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Innovative Blade and Tine Push Weeder for Enhancing Weeding Efficiency of Small Farmers

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Abstract: Sustainable agriculture is central to addressing the difficulties farmers face, such as a lack of manpower, high input prices, and environmental effects from the widespread use of chemical herbicides. In farming, eliminating unwanted plants from crops is a laborious task crucial for enhancing sustainable crop yield. Traditionally, this process is carried out manually globally, utilizing tools such as wheel hoes, sickles, chris, powers, shovels, and hand forks. However, this manual approach is time-consuming, demanding in terms of labor, and imposes significant physiological strain, leading to premature operator fatigue. In response to this challenge, blade and tine-type push weeders were developed to enhance weeding efficiency for smallholder farmers. When blade and tine push weeders are pushed between the rows of crops, the front tine blade of the trolley efficiently uproots the weeds, while the straight blade at the back pushes the uprooted weeds. This dual-action mechanism ensures effective weed elimination by both uprooting and clearing the weeds without disturbing the crops. The blade and tine-type push weeders demonstrated actual and theoretical field capacities of 0.020 ha/h and 0.026 ha/h, achieving a commendable field efficiency of 85%. The weeders exhibited a cutting width ranging from 30 to 50 mm, a cutting depth between 250 and 270 mm, a draft of 1.8 kg, a weeding efficiency of 78%, and a plant damage rate of 2.7%. The cost of weeding was 2108 INR/ha for the green pea crop.

Keywords: blade and tine-type push weeder; field capacities; field efficiency; cutting width; draft; damage rate of plant; sustainable agriculture

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1. Introduction

Sustainable agriculture is a farming approach that aims to strike a balance between environmental pollution, economic profitability, and social equity while ensuring long-term food security. Essential components for sustainable agriculture include efficient resource consumption, less environmental impact, greater soil health, and increased labor efficiency. However, many obstacles prevent its adoption, such as excessive use of herbicides, labor-intensive manual weeding, soil erosion, and limited access to affordable farm machinery for smallholder farmers. To safeguard the sustainability of agriculture, developments in small agricultural tools are required in important farm tasks, as the majority of people in India depend on agriculture and are small farmers [1]. The average size of farm holdings in India decreased to less than 1.5 hectares in 2010–2011 from more than 2 hectares in 1970–1971, while the maximum number of operational holdings increased from around 65 million to

125 million. If this development continues, the average landholding size in India will be just 0.7 hectares in 2021–2022 (NABARD) [2] and is projected to decrease further to a mere 0.32 hectares in the next ten years. It is essential to provide farmers with the right machinery for the task so they can hire farm equipment as needed [3] for sustainable agriculture.

One of the major troubles of Indian farmers is they are not successful in protecting the crops from weeds [4]. Weeds are unnecessary plants and considered one of the biggest biotic constraints in accomplishing potential yield [5], which obstruct the use of land, irrigated stores [6], and cultivated areas [7], significantly influencing plant growth [8], resulting in lowering the value of the harvested crops [9]. Weed management plays a critical role in sustainable farming, as excessive weeds compete with crops for essential resources such as [10] plant nutrients, moisture, radiance, space, and sheltering crop pests [11]. These species are well adapted to multiply in an extensive range of fields and weather situations [12]. Weed initial-phase control is the most effective approach to avoid seed dispersal [13]. Weed management in crops includes a plan to support healthy plants that are well suited to the environment, which uses knowledge about the weeds [14]. Unwanted plant control expenses have a higher value than the whole expenses of crop production [15]. From 30 to 60 percent of crop productivity is damaged due to improper removal of unwanted plants from the main field. More than 33% of the charge gained in cultivating is used for weeding, thereby dropping farmers' income. Farmers typically obtain only 60 to 65% of their potential crop income due to the impact of weeds on different crops [16]. This indicates a significant loss of yield. It is estimated that approximately INR 100 billion is spent annually on weed control in India [3]. To achieve higher productivity, crop strength, advance profits, and safeguard quality [17] for sustainable agricultural yield [18], it is necessary to manage surplus plants at the right moment with suitable processes [19].

Weeding is the process of removing those surplus plants in between the plant rows. Different types of weeding methods include manual, animal-drawn, chemical, and mechanical methods. In India, most farmers prefer manual and animal weeding methods due to the predominance of small-, marginal-, and medium-scale farmers [20]. Weeding is a very complex process manually using animal-operated equipment, which may further lead to the destruction of main crop fields. The conventional method of hand weeding is useful, but it is a time-consuming process, challenging to handle [7], labor-intensive, physically demanding, and expensive due to increasing cultivation costs reported annually [21], particularly for smallholder farmers who lack access to mechanized solutions [22]. The manual method of weeding takes one-fourth of the whole farm workers' necessity ranging from 900 to 1200 human hours/hectare during the farming period [23]. On the other hand, chemical herbicides contribute to soil degradation, water contamination, and resistance development in weed species, making them an unsustainable long-term solution. Mechanical weeding is a significant technical means for organic and regenerative agricultural systems [24]. Mechanical weeding turns/cuts weeds out of the field to control their development [25], and the mechanical approach meets the severe circumstances set by organic agriculture [26]. Interrow management of weeding by mechanical farming has been confirmed to be efficient and qualitative [27]. Many companies have come up with different types of mechanical weeders due to developments in modernization. Despite the advantages of mechanical weeders, small- and medium-sized landholders, prevalent in Indian agriculture, face financial constraints in adopting these technologies. Other drawbacks of engine-operated mechanical weeders are the increasing cost of weeding due to fuel utilized and the emitting pollutant gases, which leads to environmental problems. It has several disadvantages like noise pollution and vibration to the operator body.

In the present study, the aim is to address the requirements of small farmers rather than large-power weeders. The popularity of manual tools like wheel hoes, sickles, chris, powers, shovels hand forks, etc. lies in their affordability, flexibility, and simple design, catering to the preferences of small farmers. However, the frequent use of hand-operated weeders reduces total production by causing early weariness and back issues. Many of the existing weeders with several issues, such as poor performance in tall-crop fields, providing lower-quality weeding [28], resulting in higher labor expenses and longer working hours. Despite these developments, there is still a significant need for a more efficient, ergonomically designed, and cost-effective weeder that meets the specialized demands of small farmers. Recognizing these challenges, the current study focuses on the design, development, and performance evaluation of a blade and tine-type push weeder, aiming to provide a unique, ergonomically designed, and cost-effective hand weeder for small farmers, who make up the vast majority of the world's farmers and frequently lack the financial resources to invest in large mechanical weeders. The suggested approach uses an improved combination of blades and tines, ensuring effective penetration of soil, weed uprooting, and minimal soil disturbance, which overcomes traditional push weeders' inadequacies. The ergonomic design, including an adjusted handle height and less weeding force, reduces physical strain on operators, allowing for continuous weeding with less weariness. Furthermore, the weeder's lightweight yet sturdy design improves mobility, making the weeder more accessible and operator friendly. By overcoming these critical limitations, the suggested weeder significantly increases labor productivity, weeding effectiveness, and farm sustainability. Table 1 presents a review of related works on weeders, summarizing various studies that have focused on the design, development, and performance evaluation of different weeding technologies.

Table 1. Review of related works on weeders.

Title of Paper	Review of Literature	Limitations	Method Adopted for This Research
Performance evaluation of weeders [24]	This study evaluated the field performance of four weeders. The field capacity of kauri (W1), twine wheel hoe (W2), push–pull-type cycle weeder (W3), and push–pull-type cycle weeder (W4) was 0.002, 0.010, 0.020, and 0.035 ha/h, respectively.	This study explains the lower performance of existing weeders.	Performance and evaluation
Design and development of four-wheel weeder for wide-row crops [29]	The author developed four wheels and 'Swinging handles' for the wide row-to-row spaced crops based on anthropometric data of men and women workers. The weight of the weeder was kept lower than 10 kg, the lowest field capacity was 0.0206 ha/h, and the weeding efficiency was higher than 95%. The push force needs 6.34 N per cm cutting width.	This weeder requires more pushing force.	Design
Design, construct and evaluation of a single-row hand-pushed mechanical weed control machine [30]	This research focuses on designing, building, and performing a hand-pushed weed control machine. The components include mild steel (3 mm, 5 mm), 30 mm circular (hollow) pipes, a 10 mm diameter steel rod, and a 40 cm pneumatic tire.	These weeders are unable to provide uniform depth of cut and lateral stability due to a single wheel.	Frame design and selection of materials

Table 1. *Cont.*

Title of Paper	Review of Literature	Limitations	Method Adopted for This Research
Development of ergonomically designed weeder for increasing productivity [31]	This research explains that the weeding angle is based on the functional design and geometry of the weeder and usually lies between 30° and 45°. Based on anthropometric data, the authors suggest ergonomic handle design dimensions: the recommended handle grip diameter is 30 to 35 mm, the crossbar handle length is 450 mm, and the handle height is between 0.93 and 1.03 m.	This weeder, similar to a wheel hoe, may still cause operator strain, require manual effort, and be less effective in compact soils and varying field conditions.	Handle design
Development and evaluation of wheeled long-handle weeder [32]	The authors designed and tested a push-type wheel with an adjustable long-handle weeder. Obtained field capacity, efficiency, weeding index, and performance index were 0.050 ha/h, 87.5%, 86.5%, and 1108.48, respectively. High efficiency of 91.7% was obtained at a speed of 0.04 m/s and at 0.4 m depth of cut.	This weeder also has a single wheel and single blade, which may face stability issues and reduced cutting efficiency.	Weeder blade design
Development and evaluation of manually operated sprocket weeder [33]	The parts of this weeder were the handlebar, front axle, sprocket, wheel hub, fork, galvanized iron pipe, and a V-shaped blade made from hardened steel, which was attached to the fork with the help of an adjustable U-clamp. The wedding efficiency, field capacity, and time savings of the weeder were 94.5%, 0.032 ha/h, and 84%. The cost of operation was INR 375/ha, with a saving of 79.16% compared to the traditional method.	Single arrow blade means less efficiency and not ergonomic friendly.	Development and performance
Optimum handle height for a push-pull type manually-operated dryland weeder [34]	This study suggests a handle height of 100 cm based on the available anthropometric data of Indian workers for the push–pull-type manually operated dryland weeder.		Handle design
Fabrication and field evaluation of a wheel weeder [35]	In this research, we developed a wheel weeder with conventional weeding tools, viz. trench hoe, spade, and wheel weeder. It operates up to a depth of 22 to 35 mm with a field capacity of 0.0038 ha/h.	Less field efficiency.	Field evaluation
Development of Solar operated walking type power weeder [36]	The weeder developed by these authors was a sweep-type blade attached behind the main frame, and the BLDC motor (750 w, 48 v) was used for the drive. The performance of the weeder was evaluated at three different forward speeds of 1.0–1.5 (S1), 1.5–2.0 (S2), and 2.0–2.5 (S3) km/h, respectively. Field capacities of S1, S2, and S3 were 0.042, 0.059, and 0.075 ha/h. The weeding and field efficiency for S1, S2, and S3 were found to be 90.94, 84.69, and 83.50% and 79.21, 83.97, and 85.68%, respectively.	In continuous operation due to solar dependency; bulky structure and higher initial costs.	Design

