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ECONOMIC EVALUATION AND PERFORMANCE ASSESSMENT OF PIVOTING ARM BASED INTRA ROW WEEDER

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ABSTRACT

Manual weeding demands extensive labor and causes physical discomfort due to continuous bending posture, in addition to being time-consuming and constrained by labor unavailability during peak seasons. Chemical weeding, though effective, poses health hazards to humans and may adversely affect crops, while also increasing the overall cost of cultivation. Mechanical inter-row weeders are commercially available and widely used; however, effective intra-row weeding machinery was still unavailable in India. Ongoing research aimed to develop suitable mechanisms for this purpose. To address these limitations, a hydraulic-actuated inter and intra-row weeder was developed and evaluated under field conditions. The performance parameters of the developed unit were actual field capacity of 0.0768 ha h^{-1}, effective field capacity of 0.07725 ha h^{-1}, and a performance index of 481.8. The time required for weeding was 13.1 h ha^{-1}, with a payback period of 3.17 years and a break-even point of 3.15 years. The total cost of operation was calculated as ₹2803 ha^{-1}. The optimum field efficiency was 90.1% at a forward speed of 0.96 km h^{-1}, while the maximum performance index of 481.8 was obtained at a speed of 1.09 km h^{-1}. Compared to traditional weeding practices, the developed hydraulic inter and intra-row weeding technique achieved an 88% reduction in time and a 40.9% reduction in weeding cost, demonstrating its potential as an efficient and economical alternative for sustainable crop management.

(Key words: Weeder, intra row, inter row, hydraulic, performance index and payback period)

INTRODUCTION

Agriculture plays a vital role in the economy of India and the total labor force involved in agriculture and allied sector in our country is 54.6%. Weeding stands as a crucial agricultural task, known for its demanding labor requirements. Notably, a substantial portion i.e., one-third of cultivation expenses was incurred to manual weeding (Yadav *et al.*, 2024). This was a labor-intensive process Commands a significant workforce, accounting for approximately 25% of the overall labor demand, equivalent to 900-1200 man-hours per hectare (Srinivas *et al.*, 2024). In India, manual labor ruins the dominant approach for weeding, often involving the use of traditional hand weeding tools such as khurpi, hand hoes or trench hoes and sickles. This practice comes with drawbacks, including the continuous weeding in bending posture gives discomfort and back pain to the laborers. Furthermore, manual weeding was not only labor-intensive but also time-consuming process. After mechanical weeders like cono weeder, star weeder, cultivator and rotary weeders were used in the inter row zone. Next one was chemical weeding, chemicals applied regularly on the weeds at critical period of weed growth but it was harmful to the crop as well as to the human being directly while spraying. Around 92% of the landholding people in the country depending on the agriculture were small and marginal farmers. The percentage of small and marginal land holdings is 74.3% of total land holdings in Rajasthan for the year 2023-24 (Thanuja *et al.,* 2022). Rotary power weeders were exclusively developed to cater to this demographic, offering an economical alternative in comparison 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 tractor and tractor operated inter-row weeders were used to control weeds and mainly holds promise in meeting both customer and ecological necessities. This progress significantly contributes to the safer production of food for the population. The rotary power weeder s were very precise operation it also lies in between ability to pulverize the soil, uprooting weeds, and bury them in the same soil (Srinivas and Meena, 2020). Moreover, this process aids in maintaining soil pulverization, sunlight, nutrients and promoting proper aeration to the particular crop (Gobika and Rajkumar, 2023). A key advantage of the power weeder lies in its efficient utilization of power for blade operation, resulting in reduced draft and enhanced field performance. The cost of weeding by engine operated weeder was about one-third of weeding

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by manual labour (Rajkumar and Gobika, 2024). In intra row weeding was a challenging and tedious task which can be done manually in India still they were following traditional methods to remove the weeds in intra row zones but to remove the weeds in some other countries advanced technologies like robotic weeding and robotic sprayers and flame weeders are developed to remove the weeds (Yadav *et al.*, 2024).

