Mechanized weed management: Single-row dual rotor weeder design, development, and fabrication in Bangladesh

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Abstract: In Bangladesh, manual weeding in rice fields is labor-intensive and costly, affecting productivity. This study developed a manually operated, push-pull single-row, double-rotor weeder tailored to local conditions to improve rice farming efficiency. Fabricated using Bangladeshi available materials, the weeder consists of a mainframe, skid, and two conical-shaped rotors with plain and serrated blades for effective weed uprooting and burial. It was tested in both research and farmer fields under clay loam conditions, with results showing a weeding efficiency of 81%-82% and an effective field capacity of 0.0205 ha h^{-1}. The weeder requires a pushing force of 34.66 N and operates in fields with 2-4 cm of standing water. Weighing 5.4 kg, the weeder is lightweight, easy to handle, and causes minimal crop damage (1.84%-1.96%). Its operational cost of 28.29 USA $ ha^{-1}) makes it highly affordable for small and medium-scale farmers. The weeder's simple design, featuring adjustable handles and locally sourced materials, ensures easy use, low maintenance, and cost-effective production. It offers a sustainable and economical solution to manual weeding, enhancing productivity and reducing labor in rice cultivation. Successful field trials highlight its potential for widespread adoption in Bangladesh, advancing weed management modernization.

Keywords: Rice, Double rotor weeder, field capacity, weeding efficiency, weed

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1 Introduction

Bangladesh relies heavily on agriculture, with the sector serving as the backbone of the country's economy (Paul et al., 2023). It is particularly important in Asia, where it plays a crucial role in the economy and diet. About 75% of Bangladesh's agricultural area is used for rice production, making it one of the world's top producers and a major contributor to the nation's food supply (Jamal et al., 2023). The region's economic stability and food security depend on sustainable rice cultivation. However, weed infestation, which competes with rice plants for vital resources including nutrients, water, light, and space, is one of the many variables that frequently endanger rice production (Fahad et al., 2019). If this is not properly controlled, yield is greatly decreased. Notably, weed control is a particularly time-intensive aspect of agricultural production in Bangladesh.

Weeds pose a considerable challenge in crop cultivation, resulting in substantial yield losses (Paul et al., 2022). Depending on the extent of the infestation

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and management techniques, weeds can reduce rice yield by 15% to 60%, making them a significant production restriction (Dilipkumar et al., 2020). The primary obstacle to agricultural cultivation is weeds, which result in significant yield losses (Paul et al., 2022). Traditional weed management techniques, primarily manual hand weeding in many poor nations, including Bangladesh, remain common in rice fields. Hand weeding takes a lot of time and effort, and it frequently results in high labor costs, up to 30–40% of the entire production costs (Ahmed et al., 2021).

Weed management in Bangladeshi rice cultivation demands a multifaceted approach. While organic method, such as mulching and crop rotation, promote sustainability, they can be less effective against heavy infestations (Mwangi et al., 2024). Inorganic methods, such as herbicides, offer rapid control but pose environmental and human health risks (Upadhyay et al., 2024, Paul et al., 2024). Mechanical weeders, while potentially damaging crops, significantly increase efficiency and reduce labor. Combining mechanical weeding and carefully selected organic practices, an integrated approach offers the most promising solution (Scavo and Mauromicale, 2020). This approach optimizes weed control by balancing efficiency, environmental sustainability, and economic viability for smallholder farmers, ensuring the long-term sustainability of rice production systems.

Managing weeds in Bangladesh's agricultural landscape poses a significant challenge due to the ineffective techniques employed. While mechanical weeding is effective, costly and time-consuming than manual alternatives. Because weed control requires substantial labor, frequent weeding sessions may be necessary to keep the crops from weeds. Mechanical weeding is preferred for its efficiency, whether done manually or with power-operated weeders. However, manually operated weeders are favored for their cost-effectiveness despite requiring a substantial labor force.