Table 1. *Cont.*

Title of Paper	Review of Literature	Limitations	Method Adopted for This Research
Performance evaluation of manually operated weeder [37]	The weeder can work up to 3.0–4.0 cm depth of operation with actual field capacity of 0.031 ha/h, theoretical field capacity of 0.0428 ha/h, field efficiency of 65.54%, plant damage of 2.166, weeding efficiency of 88.15%, performance index of 12622.1, and draft requirement of 193 N (0.079 hp) for 25 cm width of operation.	Bulky structure and not ergonomic friendly.	Performance evaluation
Performance evaluation of some manually operated weeders used in jhum cultivation in hill regions of Arunachal Pradesh [38]	This study evaluated the field performance of four different types of manually operated weeders, namely, wheel hoe with tines (W1), wheel hoe with sweep blade (W2), peg-type dry-land weeder (W3), and straight blade hand hoe (W4). The average adequate field capacity of 0.0185 (W1), 0.022 (W2), 0.016 (W3), and 0.017 ha/h (W4), respectively. The maximum weeding efficiency of 79.72% (W1) followed by 78.19% (W2), 75.71% (W3), and 72.50% (W4). Percentage plant damage was highest under 2.5% (W4) followed by 1.5% (W1), 1% (W2), and 0% (W3), respectively.	This study expresses less performance of manual weeders.	Performance evaluation and weeder blade design
Development and ergonomic evaluation of manual weeder [39]	This study evaluated the field performance of four different types of manually operated weeders, namely, wheel hoe with tines (W1), wheel hoe with sweep blade (W2), peg-type dry-land weeder (W3), and straight blade hand hoe (W4). The average adequate field capacity of 0.0185 (W1), 0.022 (W2), 0.016 (W3), and 0.017 ha/h (W4), respectively. The maximum weeding efficiency of 79.72% (W1) was followed by 78.19% (W2), 75.71% (W3), and 72.50% (W4). Percentage plant damage was highest under 2.5% (W4) followed by 1.5% (W1), 1% (W2), and 0% (W3), respectively.	Balancing issues due to single-wheeled weeder.	Performance evaluation and blade design
Performance evaluation of weeders [40]	This work compares the field performance of different weeder namely khurpi (W1), push type cycle weeder (W2) and power weeder (W3). The highest field efficiency was obtained for 91.5% (W1) followed by 85.4% (W2) and 71.25% (W3). The field capacity of 0.065 (W3), 0.025 (W1) and 0.035 ha/h (W2), respectively	This study expresses less performance of push type cycle weeder (W2), and power weeder (W3)	Performance evaluation

Related Works

The structure of the paper is as follows. The Section 1 lists the primary determinants that are the subject of the research work (weeds, weeding, and farm mechanization). After that, the Section 2 explaining the design, development and field performance of the blade and tine-type push weeder. The Section 3 shows the obtained values for field testing of

the developed blade and tine-type push weeder. The obtained results are compared with the manual method of weeding and recommendations for possible further research are suggested in Section 4.

2. Materials and Methods

The blade and tine-type push weeders were designed and fabricated by considering parameters like unwanted plant stem breaking as a result of soil shearing, collision, and cut. The aspects that are taken while choosing objects include the amenability of the material, while the weeder unit was fabricated by a local artisan and simply available in the market. The shear stress and bending moment were taken into account when selecting the material. The average force a human can produce is approximately 0.1 hp [41], though a person can exert significantly more force for short periods [42]. This 0.1 horsepower was considered for pulling and pushing the 30 kg weeder. The weeder's design includes three wheels that support the blades. The wheels are adjusted to the frame to provide stability, and the frame width is set at 50 cm to ensure proper balance. The wheels can also be adjusted to fit a 50 cm frame width, but if the frame width is less than 50 cm, it becomes unstable and lacks balance. For this reason, we chose a frame width of 50 cm. When designing the weeder, we considered crops with a row spacing of more than 60 cm, which is typical for the crops we are focusing on. This can be used to remove plants in a more than 60 cm row spacing dry field. The design parameters for the weeder unit considered were the ease of weeding, average walking speed of the human (1.5 km/h), force necessity of the operation, and types of unwanted plants to be worked upon. The main components of the blade and tine-type push weeder unit are the main frame, handle, straight blade, tine blade, and clamp. The details are given in the step-by-step procedure of design and evaluation of the blade and tine-type push weeder unit.

2.1. Main Frame Design

The wheeled frame was designed to carry all the elements of the blade and tine-type push weeder. It is a fabricated 'T'-shaped design and here employed different cuttings of square-shaped cast iron (2.54 cm) pipe to make the frame to carry the handle, straight blade, and tine blade. So, the weeder unit must be rigid and able to tolerate the components of the entire push-type weeder design. It was fabricated by using fabricating processes both permanent and temporary. The main frame was made of two small tires on the front side, two edges, and one large tire at the rear side of the frame for simple motion and to withstand heavy load. Framing for the tine blade, straight blade, and handle was completed by a temporary process; i.e., the bolt and nut connection and the remaining framing for the trolley were made by a permanent fabricating process, i.e., gas welding. Tine blade weeder and straight blade weeder adjustments were placed at one front and another rear side of the frame. Figure 1 represents all views of the AutoCAD 2024 drawing of the main trolley, showing the detailed construction of the frame.

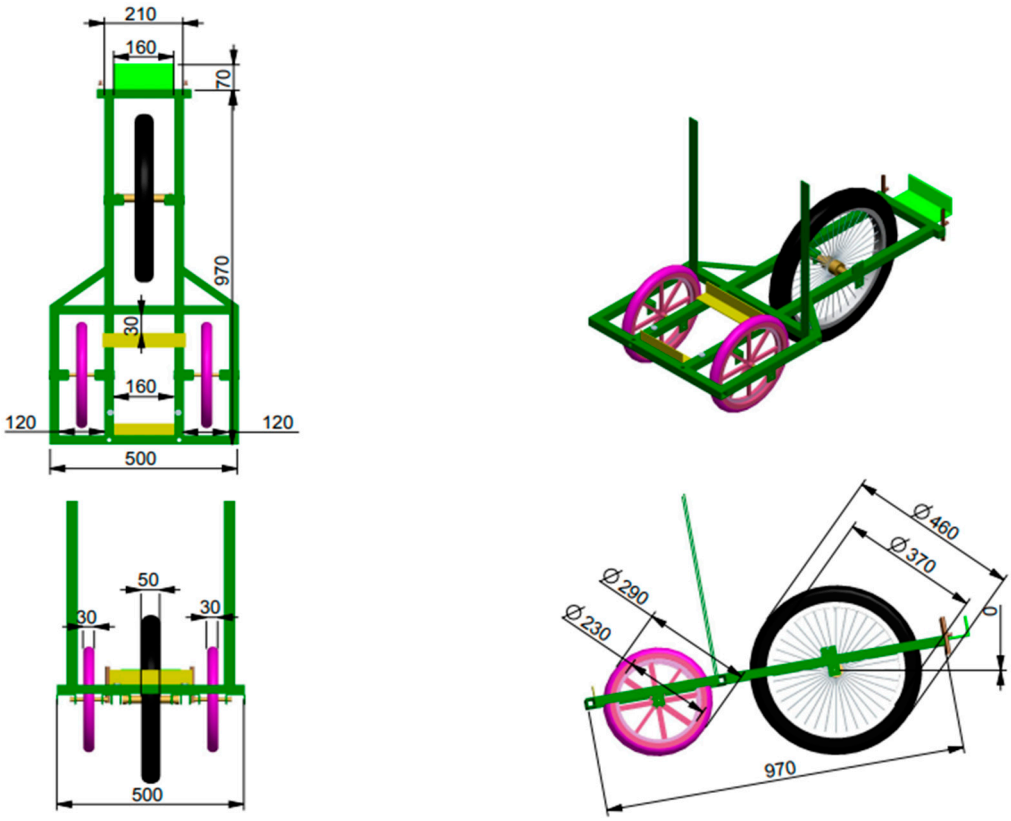


Figure 1. AutoCAD view of the frame. (All dimensions are in mm).

Main Frame Specifications

Length—970 mm;
Width—500 mm;
Height—460 mm.

2.2. Handle

The major purpose of the handle is to provide the direction to the trolley, and it is fabricated using a 2.54 cm round pipe. The handle was made based on ergonomic considerations. Ergonomic design provides stress relaxation and simple movement to the operator. This was assembled with two mild steel pipes, bent with 45° angles, and nut and bolt adjustments for convenience of operation. The AutoCAD diagram in Figure 2 explains the feature design of the handle and commercial handle grip of the bicycle that was utilized. So, the greatest handle height should be 1040 mm for the weeder unit to be operated by a female worker. An adjustment for a handle-holding height up to 1040 mm should be provided to ensure easy holding by 95th-percentile male workers. The grip helps comfort the palm and reduces the damage or compression of internal palm muscles. The handle allows the operator to push, pull, and guide the developed blade and tine-type push weeder while removing unwanted plants along the crop lines. It is fabricated to be changeable for labor comfort, regardless of the operator's height. The need for the developed weeder handle is to promote an upright posture while weeding.



Figure 2. AutoCAD diagram shows the detailed construction of the handle.