This aimed to achieve increased weeding efficiency, reduce the labour requirement, minimized the plant damage plants and finally reducing the cost economics to the weeding. Considering all these problems, to overcome from the above inter and intra row weeding problems we have designed and developed a inter and intra row hydraulic actuated system to remove the weeds. The intra row weeding mechanism was operated with oblique crank rocker mechanism which converts the rotary to reciprocating mechanism and finally it forms the sinusoidal pattern in between the plants and reduces the plant damage and increase 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 was made up of several components that work together to generate a reciprocating motion in the intra-row weeding tool. The system included a hydraulic motor (EPRM-25) that was directly connected to a chain drive with a 3:1 ratio. This chain drive was then connected to a flywheel. The flywheel received rotational energy from the chain drive, which was driven by the hydraulic motor. A specially designed oblique crank was set at an angle relative to the rocker arm and connecting rod. This crank generates an oblique motion rather than a standard rotational one. 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 was attached to the rocker, which a rigid lever was pivoting around a fixed point called the rocker pivot. This transferred the reciprocating motion to the rocker, which oscillated back and forth around the rocker pivot. The motion of the rocker was then conveyed to the reciprocating arm, which was a mechanical linkage designed to harness the back-and-forth motion. Finally, the reciprocating arm was connected to the intra-row weeding tool, which was 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 and RI, (TNAU), Coimbatore. The components of this weeder comprised the hydraulic motor, flywheel, and 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 developed unit and developed weeder performance and evaluation was conducted in vegetable crops as shown in figure 1. Prior to the evaluation, a preliminary operation of the machine was carried out within plants as well as in rows each crop to confirm its effective functioning. Specifically, the machine testing focused on vegetable crops such as tomato and chilli crops, both featuring an 800 mm working width of the machine. These crops were selected with consideration of their row-to-row spacing of 600 mm and plant to plant spacing about 450 mm.

Weeding efficiency

Weeding efficiency represents the proportion of weeds eliminated by a weeder figure 2 in relation to the total number of weeds in a given area, expressed as a percentage. The count of weeds both before and after each test was recorded and 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.

$$\text{Weeding efficiency (\%)} = \frac{W1-W2}{W1} \times 100 \quad \text{(Kumar et al., 2014)} \tag{1}$$

Where,

W_1 = Number of weeds before weeding

W_2 = Number of weeds after weeding

Plant damage

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

$$\text{Plant damage, (\%)} = \frac{q}{p} \times 100 \quad \text{(Khan et al., 2015)} \tag{2}$$

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 inter and intra row weeder, was theoretically capable of covering a field under ideal conditions without considering any operational constraints or interruptions. (Kiran *et al.*, 2014).

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

Where,

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

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

W = width of coverage, m

Effective field capacity

Effective field capacity was the practical average speed at which the weeder covers the field, taking into account the total time spent operating, and was expressed as (Alam *et al.*, 2018).

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

Where,

C_{eff} = effective field capacity, ha h^{-1}

A = Field coverage, ha

T = Actual time of operation, hr

Field efficiency

Field efficiency was calculated as the percentage ratio between the effective field capacity and the theoretical field capacity. The field capacity was 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 h^{-1}

PD = Plant damage, %

WE= Weeding efficiency, %

P = Power, hp.

Cost economics of inter and intra weeder

In the realm of agricultural equipment design, paramount consideration was given to its cost-effectiveness. The objective was to create machinery that not only exhibited optimal field performance but also boasts a minimized expenditure. Hence, the economic viability of both inter-row and intra-row weeders was evaluated using the straight-line method (Yadav *et al.*, 2024). The operational expenses of the newly devised inter-row and intra-row weeders were meticulously calculated and juxtaposed against the manual weeding approach. Fixed and variable costs associated with utilizing the prototype weeder hour^{-1} 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 hectare^{-1} was computed (Figure 3). The cost-effectiveness achieved through the weeder, in comparison to manual weeding, was quantified as the amount saved.