Hand tools for weeding are time-consuming, labor-intensive, inefficient, and tedious. Chemical weed control involves the use of herbicides, which are now extensively and intensively employed. The advantages of chemical weed control include low labor consumption, ease of application, the ability to be applied on broadcasted crops, and high effectiveness in killing the weed. However, the disadvantage of chemical weeding is that it is not environmentally friendly and affordable due to the higher cost of herbicides, making it uneconomical for small-scale farmers. Recognizing its significance, weed removal becomes essential for optimizing crop yield, especially during the early stages of crop growth, where weed interference can substantially curtail output as fertilizer (Paul et al., 2021).

The primary objective of this study is to develop a single-row, dual-rotor weeder designed explicitly for use in rice fields. This weeder works by tilting the soil, uprooting weeds, and burying them using blades attached to a rotating curved roller. The blades penetrate the soil, causing displacement along their length. This displacement within the topsoil layers helps to remove weeds effectively.

In Bangladesh, most rice farmers use manual weeding to control weeds. Mechanical weeding, such as pulling weeds between crop rows, improves soil aeration and water absorption but can also cause surface soil erosion. Manual weeders, introduced in Japan in the 1960s, have limitations in heavy soils and are not easily accessible to women. As a result, the Bangladesh Rice Research Institute (BRRI) has developed various models of weeders, including the BRRI weeder, BRRI Kishan weeder, BRRI wet and dry land weeder, BRRI conical weeder, and BRRI double row weeder. These BRRI-developed weeders have proven to be effective in removing weeds. In Bangladesh, weeds are managed using manual methods such as pulling, using tools like Niranee, Japanese rice weeders, BRRI weeders, Bangladeshi made alternatives, and using chemical techniques involving herbicides. There are operational difficulties in puddled fields, and power weeders have limitations due to their complex design, which involves many functioning components. Mechanical paddy weeders outperform hand-weeding by effectively churning the soil, incorporating weeds as organic manure, promoting aeration, and enhancing tillering and yields. Recognizing the need for efficient weeders with high uprooting capacity, an experiment was conducted to develop a manual push-pull single-row dual-rotor weeder, designed to suit Bangladesh's agricultural conditions, thereby reducing labor intensity while improving comfort and efficiency.

2 Materials and methods

The weeder was fabricated using locally available Bangladeshi materials, including GI pipe, GI sheet, MS sheet, MS flat bar, MS shaft, nuts, and bolts, sourced from the Bangladeshi market. Initially, the engineering design was created using AutoCAD tools, and a prototype was manufactured based on the design. Subsequently, the weeder was tested in lowland conditions, and observations were recorded. Some issues were identified during the field test of the first version of the conical weeder. As a result, the second version of the single-row dual-rotor weeder was fabricated, modifying the weeder's design. The weeder was tested again, and additional problems were discovered. Finally, the weeder's design was adjusted, and the final version was developed. The weeder was then evaluated in a farmer's field, and data was gathered and analyzed. The methods employed for testing and evaluation involved both laboratory trials and field experiments. Controlled laboratory conditions facilitated the assessment of the weeder's mechanical functionality, while field trials provided valuable insights into its performance. Parameters such as effective field capacity (ha h^{-1}), Degree of weeding / weeding efficiency (%), Plant damage, walking speed (k h^{-1}), Pulling force (kg), and Pushing force (N) were systematically evaluated.

2.1 Design considerations

The design was completed with the help of AutoCAD engineering drawing tools. During design, the following criteria were considered:

Ease of weeding;

Easy and simple operation and maintenance ;

Distance between rows;

It should be a minimum force requirement for operating in the field;

It should have simple and easy adjustments;

Bangladeshi available materials should be used to minimize the fabrication costs;

Light-weight for easy handling;

It should be easy to repair and maintain;

The cost of the weeder must be within the capacity of small and medium farmers;

It should be suitable for operation by a single person.

2.2 Details of the developed weeder

Based on the above design considerations, a manually controlled push-and-pull type dual-rotor weeder was designed. The following is a description of the design details:

2.2.1 Width of the weeder

20 cm between lines was considered when designing the weeder for single-row operation. The weeder's width was chosen based on the row spacing (or line-to-line distance) of transplanted and drum-seeded rice. The weeder covers an effective 20 cm width in one pass. The weeder's total width was measured at 13 cm. Weeding tools consisted of two rotors with a conical form. Rotor alignment and arrangement determine the weeding breadth, which is 10.6 cm, to reduce crop damage (Figure 1).