Specifications of Handle

Length—1050 mm;
Height—1040 mm;
Angle—45°.

2.3. Design of Weeder Blades

2.3.1. Straight Blade

Tractor-drawn scrapper weeders, animal-drawn hoes, and manual weeders all use straight blades. The straight blade's working width (A), blade width (B), blade thickness (t), and weeder blade's sharpness angle (ϕ) were all found to be at their optimal values. Because most kharif crops could be weeded most effectively at this length, a working width of 270 mm was chosen for the blade size [43]. A blade thickness of 4 mm was chosen for investigation, and a blade width of 270 mm is effective for the draft force [43]. For the investigation, a cutting angle of 27° and a sharpness angle of 15° of the blades were measured [43]. A straight blade composed of cast iron has two supports at either end. This was positioned beneath the handle and at the rear of the trolley. The bottom end's straight blade was sharpened and angled at a 15° angle with respect to the horizontal. It was bolted to a headpiece so that wear and tear could be easily replaced. The maximum cutting depth and width of the blade are 50 mm and 270 mm, respectively. The straight blade's detailed construction is explained in the AutoCAD diagram in Figure 3 [43].

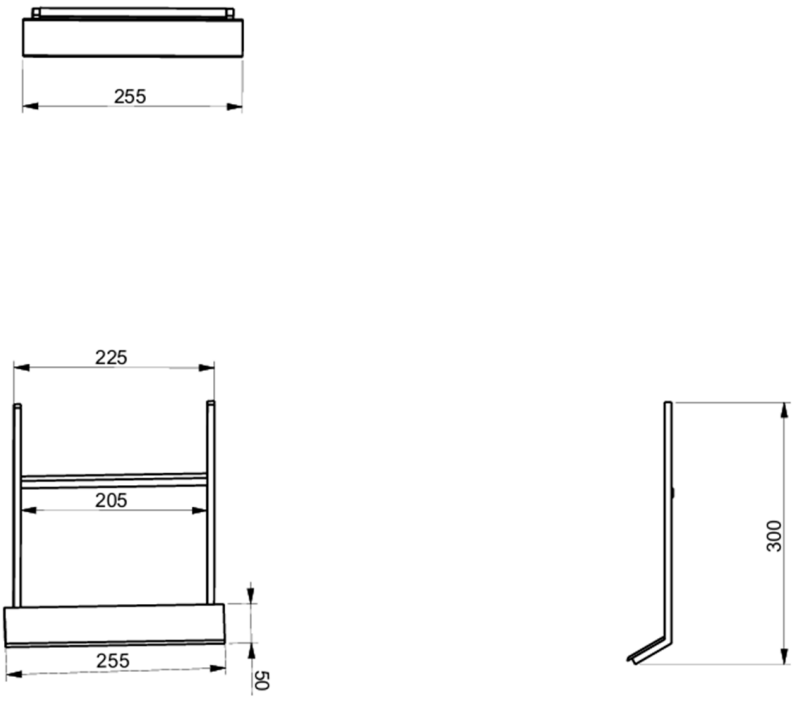


Figure 3. AutoCAD drawing of straight blade. All dimensions are in mm.

Specifications of Straight Blade Weeder

Length of blade—270 mm;
Height of blade—300 mm;
Angle between the leg and blade—30°;
Blade thickness—3 mm;
Blade width—50 mm.

2.3.2. Tine Blade

The most commonly used equipment for blind cultivation is the tine blade. The kind of toolbar, component suspension, shape, length, and width, as well as the spacing and size of the tines, all affect how well a tine weeder weeds. Tine weeders perform well with a variability of crops and environmental conditions. They can skip quite big stones without becoming hurt and do well in stony soil. The variety of obtainable tines and adjustments make doing a good job of weeding possible under difficult soil conditions and when weather prevents proper timing of operations. The tine blade was positioned in front of the small trolley. The location was in between the tank and boom supporter. It was also adjusted with a nut and bolt arrangement for easy replacement. It is also made of cast iron. The small trolley has the capacity to hold different kinds of soil-working tools. The weeder's handle alignment is fabricated with modifiable height settings to accommodate the operator's comfort. The developed weeder is controlled by the action of pushing or pulling, which affects the soil-working part to penetrate and uproot the unwanted plants in between the crop columns. This blade has three one-inch slightly curved tines at a regular spacing of 25 mm, which are connected to the front of the weeder frame. Figure 4 shows the AutoCAD design of the tine blade.

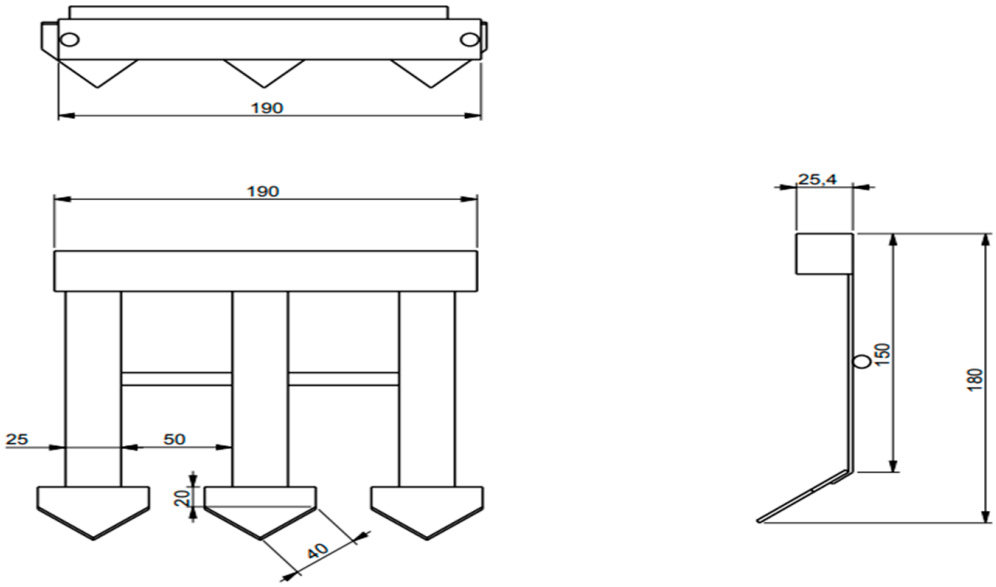


Figure 4. AutoCAD drawing of tine blade for weeder. (All dimensions are in mm).

Specifications of Tine Blade

Width of blade—170 mm;
Height of blade—180 mm;
Angle between the leg and tine—30°;
Thickness of blade—3 mm.

2.4. Clamp

The clamp for the weeder was designed to adjust the blades and made of MS pipe. The 100 mm lengths of two pipes are taken and holes are drilled at the mid-length of pipe. Nuts were introduced into the bored holes and rotated when the ends of the straight blade weeder were inserted into the pipe. The tine blade weeder was adjusted with the help of a 10 mm length nut and bolt arrangement at the front of the main trolley.

2.5. Adjustment and Working of Blade and Tine-Type Push Weeder

The developed blade and tine-type push weeder units were precisely designed for efficient weeding in agricultural fields, and the mass of the weeder was 30 kg. A versatile clamp mechanism was employed to facilitate the adjustment of the weeder blade to various heights. The straight blade weeder assembly was precisely positioned beneath the primary support on the rear side of the trolley, while the tine blade weeder found its placement at the front, strategically nestled between the tires. Both weeders were seamlessly integrated below the main frame of the trolley, ensuring optimal functionality. The handle, affixed to the trolley using nut and bolt adjustments, allowed for customization to different heights. For a comprehensive visualization of the design details, Figure 5 represents an AutoCAD drawing with clearly labeled parts of the weeder, and Figure 6 represents a developed blade and tine-type push weeder.

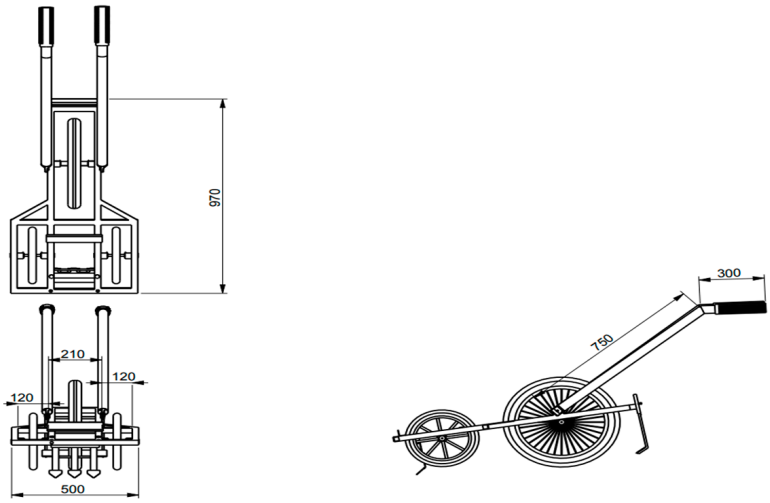


Figure 5. All views of blade and tine-type push weeder. (All dimensions are in mm).

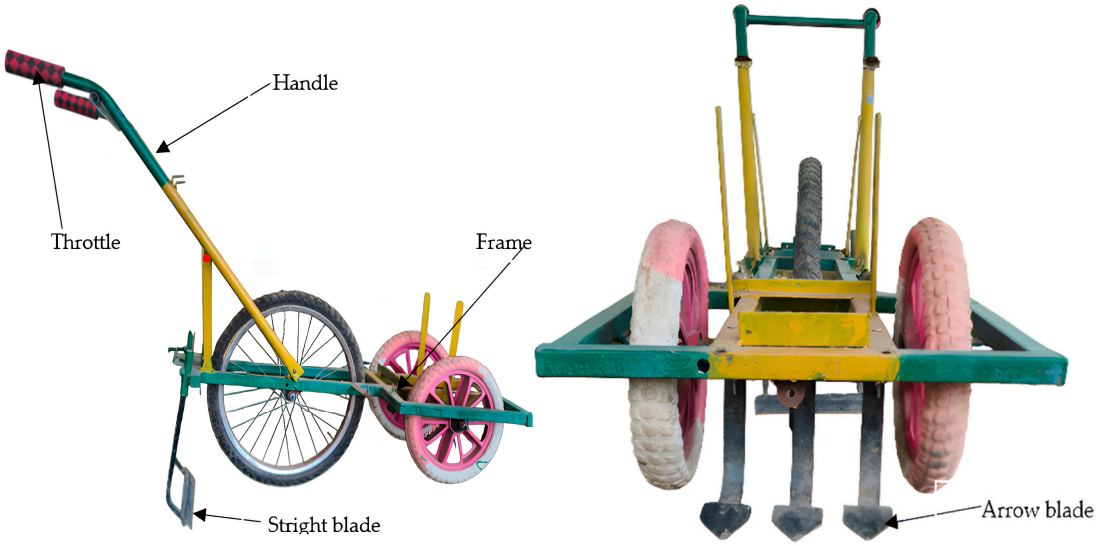


Figure 6. Developed blade and tine-type push weeder.