Determination of break-even point

It is conducted to determine the point at which profit and loss balance out, the break-even analysis gauge 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 was the duration required for an investment to recover its initial cost through yearly cash revenues generated. The calculation of the payback period involves the utilization of the following formula. Typically, this period is expressed in years for farm machinery (Venkat *et al.*, 2021).

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

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

RESULTS AND DISCUSSION

Theoretical field capacity

As forward speed increased, the theoretical field capacity also tended to rose (Figure 4). This relationship was intuitive, as higher speeds enable the machine to cover more ground in the same amount of time, resulting in an increased theoretical field capacity. For instance, when the forward speed increased 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 increased to 0.0872 ha h^{-1}at 1.09 km h^{-1}. Kiran *et al*. (2014) noted field capacity in the range of 0.049 to 0.050 ha h^{-1} with an average of 0.0494 ha h^{-1} for power weeder. This connection underscores the importance of selecting an appropriate forward speed to optimize productivity and efficiency during weeding as it directly impacts the operation of weeding ability to complete work within a given time frame.

Effective field capacity

The connection between forward speed and effective field capacity in weeding operations becomes apparent when examining. As the forward speed accelerated, the effective field capacity showed a corresponding increase. This correlation is quite intuitive since higher speeds allow the machine to cover a larger area within the same time frame, resulting in a noticeable boost in the effective field capacity. For instance, when the forward speed rose from 0.84 km h^{-1} to 0.96 km h^{-1}, the field capacity increased from 0.063 ha h^{-1} 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}. Olaoye and Adekanye (2015) stated that power weeder 5 hp machine operated at the field capacity of 0.079 ha h^{-1}. This relationship underscores the pivotal role of selecting an appropriate forward speed to optimize efficiency (Figure 5) and productivity during weeding operations, as it directly impacted the amount of work that can be completed within a given time frame.

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% was found with F1 (0.84 km h^{-1}) forwards peed but optimum field efficiency of 90.1% at forward speed of 0.96 km h^{-1}. Hegazy *et al*. (2014) reported that the maximum value of field efficiency was 89.88% and was recorded by using two blades with 1.8 km h^{-1} weeder forward speed. The results concluded that forward speed increased the field efficiency decreased (Figure 6).

Performance index

The Performance Index was found maximum of 481.8 at a forward speed was 1.09 km $h^{-1}$and the minimum performance index was 400.8 at a forward speed of 0.84 km h^{-1}. The performance Index directly depends on the effective 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 available labour for manual weeding, resulting in considerably longer durations required to weed each hectare of a given area. With the introduction of the developed inter and intra-row 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 ha^{-1}. In comparison to 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 was calculated at 3.15 years, with a favorable 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 associated with weeding when compared to traditional methods but has also proven to be economically feasible. Additionally, it addresses the issue of labour scarcity, reducing the reliance on manual weeding and alleviating associated challenges.

To put it succinctly, the developed weeder resulted in substantial cost savings of ₹15684.8 ha^{-1}, translating to a 40.9% reduction in weeding expenses when compared to conventional methods. The inter and intra-row weeder only required 13.1 hours for weeding, a remarkable improvement over the 130 hours needed for traditional weeding of a 1hectare area as shown in Table1.

The oblique crank rocker mechanism was chosen after an assessment in the soil bin. It was found to operate smoothly and produced better results than the other mechanisms. Maximum weeding efficiency found was 92.72% at 30 mm depth with forward speed of 1.09 km h^{-1}. It was observed that the weeding efficiency increased with increase in depth of the cutting blade at all forward speeds. This was due to reduction in bite length. Higher depth and minimum forward speed led to finer soil breakup because of 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 operational speed of 0.96 km h^{-1}.