2.2.2 Main frame and skid

The basements of the dual-rotor weeder consist of the main frame and skid, equipped with handles, blades, and skids, are attached to the main frame. The two conical rotors, which assist with soil surface rotation, are housed within the main frame. Rotors are subjected to all forces (push and pull) from the main frame. The weeder needed to have a skid to function in the wetland situation. It will keep the weeder from piercing through and facilitate its ability to skid in the marsh. To keep it from penetrating the soil, a float with dimensions of 220 mm by 121 mm has been devised for the front part. The skid was designed with a side wall height of 62 mm and an apex height of 45 mm. Therefore, it was determined that the skid's 26,620 mm^2 area could withstand the applicator's penetration under various soil conditions. A 2 cm MS to increase the float's strength. A 25-degree skidding angle and 140 mm length were employed at the skid's apex to aid body slippage. The handle was fastened to the main frame so the conical weeder could be pushed and pulled.

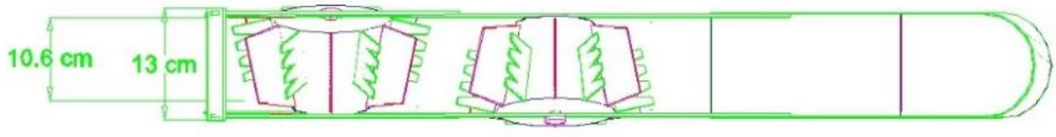

Figure 1 Top view of conical rotor arrangement and skid

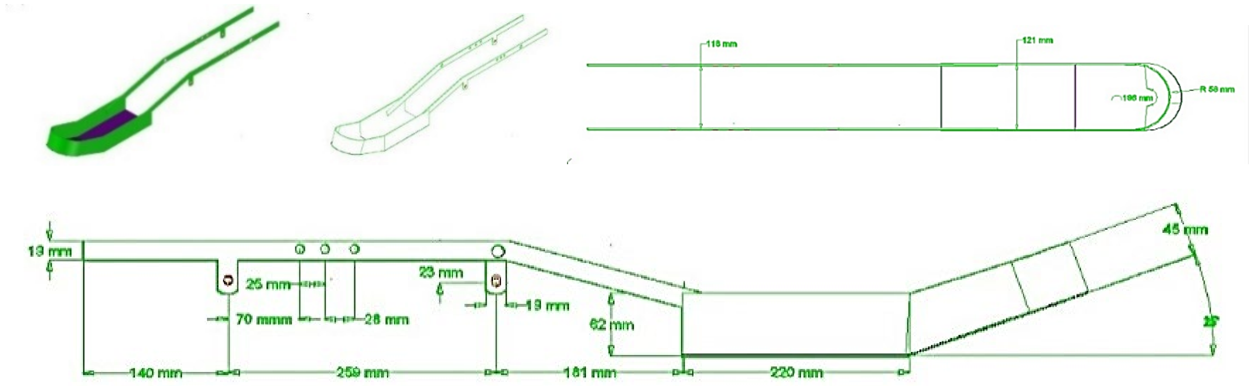

Figure 2 Different view of the main frame and skid of conical weeder

2.2.3 Conical-shaped rotor

The key component of the dual rotor weeder for uprooting weeds is the conical-shaped rotor. The BRRI dual-rotor weeder was equipped with a main frame and had two conical-shaped rotors. It cooperates with the other orientation. Because of the arrangement of their blades, weeder rotors are also employed as weeding instruments. During operation, blades were applied to the rotor drum at a 90-degree angle to grasp the soil and uproot weeds. The bigger and smaller diameter rotor drums were 140 mm and 92 mm, respectively, while the conical-shaped drum measured 103 mm in length (Figure 3). To uproot and bury weeds with traction and shear force when the rotors make a back-and-forth movement in the top 3 cm of soil, six smooth and six serrated blades are positioned alternately on the rotor's periphery. The width of the operation was 103 mm.