Working Mechanism

The weeding action was executed through the straightforward process of either pushing or pulling, providing ease of operation in the field. When the blade and tine push weeders are pushed between the rows of crops, the front tine blade of the trolley efficiently uproots the weeds, while the straight blade at the back pushes the uprooted weeds. This dual-action mechanism ensures effective weed elimination by both uprooting and clearing the weeds without disturbing the crops. Table 2 provides the technical specifications of the blade and tine-type push weeder.

Table 2. Technical specifications of the blade and tine-type push weeder unit.

S. No	Particular	Values
1	Length, mm	970
2	Width, mm	500
3	Height, mm	1040
4	Weight, kg	30

2.6. Machine Parameters

The performance evaluation of a blade and tine-type push weeder was conducted in green pea crops. Different weeder parameters were studied to provide a comprehensive calculation of the weeder's efficacy. The parameters observed involved theoretical and actual field capacities, field and weeding efficiencies, plant damage, the performance index, the power requirement (in horsepower), as well as the width and depth of cut for the weeder.

2.6.1. Experimental Procedure

The experiment was conducted for independent variables with three replications of each combination. Three levels of the forward speed, 0.8 km/h, 1 km/h, and 1.2 km/h, were selected by conducting some initial trials and based on past studies. At the end of each experiment, the average of three replications was recorded for observations such as effective field capacity, field efficiency, weeding efficiency, plant damage, and the performance index.

2.6.2. Experimental Design

The following research plan was used to evaluate the blade and tine-type push weeder. The evaluation involves the identification and categorization of independent and dependent parameters, each assigned specific codes for clarity. Table 3 presents a detailed list of these selected parameters along with their respective codes.

Table 3. Plan of the experiment of the weeder in the field.

Replication	Independent Variable (A)	Dependent Variables (B)	Trail Code
R1 R2 R3	1. Forward speeds (T): T_1 = 0.8 km/h, T_2 = 1 km/h, T_3 = 1.2 km/h	1. Effective field capacity, (ha/h) 2. Theoretical field capacity, (ha/h) 3. Field efficiency, (%) 4. Weeding efficiency, (%) 5. Plant damage, (%) 6. Performance index	R1 * T_1 * B R2 * T_1 * B R3 * T_1 * B R1 * T_2 * B R2 * T_2 * B R3 * T_2 * B R1 * T_3 * B R2 * T_3 * B R3 * T_3 * B

Layout of Experimental Plot

As per Table 3, the total block was divided into nine plots to accommodate three different speeds, with each speed replicated three times (Figure 7). The average value was recorded for subsequent calculations.

R1* T_1*B	R1* T_2*B	R1* T_3*B
R2* T_1*B	R2* T_2*B	R2* T_3*B
R3* T_1*B	R3* T_2*B	R3* T_3*B

Figure 7. Actual field layout of selected crops for weeding.

2.6.3. Field Preparation

The performance evaluation of the blade and tine-type push weeder unit was conducted in a green pea field. Throughout the experiment, the prevailing ambient conditions remained thermally comfortable, with an air temperature of 26.2 °C, a relative humidity of 67%, and an air velocity below 10 km/h. The weather conditions during the weeding were characterized by moderate temperatures, with the time set at 11:30 a.m.

2.6.4. Physical Properties of Soil

The weeder's blades directly engage with the soil to uproot weeds, making soil properties a crucial factor affecting its performance. Therefore, the following properties of the soil were evaluated:

Moisture Content

The oven-drying method was used to measure the moisture content on a dry-weight basis. Soil samples were randomly taken from the experimental field at a depth of 0–150 mm with a core cutter before field preparation. The weight of the wet soil sample was measured, and then the soil sample was put in an oven at 105 °C for 24 h, and then the weight of the dry sample was measured. The following formula was used for calculating the soil moisture content [44].

$$MC(db) = \frac{W_w - W_d}{W_d} \times 100 \quad (1)$$

where

MC (db) = Moisture content dry basis (%);
W_w = Weight of undried soil (g);
W_d = Weight of oven-dried soil (g).

Bulk Density

Bulk density, which represents the soil mass per unit volume and indicates soil compaction, was determined on a dry weight basis. Before field preparation, a core cutter with a diameter of 10 cm and a length of 15 cm was used to measure the bulk density of randomly collected samples from the field. The sample thus collected was kept in the hot air oven at a temperature of 105 ± 5 °C for 24 h. The experiment was replicated from different locations, the weight of the dry soil was recorded using an electronic balance, and the average bulk density was determined using the following formula [45].

$$\rho = \frac{M}{V} \quad (2)$$

$$V = \frac{\pi D^2}{4} \times L$$

where

ρ = Bulk density of soil, g cm^{-3};
M = Weight of dry soil, g, $A = r^2$;
V = Core cutter's volume, (cm^3);
D = Core cutter's diameter (cm);
L = Core cutter's length (cm).

2.6.5. Effective Field Capacity

The operational capacity of the blade and tine-type push weeder was calculated as the entire area covered during the weeding divided by the total time taken for weeding. This simply measures the weeder's area coverage relative to time [46].

$$E.F.C = \frac{area}{totaltime} \quad (3)$$

where

E.F.C = Effective field capacity, ha/h;
Area = Area of the selected test plot, ha;
Total time = Total weeding time, h.

2.6.6. Theoretical Field Capacity

The blade and tine-type push weeder theoretical field capacity is the amount of area that it will cover under ideal conditions, taking into account its rated width and forward speed. This measure expresses what the highest productivity could be for the implementation under ideal circumstances. The general equation for computing theoretical field capacity is as follows [47]:

$$\text{T.F.C} = \frac{\text{W} \times \text{S}}{10} \quad (4)$$

where

T.F.C = Theoretical field capacity of developed weeder, ha/h;
W = Effective working width of weeder, m;
S = Travel speed, km/h.

2.6.7. Weeding Efficiency

Weeding efficiency represents the effectiveness of the weeder in removing weeds, expressed as a percentage of the total weeds present in a unit area before weeding. The data for evaluating weeding efficiency were collected using the quadrant method [48].

$$\text{W} = \frac{\text{W}_1 - \text{W}_2}{\text{W}_1} \times 100 \quad (5)$$

where

W_1 = Total number of unwanted plants per unit area before weeding;
W_2 = Sum of unwanted plants per unit area after weeding.

2.6.8. Plant Damage

The percentage of a row's plants that are impacted by weeding is referred to as 'plant damage' and is stated as a percentage of plant damage. Plant damage was determined by the following formula [41]:

$$\text{PD} = (1 - \frac{\text{n}_1}{\text{n}_2}) \times 100 \quad (6)$$

where

PD = Plant damage, %;
n_1 = Sum of plants after weeding;
n_2 = Sum of plants before weeding.

2.6.9. Performance Index of Developed Weeder

The performance index (PI) of the developed weeder provides a complete measure of its efficiency and effectiveness. The performance index takes into account both the weeder's capacity to cover the field and its effectiveness at removing weeds while minimizing damage to the main crop. The relationship for calculating the performance index is typically expressed as follows [49]:

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

where

PI = Performance index;
FC = Weeder field capacity, ha h^{-1};
PD = Plant damage, %;
WE = Weeding efficiency %;
p = Power, hp.

2.6.10. Actual Weeding Depth of Cut

The depth of cut of the developed weeder was measured in the selected field by measuring the depth of the soil layer tilled by the blade in a row. The depth of the weeding was measured by scale in different rows at different places. The average of three observations was taken as the depth of weeding and expressed in cm [50].

2.6.11. Actual Weeding Width of Cut

The width of the disturbed soil layer was determined in several strips at different locations in the selected field. This width measurement was taken using a scale. The width of the soil affected by weeding is measured by the slice [50]. The distributive nature of the cultivator can be evaluated by looking at its uniformity and coverage based on several strips and locations where soil disturbance happened.

2.6.12. Draft Measurement

The draft is defined as the pull's parallel element that runs parallel to the action's direction [49]. The draft was measured with a load cell. The selected load cell had a minimum count of 0.01 kg and could measure drafts up to 125 kg. The load cell provided the draft value directly in kilograms because it was installed horizontally in the pull line. The manual worker drives the weeder unit at a constant speed using a power tiller. The draft of the weeder unit in the prepared field and the unprepared field was measured, and the reading was recorded with a digital indicator. The recorded data can be used for further calculations.

2.6.13. Economic Evaluation of Blade and Tine Push Weeder

Machinery ownership (fixed) and operational (variable) costs represent a substantial portion of total production experiences. Machinery ownership costs usually include charges for depreciation, interest on investment, taxes, insurance, and housing facilities. Operational costs include repair and maintenance costs of farm machinery that are necessary to restore or maintain the technical soundness and reliability of the weeder [51–53].

Fixed Cost

Fixed costs include depreciation, interest, housing, insurance, and taxes.

Depreciation

Depreciation measured the extent to which the weeder's value declined over time. The formula of annual depreciation was as follows:

$$D = \frac{C - S}{L \times H} \quad (8)$$

where

C = Capital cost, INR;
D = Depreciation, INR/h;
S = Salvage value, 10 percent of capital cost, INR;
H = Number of working hours per year;
L = Life of machine, year.

Interest

Interest is calculated on the average investment of the machine, taking into consideration the machine's value in the first and last year. These are calculated on a yearly basis. The annual interest on the investment can be calculated as follows:

The annual interest is calculated based on the average cost of the weeder, considering its value in the first and last years. This is determined annually, and the following formula can be used for the annual interest on the investment:

$$I = \frac{C + S}{2} \times \frac{i}{H} \quad (9)$$

where

I = Interest per year;
i = 10 percent per year;
C = Capital cost.