The optimum field capacity found was 0.0672 ha h^{-1} at 1.09 km h^{-1}. The optimum effective field capacity was 0.0695 ha h^{-1}, and it continued to climb, as the forward speed accelerates, the effective field capacity showed a corresponding increase. 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 concluded that as forward speed increased then field efficiency decreased. The relationship was intuitive, as higher speeds enable the machine to cover more ground in the same amount of time, resulting in an increased theoretical field capacity. The performance index was found maximum of 481.8 at a forward speed 1.09 km h^{-1}**.** The performance Index directly depends on the effective field capacity, plant damage, and weeding efficiency and indirectly depends on the power of the weeder. The performance index was found maximum of 481.8 at a forward speed of 1.09 km h^{-1}. The performance Index directly depends on the effective field capacity, plant damage, and weeding efficiency and indirectly depends on the power of the weeder.

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Table 1. Inter and Intra row weeding and traditional weeding method

S. No.	Particulars	Inter and intra row weeding	Traditional weeding	Comparison with manual weeding (%)
		X	Y	$\frac{X-Y}{Y} \times 100$
1.	Total time required, man-h ha^{-1}	13.1	103	-88%
2.	Total cost of weeding, ₹ ha^{-1}	2803	5687.5	-40.9%
4.	Payback period, years	3.15	-	-
5.	B:C ratio	3.17	-	-