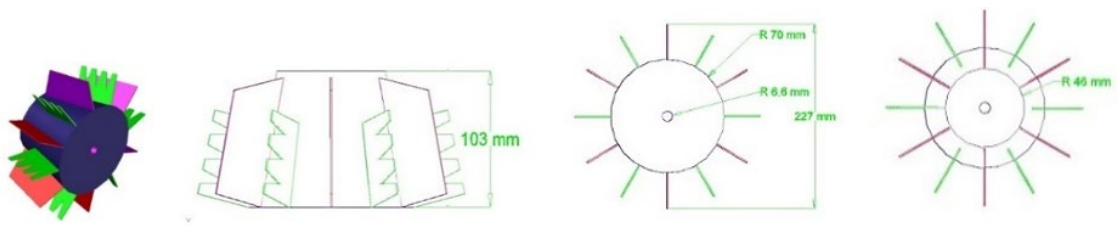

Figure 3 Different view of the conical rotor of the dual rotor weeder

2.2.4 Blade

Six plain and six serrated blades total, each with a thickness of 1.2 mm, were designed into each conical-shaped roller or drum (Figure 4). To uproot and bury weeds using traction and shear force, these blades on the periphery were positioned alternately on the rotor. The simple blade's measurements were 45 mm in width and 100 mm in length. The simple blade had a 60° side inclination. The serrated blade had an 8 mm space between its two teeth. Serrated blade dimensions were 45 mm in width and 65 mm in length.

2.2.5 Handle and adjustment lever

The force needed to run the weeder and the operators' comfort are directly correlated with the handle's length (1363 mm) and height above the ground. Five possibilities were available to adjust the handle's height from ground level to an adjustment lever attached to the handle and main frame. When the adjustment lever was lowered, the handle's height above ground was 760 mm (Figure 5). However, when the adjustment lever was in the highest position, the measurement was 1070 mm.