Shelter, Insurance, and Taxes

Shelter refers to the expense of protective structures of the weeder, insurance provides financial coverage for weeder investments, and taxes are mandatory charges imposed by the government on weeder ownership and usage. It may be taken as 2 percent of the initial cost of the machine per year.

Operating Cost

The operating cost includes fuel cost, lubricants, repairs and maintenance, and wages of the operator.

Repair and Maintenance

The repair and maintenance value is determined by multiplying the weeder's initial investment by the percentage factor of repair and maintenance.

Repair and maintenance = 5 percent × Purchase price or capital investment per year.

Wages of Operator

Wages are calculated based on the actual worker wages per hour.

Total Cost of Weeding per Ha

The blade and tine push weeder's total weeding cost per hectare was determined by adding the total fixed and variable costs per hectare.

Total Cost/ha = Fixed cost per ha + variable cost per ha.

3. Results and Discussion

The experimental soil type was vertisol, characterized by rough topography in the field. Before field operations, the soil had a moisture value of 19.31%. The moisture percentage of the soil is a critical factor influencing the effectiveness of the weeder. Soil moisture affects the soil's cohesion and resistance to penetration, which in turn impacts the weeder's ability to penetrate the soil and uproot weeds efficiently. Soil with high moisture content may be more cohesive and stickier, potentially causing clogging or reduced performance of the weeder. On the other hand, excessively dry soil might be too hard and compacted, making it difficult for the weeder to penetrate deeply and effectively uproot weeds. The soil's average bulk density before field preparation was measured at 1.23 g/cc. If the soil is denser, i.e., has higher bulk densities, and the weeder would have to face difficulty in its weeding process. The blades of the weeder may not work as effectively in tearing out the weeds when the soil becomes compacted. Furthermore, bulk density may be more of an issue than compaction in severely eroded landscapes, as high bulk density can restrict root growth and water infiltration, doubly increasing weed growth and reducing crop production.

In the comparative study between three different speeds using the developed weeder (Table 4), the condition of the weeds, the number of weeds per m^2, and the height of the weeds (Table 5) and the crop (Table 6) played crucial roles in determining the effective

performance of the weeder (Table 7). By analyzing these tables collectively, we can gain insights into how variations in weeding speed impact weed and crop conditions, ultimately influencing the efficiency and efficacy of the weeding process.

Table 4. Comparative study between three different speeds with developed weeder.

S. No	Particulars	(T_1)	(T_2)	(T_3)
1	Weeding time (h/ha)	41.67	33.34	29.41
2	Draft (kgf)	1.8	2.0	2.4
3	Power (hp)	0.007	0.007	0.009

Table 5. Condition of weeds.

S. No	Particular	T_1	T_2	T_3
1	Weed population (weed m^{-2})	102	86	92
2	Height of weed (cm)	10–15	10–15	10–15

Table 6. Condition of the crop.

S. No	Particular	Values
1	Name of crop	Green pea
2	Row-to-row spacing	60 cm
3	Crop stage	15 to 20 cm height from field (vegetative stage)

Table 7. Effective performance of weeder.

Particular	Trail 1	Trail 2	Trail 3
Width of cut, (cm)	27–29	27–29	27–29
Depth of cut, (cm)	3–5	3–5	3–5

For the field performance assessment of the developed push-type manual weeder, three different trials were conducted, each with varying walking speeds:

T_1 = Average of three replications value at weeding speed of 0.8 km/h;

T_2 = Average of three replications value at weeding speed of 1 km/h;

T_3 = Average of three replications value at weeding speed of 1.2 km/h.

3.1. Actual Field Capacity of the Blade and Tine-Type Push Weeder

Figure 8 summarizes the influences of soil and weeder working parameters on selected field evaluations for three different speeds conducted on the green pea crop. Specifically, it provides insights into the average of three replications of actual field capacity observed at various speeds. The results observed during the first trial were 0.01 ha/h at a speed of 0.8 km/h, 0.020 ha/h at a speed of 1 km/h, and 0.024 ha/h at a speed of 1.2 km/h. These observations indicate that the actual capacity increased with the rise in weeding speed. This increase can be attributed to the weeder covering more area within a shorter period due to the higher speed. The field capacities of the single-wheel hoe, double-wheel hoe, and the weeder developed by Sundaram et al. (2021) were 0.0057 ha/h, 0.0089 ha/h, and 0.0120 ha/h, respectively [54]. In comparison, Shekhar et al. (2010) found the field capacities for the wheel hoe (0.009 ha/h), grubber (0.008 ha/h), and Khurpi (0.002 ha/h) [55]. When compared to these two studies, the blade and tine push weeders exhibited higher field capacities, ranging from 0.01 ha/h to 0.024 ha/h, all within the manual speed range of

less than 1.5 km/h. The developed blade and tine push weeder consist of two blades at the front and back, which makes it easier to operate in the field. It is designed to be easily controlled by a pushing force and supported by a robust frame, allowing for efficient and effective use during field operation. As a result, the weeding operation becomes more efficient, allowing for a greater area to be covered in less time.

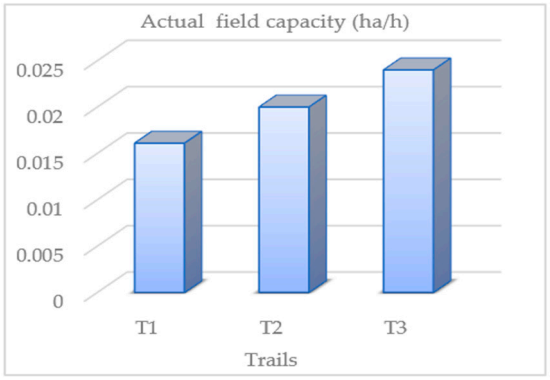


Figure 8. Actual field capacity of weeder at three different trails.

3.2. Field Efficiency of Push-Type Manual Weeder

The field efficiency of the developed weeder was found to be highest at a walking speed of 1.2 km/h for all three trials, with observed values of 80.5%, 81.08%, and 85%, for 0.8, 1, and 1.2 km/h, respectively. Furthermore, it was noted that, among the three different intervals, the calculated field efficiency during the first trial was lower compared to the remaining two trials. This suggests that the weeder's performance improved as the walking speed increased. The effect of weeding parameters on the field efficiency of the push-type manual weeder is depicted in Figure 9.

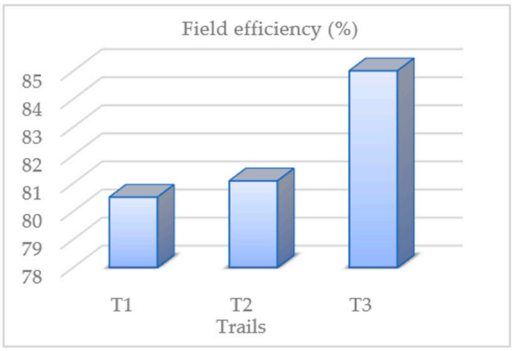


Figure 9. Field efficiency of weeder in three trails.

3.3. Weeding Efficiency of the Blade and Tine-Type Push Weeder

Figure 10 summarizes the influence of weeding efficiency for three trials conducted using the blade and tine-type push weeder. The weeding efficiency for different speeds of operations was observed to be 74.5% for 0.8 km/h, 79.06% for 1 km/h, and 78.26% for 1.2 km/h, respectively. As shown in Figure 10, the weeding efficiency was reduced with an increase in the weeding speed. This decrease in efficiency can be attributed to the higher speed at which the weeder moves, resulting in a reduction in the length of the bite taken by the weeder. A weeding efficiency of 75% was observed with a single-wheel hoe [54]. Studies by Kachhot et al. (2021) [36] have noted similar trends, where increasing the speed of the weeder led to a decrease in its efficiency due to reduced bite length.

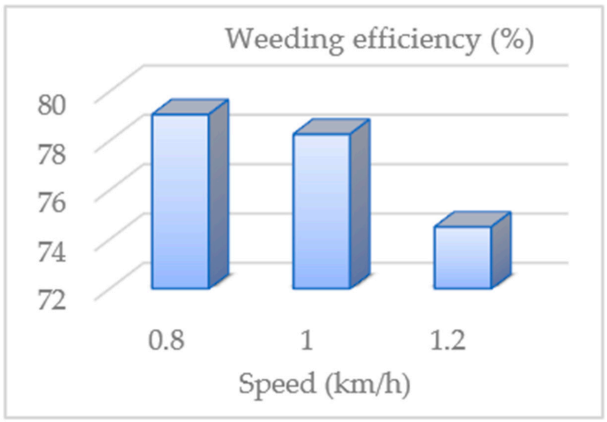


Figure 10. Weeding efficiency of weeder in three different trails.

3.4. Effect of Developed Weeder Working Parameters on Plant Damage in Green Pea

Figure 11 summarizes the impact of soil and weeder operative parameters on crop damage for three trials conducted on green pea crops using the blade and tine-type push weeder unit. The plant damage observed for the three trials (0.8, 1, and 1.2 km/h) was 1.51%, 2.73%, and 4.28%, respectively. The maximum plant damage of the single wheel hoe was 3.61%; the weeder developed by the authors of [54] was 3.21% and 1.94% for a double wheel hoe [54]. In comparison, the developed weeder causes less plant damage at lower speeds. The high damage of plants with the single-wheel hoe could be attributed to its heaviness and imbalances during operation, while the lesser damage of plants with the blade and tine-type push weeder could be attributed to its small weeding gap with respect to the plants. It was found that the maximum plant damage occurred at larger speeds of the weeder. Among the three different trials, the crop damage was highest during the third trial, which can be attributed to the highest walking speed utilized during that trial. These observations suggest that the developed blade and tine-type push weeder unit should ideally operate at the lowest speed possible to minimize plant injury. Operating at lower speeds allows for more precise control and reduces the likelihood of damage to the crop plants. Therefore, when using this weeder unit, it is recommended to prioritize lower speeds to achieve the lowest levels of plant damage and ensure optimal crop health and yield.

