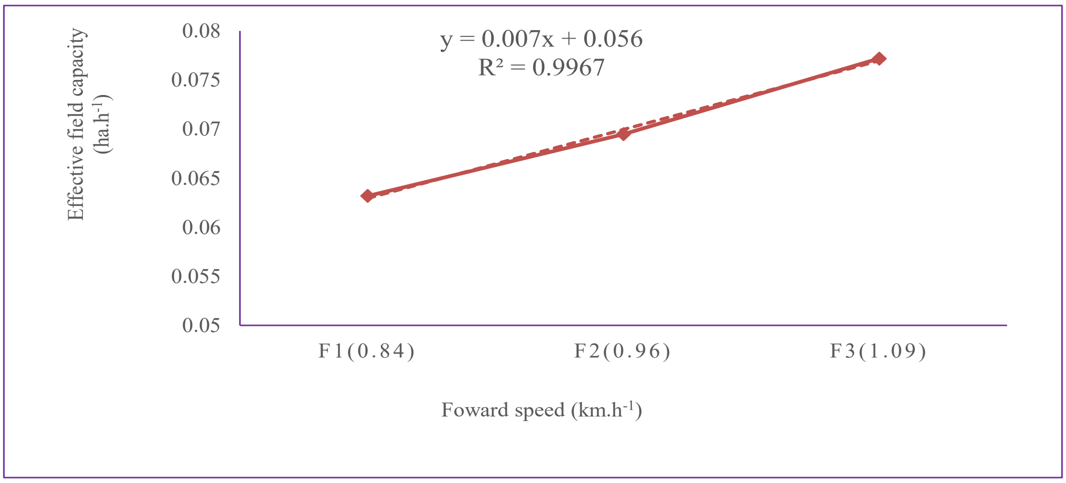

Fig.5. Effect of forward speed on adequate field capacity

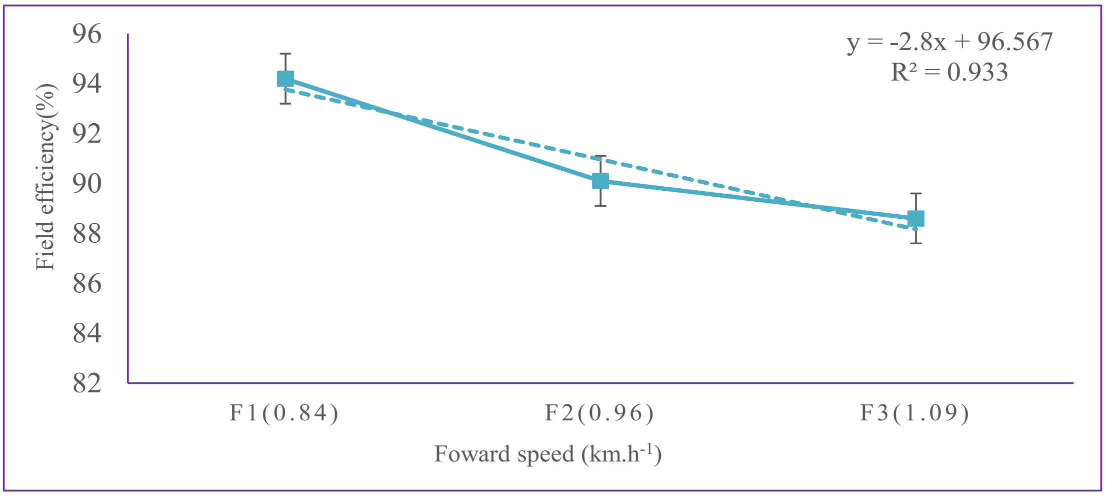

Fig.6. Effect of forward speed on-field efficiency

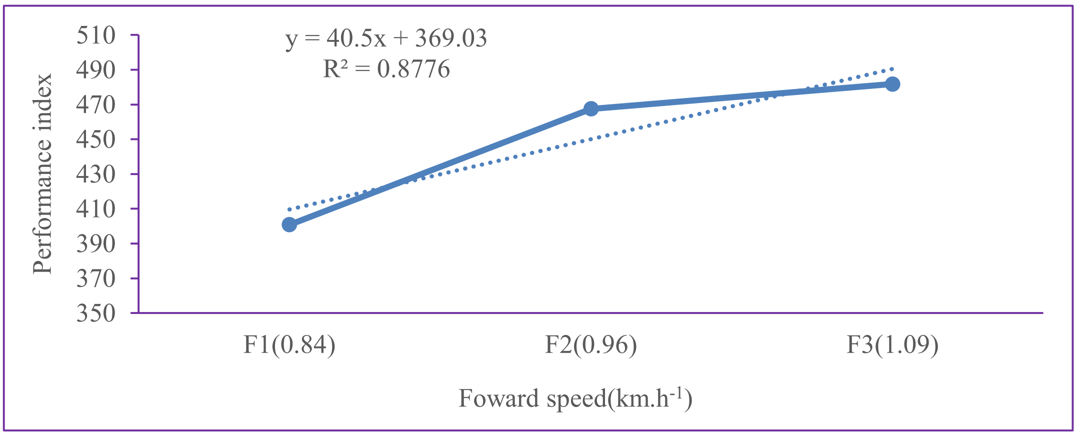

Fig.7. Performance index of inter-intra row weeder

Field efficiency

The minimum field efficiency, i.e., 88.6 % was found with F3(1.09 km.h^{-1}). Maximum field efficiency, i.e., 94.2% (Hegazy *et al.*, 2014) was found with F1(0.84 km.h^{-1}) forward speed but optimum field efficiency of 90.1% at forward speed of 0.96 km.h^{-1}. The results conclude that forward speed increases, while field efficiency decreases (Fig. 6).