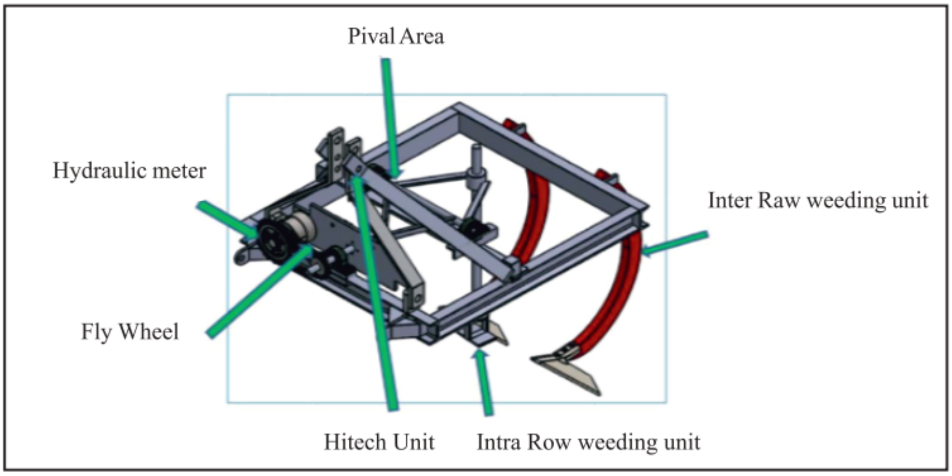

Figure 1. Isometric view of intra row weeder pivot arm

Figure 2. Measuremet of weeding efficiecy in field

Figure 3. Assessment of pivot arm in field conditions

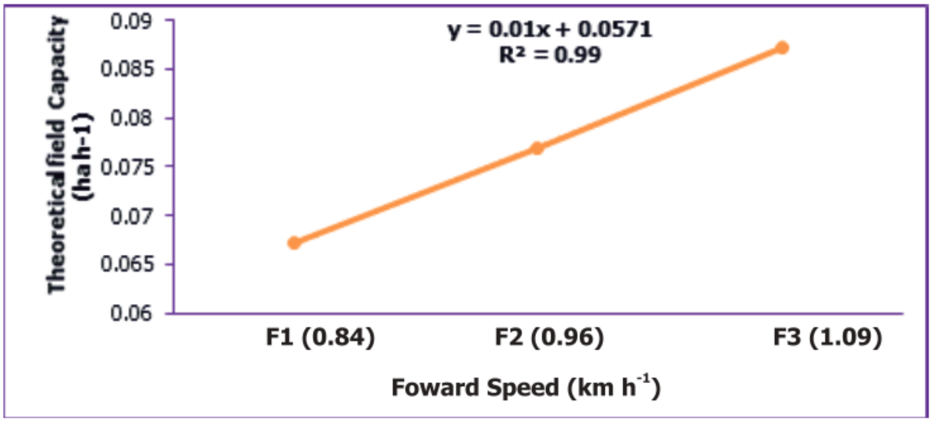

Figure 4. Effect of forward speed on theoretical field capacity

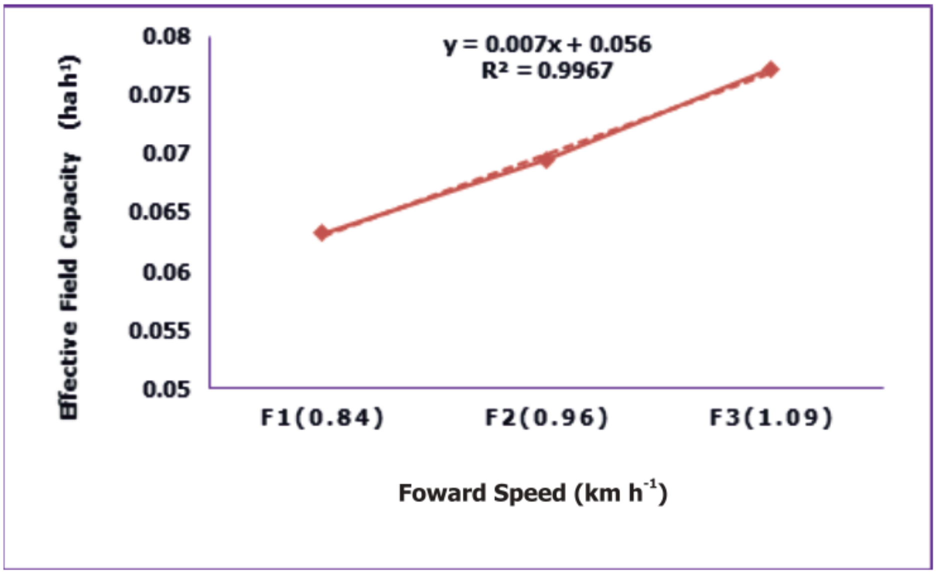

Figure 5. Effect of forward speed on effective field capacity

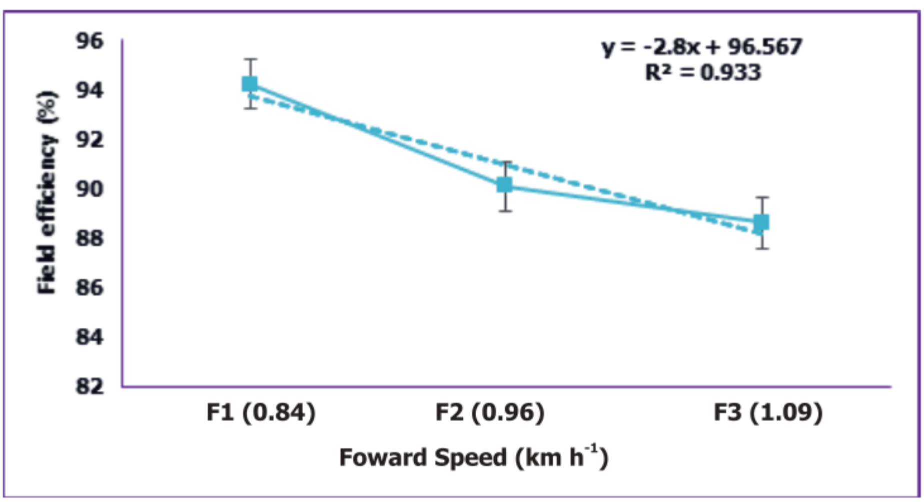

Figure 6. Effect of forward speed on-field efficiency

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