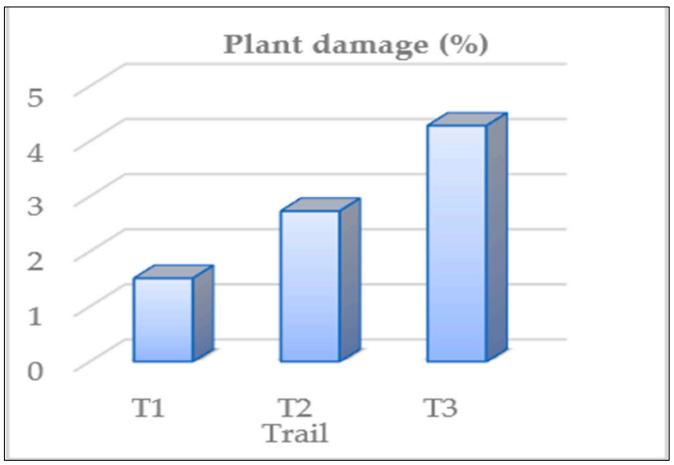


Figure 11. Plant damage of blade and tine-type push weeder unit in three different trails.

3.5. Effect of Developed Weeder Working Parameters on the Performance Index

Figure 12 illustrates the effect of weeder working parameters on the performance index of the developed push-type weeder for three different trials (0.8, 1, and 1.2 km/h)

conducted on green pea crops. The performance index of the developed push-type weeder was estimated for different speeds of operation. This index of the push-type weeder is directly linked to the effective field capacity and weeding efficiency and inversely linked to crop damage and power used. It provides a comprehensive amount of the weeder's efficiency and effectiveness in weed control operations. It was found that the working index increased with the increase in the weeder speed. This recommends that larger speeds of the weeder resulted in increased overall performance of the developed push-type weeder. The rise in the performance index may be attributed to factors such as increased field capacity (more area covered in less time) and possibly higher weeding efficiency at higher speeds. However, it is important to note that, while higher speeds may lead to higher performance index values, they may also result in increased plant damage. Therefore, a balance must be struck between speed and precision to optimize the performance of the weeder unit while minimizing negative impacts on crop health.

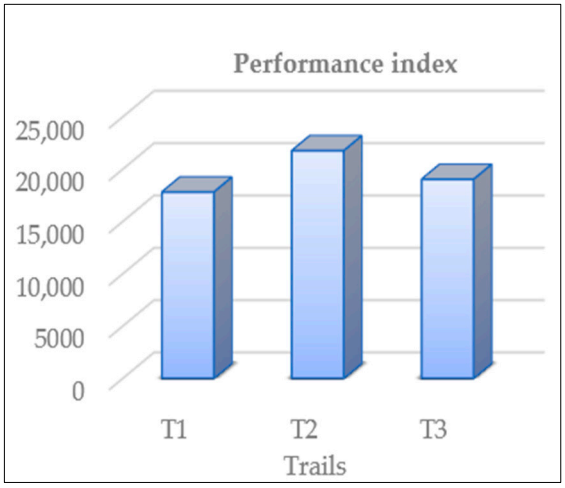


Figure 12. Performance index of blade and tine-type push weeder unit in three different trails.

Table 8 provides the average values of three replications for observations such as effective field capacity, weeding efficiency, plant damage, and performance index, at three forward speeds of 0.8 km/h (T_1), 1 km/h (T_2), and 1.2 km/h (T_3), respectively.

Table 8. Effect of soil and developed weeder working parameters on the performance index.

Treat No	Field Capacity (ha/h)	Plant Damage (%)	Weeding Efficiency (%)	Power (hp)	Performance Index
T_1	0.0161	1.51	79.06	0.007	17,797
T_2	0.020	2.73	78.26	0.007	21,749
T_3	0.024	4.28	74.5	0.009	19,016

3.6. Draft

Draft requirements of the developed blade and tine-type push weeder ranged from 1.8 kgf to 2.3 kgf.

The developed weeder's ability to weed in all crops that have row spacings greater than 60 cm, in soils with moisture levels higher than 10%, and efficiently manage weeds up to a height of 30 cm is noted.

3.7. Calculation of Cost of Operation of Blade and Tine Push Weeder

The blade and tine push weeder's initial cost was determined by summing the cost of all components at current prices and the fabrication cost. The total cost of the developed weeder is categorized into fixed cost and variable cost.

Cost of blade and tine push weeder/Capital cost = 7500/-.

Economic Analysis:

The economic analysis of the developed weeder was based on the following assumption.

1. Estimated lifespan of the weeder = 10 years.
2. The annual usage of the weeder is determined using the following assumption:
   Working hour (h) = 300 h/year;
   Salvage value (S) = 10 percent of initial cost;
   Rate of interest = 10 percent per annum;
   Repair and maintenance = 5 percent of initial cost;
   Labor required = 01;
   Shelter, insurance, and tax cost = 2 percent of capital cost.

A. Fixed Cost

1. Depreciation (D)

The depreciation is the reduction in the weeder's value over time due to wear, usage, and aging.

$$\text{D (INR/h)} = \frac{7500 - 750}{10 \times 300} = 2.25$$

2. Interest

Interest on investment/h @ 10% per annum.

$$\text{I} = \frac{7500 + 750}{2} \times \frac{0.10}{300} = \text{INR}1.36/\text{h}$$

3. Shelter, Insurance, and Tax Cost

Two per cent of initial cost = INR 150/year = INR 0.3/h;
Total fixed cost = (INR 2.25 + INR 1.36 + INR 0.3)/h = INR 3.91/h.

B. Variable Cost

1. Repair and Maintenance @ 5 percent of Initial Cost
= 375/year
= INR 0.75/h
2. Labor Charge
INR 300 per worker per day for an 8 h period of weeding
= INR 300/ day = INR 37.5/h;
Total variable cost for = INR 38.25/h;
Total cost for weeding = Fixed cost + variable cost = 3.91 + 38.25 = 42.16;

- ➢ Average effective field capacity for green pea weeding = 0.020 ha/h;
- ➢ Cost of operation of weeder for green pea crop = $\frac{42.16}{0.020}$ = INR 2108/ha.

3.8. Comparative Study Between Blade and Tine Push Weeder with Wheel Hoe

T_1 = Wheel hoe;
T_2 = Blade and tine push weeder;
A—Weeding with Wheel hoe.

The manually operated wheel hoe is generally used for weeding. However, it is not provided with the adjustment for handle height as per the height of the operator and the adjustment for the depth of cut as per the requirement. Weeding with a wheel hoe is a very time-consuming and fatiguing process. Table 9 shows the comparative study between the developed weeder and wheel hoe. The wheel hoe was designed with a small tine; hence, its performance is low because the performance depends upon the working width of the implement.

Table 9. Comparative study between developed weeder unit and wheel hoe.

Particular	T_1	T_2
Actual field capacity (ha/h)	0.022	0.024
Field efficiency (%)	73.66	85
Weeding efficiency (%)	74.0	79
Plant damage (%)	2.20	1.5

B—Weeding with Blade and Tine Push Weeder

Blade and tine push weeder has three wheels, so it is easily balanceable compared to the wheel hoe, which has only one wheel. Weeding with a developed weeder unit requires less time, causes less human fatigue, and is a very efficient process compared to the wheel hoe. A push-type trolley may be tried to eliminate the manual load carrying of the weeder during transportation.

3.8.1. Comparison of Blade and Tine Push Weeder's Actual Field Capacity with Wheel Hoe's Actual Field Capacity

Figure 13 shows the actual field capacities of T_1 and T_2, observed as 0.022 and 0.024 ha/h, respectively. The developed weeder unit showed the highest actual field capacity when compared with the wheel hoe. The field capacities of the developed weeder and wheel hoe were dependent on the pulling capacity of the operator and walking speed. Field topography and weed intensity affect the weeding speed. Field capacity depends on the weeder's working width and weeding speed, both influenced by the blade type.

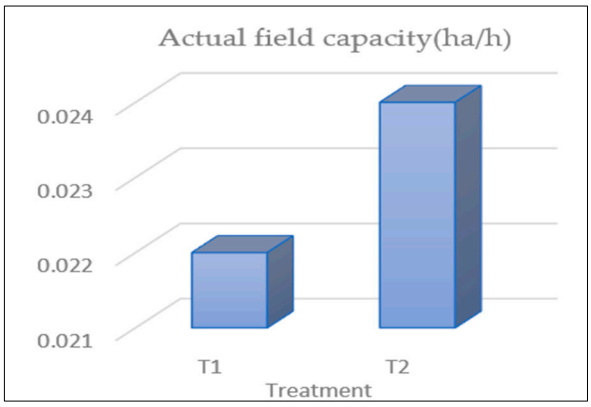


Figure 13. Comparison of actual field capacities of T_1 and T_2.

3.8.2. Comparison of Blade and Tine Push Weeder's Field Efficiency with Wheel Hoe's Field Efficiency

Figure 14 shows the field efficiency difference between T_1 and T_2. Treatment T_2 shows maximum field efficiency as compared to T_1. Field efficiency mainly depends on actual field capacity.

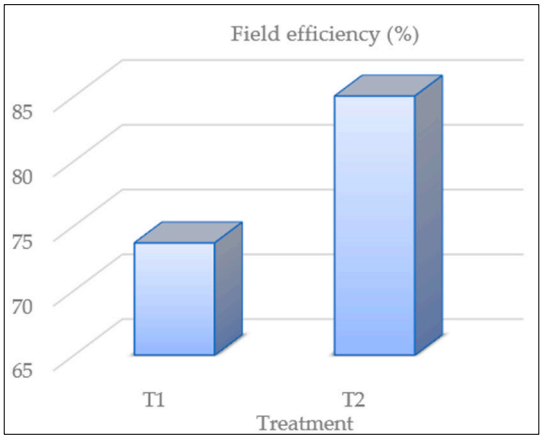


Figure 14. Comparison of field efficiencies of T_1 and T_2.

3.8.3. Comparison of Blade and Tine Push Weeder's Weeding Efficiency with Wheel Hoe's Weeding Efficiency

Weeding efficiency was calculated by counting the number of weeds in a 1 m^2 area before and after weeding. The weeding efficiency of T_2 was 79%, which is more than T_1, as shown in Figure 15. The blade and tine push weeder had the maximum weeding efficiency among the wheel hoe. This consequence could be credited to the adjustability of two cutting blades (tine blade and straight blade), which can simply change their direction for easy movement as well as their proximity of operation.