4.4.8 Performance index

The Performance Index is found to be a maximum of 481.8 at a forward speed is 1.09 km.h^{-1}and the minimum performance index is 400.8 at a forward speed of 0.84 km.h^{-1} as shown in (Fig.7). The performance Index directly depends on the practical field capacity, plant damage, and weeding efficiency and indirectly depends on the power of the weeder.

Cost economics of inter- and intra-row weeder

Nowadays, there is a significant shortage of labour for manual weeding, resulting in considerably longer time required to weed each hectare. With the introduction of the developed inter- and intra-row weeder, the time required to weed 1.0 hectare of land has been reduced to 13.1 hours. This innovative approach has led to a weeding cost of ₹2803 per hectare. Compared with traditional weeding methods, the inter- and intra-row weeding technique has achieved an impressive 88% reduction in time and a 40.9% reduction in weeding costs. The payback period for the machine has been calculated at 3.15 years, with a favourable B-C ratio of 3.17.

The implementation of the developed inter- and intra-row weeder has not only significantly reduced the time and cost of weeding compared to traditional methods but has also proven economically feasible. Additionally, it addresses labour scarcity, reducing reliance on manual weeding and alleviating associated challenges.

To put it succinctly, the developed weeder has resulted in substantial cost savings of ₹15684.8 per hectare, translating to a 40.9% reduction in weeding expenses when compared to conventional methods. The inter- and intra-row weeder requires only 13.1 hours for weeding, a remarkable improvement over the 130 hours needed for traditional weeding of a 1-hectare area, as tabulated in .3.

CONCLUSION

The oblique crank rocker mechanism was chosen after an assessment in the soil bin. It was found to operate smoothly and produce better results than the other mechanisms. The maximum weeding efficiency

Table 2. Average wheel slip

S. No.	Particulars	Test No.			Average	Slip
		T1	T2	T3		
1	Distance Covered in 10 revolutions under no load, m	22.6	22.5	20.3	21.8	9.17%
2	Distance Covered in 10 revolutions under load, m	19.5	20.2	19.8	19.8	

Table 3. Inter and Intra row weeding and traditional weeding method

S. No.	Particular	inter and intra row weeding	Traditional weeding method	Increase / decrease over manual weeding (%)
		X	Y	$\frac{X-Y}{Y}$ X 100
1.	Total time required, man-h/ha	13.1	103	-88%
2.	Total cost of weeding, ₹/ha	2803	5687.5	-40.9%
4.	Payback period, years	3.15	-	-
5.	B-C ratio	3.17	-	-

was 92.72% at a depth of 30 mm with a forward speed of 1.09 km.h^{-1}. It was observed that weed control efficiency increased with increasing depth of the cutting blade at all forward speeds. This was due to a reduction in bite length. Higher depth and lower forward speed led to finer soil breakup due to shorter bite length. When the blade stroke length increased from 130 mm to 210 mm, plant damage escalated from 21% to 29% at depths of 20 and 50 mm at an operational speed of 0.96 km.h^{-1}.

The optimum field capacity found was 0.0672ha.h^{1} at 1.09 km.h^{-1}. The optimal effective adequate field capacity was 0.0695 ha.h^{-1}, and it continues to climb. As forward speed increases, the effective field capacity increases accordingly. The minimum field efficiency of 88.6 % was found with F3 (1.09 km.h^{-1}). Maximum field efficiency of 94.2% was found with F1 (0.84 km.h^{-1}) forward speed. The results conclude that as forward speed increases, the field efficiency decreases. The relationship is intuitive: higher speeds enable the machine to cover more ground in the same amount of time, thereby increasing theoretical field capacity. The performance index is found to be a maximum of 481.8 at a forward speed of 1.09 km.h^{-1}. The performance Index depends directly on the practical field capacity, plant damage, and weeding efficiency, and indirectly on the power of the weeder. The performance index is found to be a maximum of 481.8 at a forward speed of 1.09 km.h^{-1}. The performance Index depends directly on the effective field capacity, plant damage, and weeding efficiency, and indirectly on the power of the weeder.

The time needed for weeding 1.0 hectare of land has been reduced to 13.1 hours. This innovative approach has led to a weeding cost of ₹2803 per hectare. Compared with traditional weeding methods, the inter- and intra-row weeding technique has achieved an impressive 88% reduction in time and a 40.9% reduction in weeding costs. The payback period for the machine has been calculated at 3.15 years, with a favourable B-C ratio of 3.17.

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