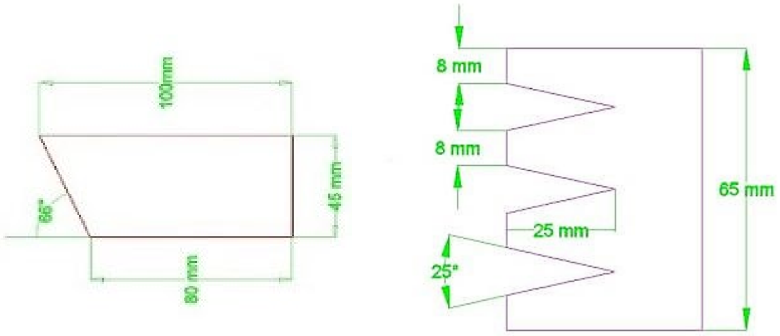

Figure 4 Different view of blades of dual rotor weeder

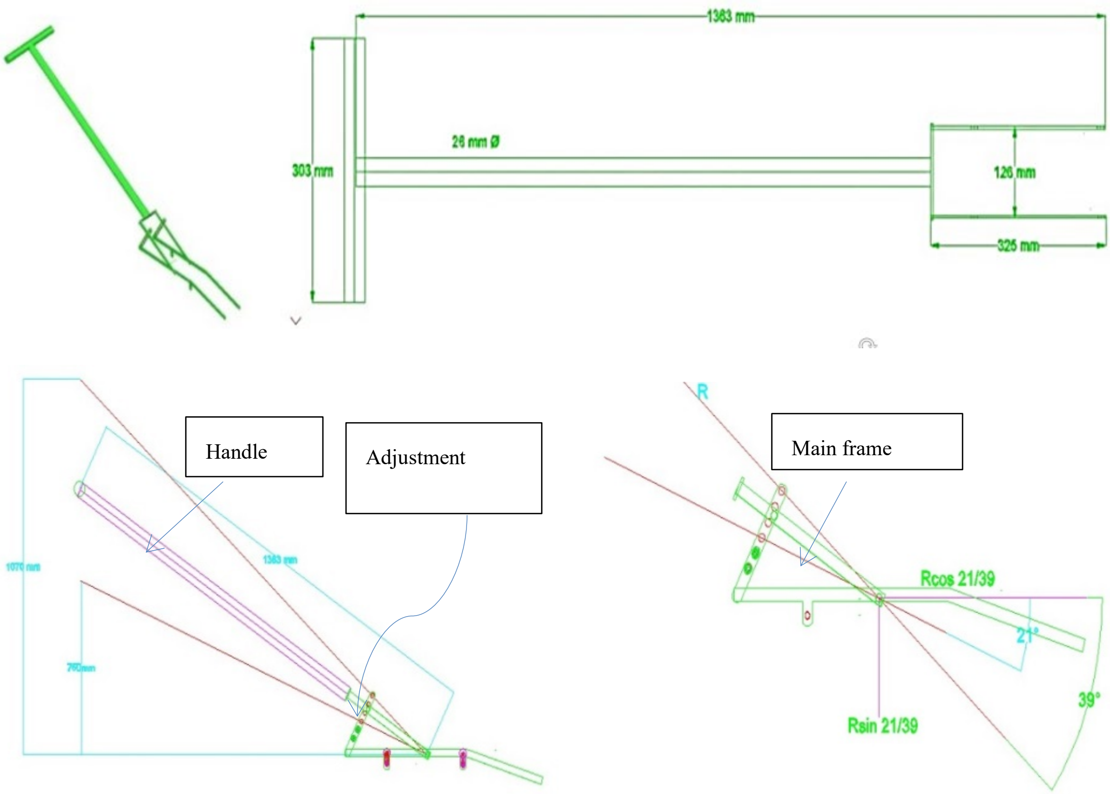

Figure 5 Different view of the handle and adjustment lever of the weeder

2.2.6 Spindle / Axle and Bush

Two large, two small, and two spindles were created for the design. The spindle had a head diameter of 24 mm and dimensions of 13 mm in diameter and 118 mm in length, as shown in Figure 6. Large and small bushes were developed and used in the conical-shaped rotor, which was welded to the large bushes.

2.2.7 Complete isometric view of the weeder

Below is an isometric representation of a complete view of the weeder designed with AutoCAD engineering tools. Figure 7 displays the entire perspective of the machine. The full isometric view allows for a comprehensive understanding of the dual rotor weeder's development and parts. Visualizing the dual rotor weeder's design and operation is made easier with the help of its full isometric view. It provides a comprehensive understanding of using the weeder optimally and effectively in weed management tasks.