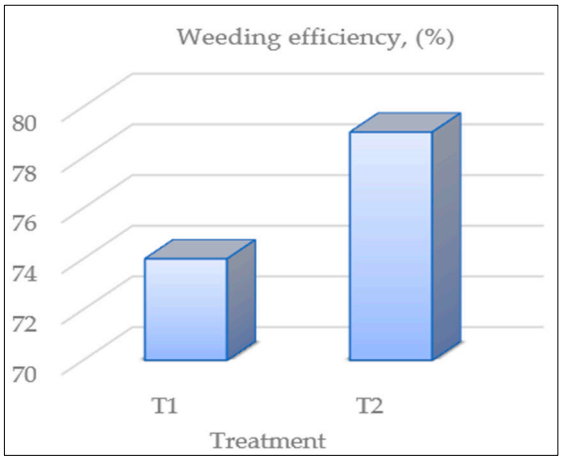


Figure 15. Comparison of weeding efficiencies of T_1 and T_2.

3.8.4. Comparison of Blade and Tine Push Weeder's Plant Damage with Wheel Hoe's Plant Damage

Figure 16 shows the percentage of plant damage with 'T1' and 'T2'. The maximum percentage of plant damage was observed with 'T1' (2.20%), followed by 'T2' (1.5%). The results indicated that the lowest percentage of damaged plants (1.5%) was obtained in the developed weeder unit. Plant damage is influenced by various factors related to both the weeder and the crop. It depends on the weeder's working width, which is determined by the blade type, as well as the weeding speed.

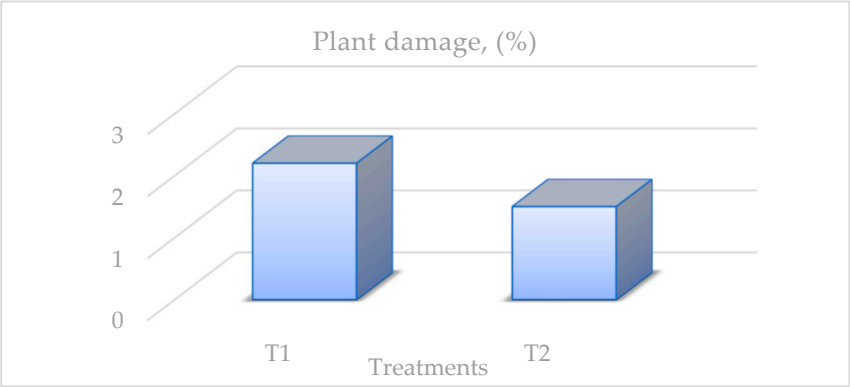


Figure 16. Comparison of plant damage of T_1 and T_2.

3.9. Comprehensive Comparison of Current Weed Control Technologies

Table 10 provides a comparison of current weeding methods in agriculture and positions the blade and tine push weeder relative to these existing weeding methods. The various advancements in automated, robotic weeders, mechanical weeding methods, precision herbicide sprayers, and laser-based weed control systems classify the major limitations of these weeding methods and demonstrate how the fabricated weeder offers a novel contribution to the field of sustainable agriculture. Table 10 outlines key aspects such as cost, complexity, labor requirements, effectiveness, environmental impact, and accessibility for smallholder farmers.

Table 10. State-of-the-art weed control method comparison.

Method of Weeding	Adopted Technology	Price	Complication	Number of Operators	Efficiency	Impact on Environment	Availability
Robots	Autonomous robots with sensors and cameras for weed detection and removal	High	High (requires programming, maintenance)	High (requires specialized knowledge)	High (precise weed control)	Medium (potential herbicide use)	Low (expensive, requires infrastructure)
Precision Sprayers	GPS and sensors for targeted herbicide application	Medium-High	Medium	Medium (operator needed for setup)	High (precise herbicide use)	High (minimized chemical use	Medium (requires advanced tech)
Laser method	Lasers to destroy weeds without chemicals	High	High (requires setup and maintenance	Low (automated)	Medium (effective but expensive)	Medium (energy use)	Low (not feasible for small farms)
Power weeder	Tines or blades for mechanical weed removal	Medium	Medium	Medium (operator needed)	High (mechanical removal)	Medium (reduced chemical use)	Medium (costly, not universally adaptable)
Blade and Tine Push Weeder (Proposed)	Manual push mechanism with blade and tine system	Low	Low (simple operation)	Low (ergonomically designed to reduce fatigue)	High (effective weed control)	Low (no herbicide use, minimal soil disturbance)	High (affordable, practical for smallholder farms)

3.10. Limitations of the Proposed Weeder

- ➢ Inadequate efficiency in denser weeds.
- ➢ Labor-intensive for heavy fields.

- ➢ Limited adaptability for diverse soils.
- ➢ Not ideal for every crop.
- ➢ Not added autonomous method.
- ➢ Long-term durability and wearability.
- ➢ Limited customization for different weed species.

Table 11 provides a comprehensive overview of the specifications of the developed blade and tine-type push weeder unit. These specifications encapsulate key attributes and features of the weeder, providing valuable insights into its design and capabilities.

Table 11. Overall specification of the developed blade and tine-type push weeder.

S. No	Particular	Values
1	Actual field capacity, ha/h	0.020
2	Theoretical field capacity, ha/h	0.025
3	Field efficiency, %	85
4	Width of cut, cm	25–27
5	Depth of cut, cm	3–5
6	Draft of weeder, kgf	2.2
7	Weeding efficiency, %	78
8	Plant damage, %	2.7
9	Performance index	21,749
10	Cost of operation, INR/ha	2108
11	Cost of machine, INR	7500

4. Conclusions

1. In the current paper, the blade and tine-type push weeder for agriculture was developed to perform interrow mechanical weed control in >60 cm row-spaced crops. A conventional weeder was modified and equipped with blades, tines, a long handle, and a three-wheeled frame. Theoretical and actual calculations were completed based on the existing equations, and AutoCAD drawings of weeders were presented.
2. The developed blade and tine push weeder has a faster speed and weeding efficacy than traditional weeders like wheel hoes, sickles, chris, powers, shovels, hand forks, etc. Its advantages, such as eliminating the need for prolonged sitting and bending postures, contribute to reduced fatigue and increased efficiency. In contrast, the developed weeder with two blades is more efficient than a single-working-element weeder.
3. This translates into increasing efficiency, which is reasonably available to small and marginal farmers. Additionally, the low-cost maintenance and user-friendly fabrication make it accessible for various operators, including women, thereby improving the overall agricultural yield.

Future Directions:

- ➢ Incorporating adjustable seating features for improved operator comfort.
- ➢ Adjust the BLDC motor for self-propelled weeding.
- ➢ Conduct comprehensive testing of the weeder across various crops to ensure its versatility and effectiveness.
- ➢ Consider the implementation of lugged wheels for increased traction and improved performance in diverse soil conditions.

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Abbreviations

Hp: horsepower; MS: Mild steel; kgf: Kilogram-force; NABARD: National Bank for Agriculture and Rural Development.

References

1. Michaliszyn-Gabryś, B.; Bronder, J.; Krupanek, J. Social Life Cycle Assessment of Laser Weed Control System: A Case Study. *Sustainability* **2024**, *16*, 2590. [CrossRef]
2. Press Information Bureau, Government of India. *Empowering Rural India: NABARD Survey on Rural Financial Inclusion*; Press Information Bureau, Government of India: New Delhi, India, 2024. Available online: https://pib.gov.in/PressNoteDetails.aspx?NoteId=153270&ModuleId=3&reg=3&lang=1 (accessed on 10 February 2025).
3. *ICAR's "Vision-2030" Unveiled by Agriculture Minister | ICAR*. Icar.gov.in. Available online: https://icar.gov.in/node/1646 (accessed on 8 January 2025).
4. Hajjar, M.J.; Ahmed, N.; Alhudaib, K.A.; Ullah, H. Integrated Insect Pest Management Techniques for Rice. *Sustainability* **2023**, *15*, 4499. [CrossRef]
5. Nath, C.P.; Singh, R.G.; Choudhary, V.K.; Datta, D.; Nandan, R.; Singh, S.S. Challenges and Alternatives of Herbicide-Based Weed Management. *Agronomy* **2024**, *14*, 126. [CrossRef]
6. Rao, V.S. *Principles of Weed Science*; CRC Press: Boca Raton, FL, USA, 2000. [CrossRef]
7. Opasatian, I.; Ahamed, T. Driveway Detection for Weed Management in Cassava Plantation Fields in Thailand Using Ground Imagery Datasets and Deep Learning Models. *AgriEngineering* **2024**, *6*, 3408–3426. [CrossRef]
8. Massenssini, A.M.; Bonduki, V.H.A.; Melo, C.A.D.; Tótola, M.R.; Ferreira, F.A.; Costa, M.D. Soil Microorganisms and Their Role in the Interactions between Weeds and Crops. *Planta Daninha* **2014**, *32*, 873–884. [CrossRef]
9. Farooq, M.; Flower, K.C.; Jabran, K.; Wahid, A.; Siddique, K.H. Crop Yield and Weed Management in Rainfed Conservation Agriculture. *Soil Tillage Res.* **2011**, *117*, 172–183. [CrossRef]
10. Ramesh, D.; Chandrasekaran, M.; Soundararajan, R.P.; Subramanian, P.P.; Palled, V.; Kumar, D.P. Solar-Powered Plant Protection Equipment: Perspective and Prospects. *Energies* **2022**, *15*, 7379. [CrossRef]
11. Gharde, Y.; Singh, P.K.; Dubey, R.P.; Gupta, P.K. Assessment of Yield and Economic Losses in Agriculture Due to Weeds in India. *Crop Prot.* **2018**, *107*, 12–18. [CrossRef]
12. Varanasi, A.; Prasad, P.V.; Jugulam, M. Impact of Climate Change Factors on Weeds and Herbicide Efficacy. *Adv. Agron.* **2016**, *135*, 107–146. [CrossRef]
13. Roslim, M.H.M.; Juraimi, A.S.; Che'Ya, N.N.; Sulaiman, N.; Manaf, M.N.H.A.; Ramli, Z.; Motmainna, M. Using Remote Sensing and an Unmanned Aerial System for Weed Management in Agricultural Crops: A Review. *Agronomy* **2021**, *11*, 1809. [CrossRef]
14. Ghersa, C.M.; Benech-Arnold, R.L.; Satorre, E.H.; Martínez-Ghersa, M.A. Advances in Weed Management Strategies. *Field Crops Res.* **2000**, *67*, 95–104. [CrossRef]
15. Rajković, M.; Malidža, G.; Tomaš Simin, M.; Milić, D.; Glavaš-Trbić, D.; Meseldžija, M.; Vrbničanin, S. Sustainable Organic Corn Production with the Use of Flame Weeding as the Most Sustainable Economical Solution. *Sustainability* **2021**, *13*, 572. [CrossRef]
16. Binni, I.M.; Rabiu, A.L.; Kabir, M.H.; Jibril, A. A Survey on Performance Evaluation of Different Types of Weeders. *Int. J. Appl. Eng. Technol.* **2016**, *6*, 8–13.
17. Jia, W.; Tai, K.; Wang, X.; Dong, X.; Ou, M. Design and Simulation of Intra-Row Obstacle Avoidance Shovel-Type Weeding Machine in Orchard. *Agriculture* **2024**, *14*, 1124. [CrossRef]
18. Matsuda, Y.; Kakutani, K.; Toyoda, H. Unattended Electric Weeder (UEW): A Novel Approach to Control Floor Weeds in Orchard Nurseries. *Agronomy* **2023**, *13*, 1954. [CrossRef]
19. Singh, G. Weed Management in Peas (*Pisum sativum* L.)—A Review. *Agric. Rev.* **2003**, *24*, 217–222.