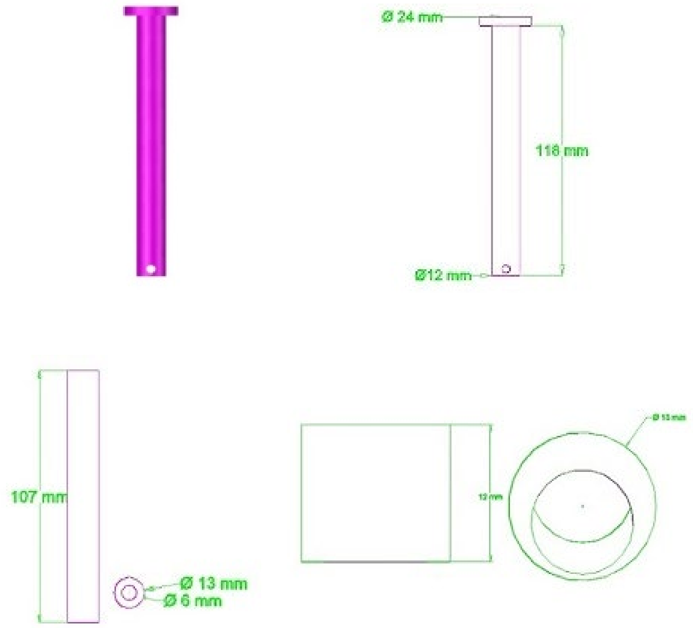

Figure 6 Different view of the spindle and bush of the weeder

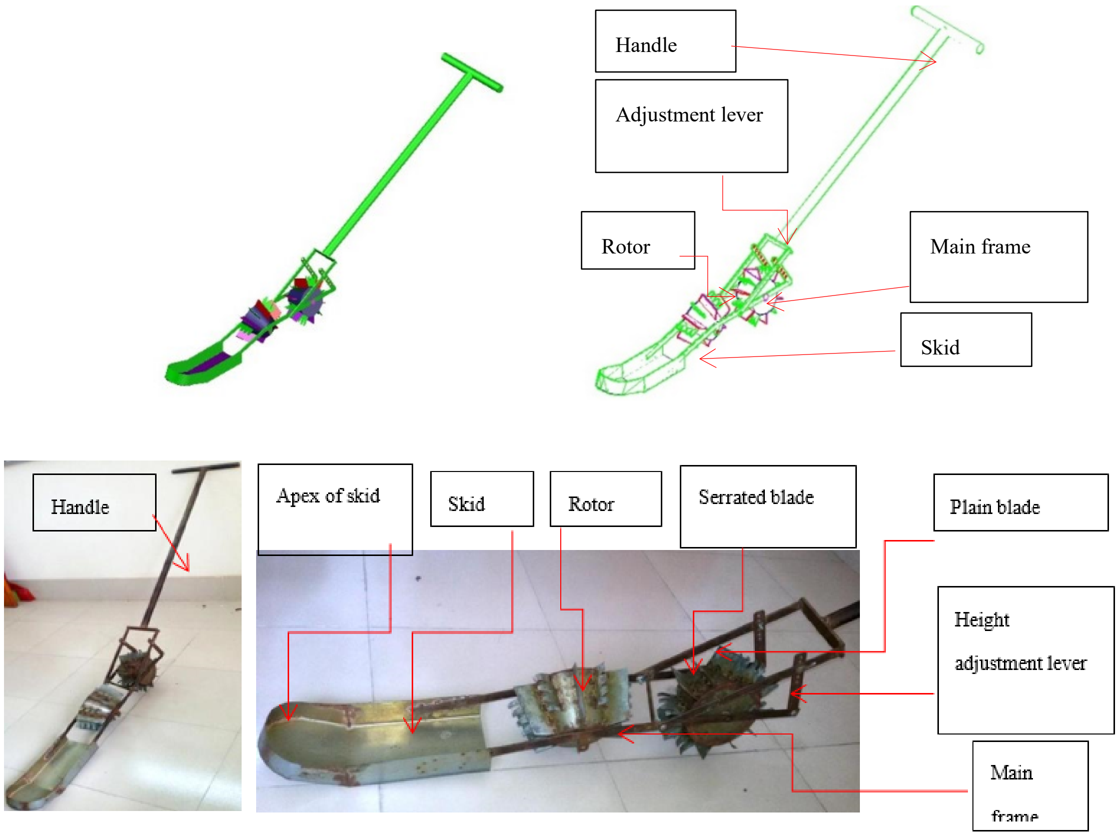

Figure 7 Complete isometric and pictorial views of the developed BRRI dual rotor weeder.

2.3 Operational pre-conditions

Several operational protocols should be adhered to for optimal performance, including:

Handle height varies from operator height, making height adjustment crucial for efficient field operation;

Dual rotor weeder design force is pushing and pulling.

Weeding will result from any pushing or pulling action; therefore, a minimum of 2 to 4 cm of standing water must be maintained during field operations.

Maintaining soft soil will facilitate the weeder's work and ensure proper weeding; a standard walking pace of 1.72 km h^{-1} is recommended.

2.4 Working principles of dual rotor weeder

Two rotors make up a single-row twin-rotor weeder. To effectively uproot weeds, the rotor's forward and backward movements must be parallel to the soil surface at the same time. When the handle height is raised above ground level, the Weeder tends to penetrate rather than move ahead. When the height grew, the minimum operational force needed to operate the weeder at the lower setting of the adjustment lever also increased. The handle height must be adjusted before use so the operator can comfortably operate the weeder. However, considering the operator's height, the amount of force needed, and the handle's convenience, handle height modification is also crucial. Because of this, when the handle height is raised above ground level, the weeder tends to penetrate rather than move ahead. Therefore, a minor operational force was needed to operate the weeder at the lowest setting of the adjustment lever.

2.5 Theoretical considerations

The weight of the machine, its capacity, the depth of the blade in the soil, leaf cutting, walking speed, field capacity, field condition, ease of operation, weeder adjustment, soil conditions, land topography, field size, and shape were all important considerations when evaluating the performance of a dual rotor weeder.