20. Nag, P.K.; Gite, L.P. Farm Mechanization: Nature of Development. In *Human-Centered Agriculture: Ergonomics and Human Factors Applied*; Nag, P.K., Gite, L.P., Eds.; Springer: Singapore, 2020; pp. 149–171. [CrossRef]
21. Gianessi, L.P.; Reigner, N.P. The Value of Herbicides in U.S. Crop Production. *Weed Technol.* **2007**, *21*, 559–566. [CrossRef]
22. Dhananivetha, M.; Amnullah, M.M.; Murali Arthanari, P.; Mariappan, S. Weed Management in Onion: A Review. *Agric. Rev.* **2017**, *38*, 76–80. [CrossRef]
23. Kumar, N.; Kumar, S.; Nayak, M.; Ramya, V. Performance Evaluation of Weeders. *Int. J. Sci. Environ. Technol.* **2014**, *3*, 2160–2165.
24. Ye, S.; Zhang, X.; Wang, Q.; Li, X.; Hu, F.; Song, H.; Zheng, D. Design and Experiment of a High-Clearance Mid-Tillage Weeder for Dryland Farming. *Agriculture* **2024**, *14*, 435. [CrossRef]
25. Fang, H.; Xu, G.; Xue, X.; Niu, M.; Qiao, L. Study of Mechanical-Chemical Synergistic Weeding on Characterization of Weed–Soil Complex and Weed Control Efficacy. *Sustainability* **2023**, *15*, 665. [CrossRef]
26. Zawada, M.; Legutko, S.; Gościańska-Łowińska, J.; Szymczyk, S.; Nijak, M.; Wojciechowski, J.; Zwierzyński, M. Mechanical Weed Control Systems: Methods and Effectiveness. *Sustainability* **2023**, *15*, 15206. [CrossRef]
27. Sampurno, R.M.; Liu, Z.; Abeyrathna, R.M.R.D.; Ahamed, T. Intrarow Uncut Weed Detection Using You-Only-Look-Once Instance Segmentation for Orchard Plantations. *Sensors* **2024**, *24*, 893. [CrossRef]
28. Ma, Z.; Wang, G.; Yao, J.; Huang, D.; Tan, H.; Jia, H.; Zou, Z. An Improved U-Net Model Based on Multi-Scale Input and Attention Mechanism: Application for Recognition of Chinese Cabbage and Weed. *Sustainability* **2023**, *15*, 5764. [CrossRef]
29. Singh, S.P.; Singh, M.K.; Solanki, R.C. Design and Development of Four-Wheel Weeder for Wide-Row Crops. *Indian J. Agric. Sci.* **2016**, *86*, 42–49. [CrossRef]
30. Saleh, A.; Suleiman, M.L. Design, Construct and Evaluation of a Single Row Hand-Pushed Mechanical Weed Control Machine. *J. Appl. Sci. Environ. Manag.* **2021**, *25*, 401–406. [CrossRef]
31. Jena, P.P.; Mohanty, S.K.; Mishra, J.N. Development of Ergonomically Designed Weeder for Increasing Productivity. *J. Agric. Technol.* **2016**, *3*, 59.
32. Nkakini, S.; Husseni, A. Development and Evaluation of Wheeled Long-Handle Weeder. *West Indian J. Eng.* **2015**, *37*, 37.
33. Manjunatha, K.; Sushilendra, S.S.; Vijayakumar, P. Development and Evaluation of Manually Operated Sprocket Weeder. *Int. J. Agric. Eng.* **2014**, *26*, 64–72.
34. Gite, L.P.; Yadav, B.G. Optimum Handle Height for a Push-Pull Type Manually-Operated Dryland Weeder. *Ergonomics* **1990**, *33*, 1487–1494. [CrossRef]
35. Choudary, R.B.; Sekhar, V.C.; Ajayaram, B.; Rao, G.N. Fabrication and Field Evaluation of a Wheel Weeder. In *IOP Conference Series: Materials Science and Engineering*; IOP Publishing: Bristol, UK, 2021; Volume 1070, p. 012134. [CrossRef]
36. Kachhot, A.R.; Dulawat, M.S.; Makavana, J.M.; Dobariya, U.D.; Vadher, A.L. Development of Solar Operated Walking Type Power Weeder. *Agric. Sci. Green Energy* **2021**, *2*, 30–41. [CrossRef]
37. Singh, S.; Dave, A.K.; Padhee, D.; Kulhariya, S.K.; Yadav, N.K. Performance Evaluation of Manually Operated Weeder. *J. Pharmacogn. Phytochem.* **2020**, *9*, 1370–1374.
38. Singh, M.U. Performance Evaluation of Some Manually Operated Weeders Used in Jhum Cultivation in Hill Regions of Arunachal Pradesh. *Indian J. Hill Farming* **2017**, *30*, 2.
39. Yadav, R.; Pund, S. Development and Ergonomic Evaluation of Manual Weeder. *Int. J. Agric. Eng.* **2007**, *9*, 1–9.
40. Babu, D.A.; Ramana, C.; Kumar, A.A. Performance Evaluation of a Prototype Weeder with Various Blades and Orientations. *Int. J. Agric. Eng.* **2024**, *26*, 4.
41. Sharma, D.N.; Mukesh, S. *Farm Machinery Design Principles and Problems*; Jain Brothers: New Delhi, India, 2013.
42. Michael, A.M.; Ojha, T.P. *Principles of Agricultural Engineering: Farm Power, Farm Machinery, and Farm Buildings*, 15th ed.; Jain Brothers: New Delhi, India, 2021; Volume 1.
43. Balachand, C.H. Design, Development and Evaluation of Animal Drawn Weeder Suitable for Non-Descript Bullocks of Chhattisgarh Region. M.Tech. Thesis, Indira Gandhi Krishi Vishwavidyalaya, Raipur, India, 2006.
44. Javadi, A.; Hajahamad, A. Effect of new combined implement for reducing secondary tillage operation. *Int. J. Agric. Biol.* **2006**, *8*, 724–727.
45. Kushwaha, D.K.; Thomas, E.V.; Maiti, B.; Ghosh, B.C.; De, B. Assessment and Optimization of Bulk Density and Angle of Repose of Tea Leaves for Metering Device Using Desirability Function. *Int. J. Sci. Eng. Technol.* **2015**, *4*, 36–39.
46. Jain, S.C.; Grace Philip, G. *Farm Machinery an Approach*; Standard Publishers Distributors: New Delhi, India, 2003.
47. Sahay, J. *Elements of Agricultural Engineering*; Standard Publishers Distributors: New Delhi, India, 2006.
48. Tajuddin, A. Design, Development and Testing of Engine Operated Weeder. *Agric. Eng. Today* **2006**, *30*, 25–29.
49. Srinivas, I.; Adake, R.; Reddy, B.; Korwar, G.; Thyagaraj, C.; Dange, A.; Veeraprasad, G.; Reddy, C. Comparative Performance of Different Power Weeders in Rainfed Sweet Sorghum Crop. *Indian J. Dryland Agric. Res. Dev.* **2010**, *25*, 63–67. Available online: http://drylandagri.org.in/Journals/2010%20Vol.%2025-num-2-8.pdf (accessed on 8 January 2025).
50. Devojee, B.; Meena, S.; Sharma, A.; Agarwal, C. Performance Evaluation of Weeder by Number of Blades per Flange in maize Crop. *Int. J. Curr. Microbiol. Appl. Sci.* **2019**, *8*, 2389–2397. [CrossRef]

51. Mehra, N.; Gautam, A.K.; Pathak, U.; Shrivastava, A.K. Development of Mathematical Model for Repair and Maintenance of Farm Tractors. *J. Multidiscip. Adv. Res.* **2017**, *6*, 93–98.
52. Kamboj, P.; Khurana, R.; Dixit, A. Farm Machinery Services Provided by Selected Cooperative Societies. *Agric. Eng. Int.* **2012**, *14*, 123.
53. *IS: 9164-1979*; Bureau of Indian Standards. Guide for Estimating Cost of Farm Machinery Operation. Bureau of Indian Standards: New Delhi, India, 1982.
54. Sundaram, P.K.; Rahman, A.; Singh, A.K.; Sarkar, B. A Novel Method for Manual Weeding in Row Crops. *Indian J. Agric. Sci.* **2021**, *91*, 946–948. [CrossRef]
55. Shekhar, S.; Chandra, S.; Roy, D.K. Performance Evaluation of Different Weeding Tools in Maize. *Indian J. Weed Sci.* **2010**, *42*, 95–97.

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