2.6 Evaluation procedure

2.6.1 Site characterization and experimental setup

The field trial was conducted in Jogitola, Gazipur (Latitude and longitude coordinates are: 23.999941, 90.420273), Bangladesh, and at the Bangladesh Rice Research Institute (BRRI) (Latitude: 23°59'35.88"; Longitude: 90°24'27"). With just one power tiller operation, the field was prepared. An evaluation of the effectiveness of weeding in a rice field was conducted using hand transplanting and a row spacing of 20 cm. In the experimental field, grassy weeds predominated more. The field had two to four centimeters of standing water. The plants ranged in height from 28 to 50 cm (Table 1).

Table 1 Condition of the field

Parameters/ Items	Jogitola, Gazipur	BRRI, Research field
Depth of standing water (cm)	2-4	2-3
Type of predominant weed	*Scirpus maritimus*	*Scirpus maritimus*
Size of weeds (cm)	13-23	15-24
Stage of maturity of crop, days	28	32
Row spacing of crop, cm	20	20
Plant height (cm)	28-37	34-50

2.6.2 Machine parameters

2.6.2.1 Travel/ walking speed (km h^{-1})

The machine travel speed during the weeding operation was measured by timing how long it took to cover a 10 m row length. Five readings were obtained for each procedure, and the average was calculated. The time in seconds was recorded using a digital stopwatch.

2.6.2.2 Effective working width (mm)

Both the Weeding and the Weeder have the same effective width. Although the tested weeder's effective width was marginally less than the theoretical actual width, the genuine working width of the weeder was measured at 130 mm. A 5-meter steel tape was used to measure the weeding's precise coverage.

2.6.2.3 Actual field capacity

Measurements were taken of the developed weeder's actual field capacity in the research areas. The machine running duration considered the weeder's turning time, operator time, adjustment time, re-starting time, and other factors to calculate the weeder's actual field capacity. It is the ratio of the machine's actual average field coverage rate to the whole operating time (Hunt, 1995). Therefore,

$$C = \frac{A}{T} \quad (1)$$

Where,

C= actual field capacity in ha h^{-1};

A=area of weeding in hector;

T= time of weeding in h.

2.6.2.4 Theoretical field capacity

Theoretical field capacity is the rate of field coverage obtained if the weeder is operating without interruptions. It is based on theoretical width and speed. The theoretical field capacity was calculated using the relationship given below:

$$\text{Theoretical field capacity (ha h}^{-1}) = \frac{Width\ of\ the\ implement\ (m) \times speed\ of\ operation\ (km\ h^{-1})}{10} \quad (2)$$

2.6.2.5 Field efficiency

The field efficiency was calculated using the equation:

$$\text{Field efficiency (\%)} = \frac{Actual\ field\ capacity\ (ha\ h^{-1})}{Theoritical\ field\ capacity\ (ha\ h^{-1})} \times 100 \quad (3)$$

2.6.2.6 Weeding efficiency

Before weeding, the average number of weeds per square meter area should be ascertained. Similarly, the number of weeds left out per square meter can be counted. Five days following the conclusion of the weeding test. The quantity of weeds removed will be indicated by the difference between the two, and the weeder's efficiency can be calculated using the following formulas (Remesan et al., 2007).

$$\text{Weeding efficiency} = \frac{Number\ of weedes\ eliminated\ per\ m^2}{Total\ number\ of\ weeds\ present\ per\ m^2} \times 100 \quad (4)$$

$$WE = \frac{W1-W2}{W1} \times 100 \quad (5)$$

Where,

WE = efficiency of weeding in percentage;

$W1$= population of weeds before the operation;

$W2$= population of weeds after the operation.

2.6.2.7 Damaged tiller rate

The percentage of rice tiller breakage was determined using the following equation (Muralidharan and Pasalu, 2006):

$$DTR = \frac{T1-T2}{T1} \times 100 \quad (6)$$

Where,

DTR = damage of tiller in percentage;

$T1$= tiller number before weeding;

$T2$= tiller number after weeding.

2.6.3 Weight measurement

The weeder's weight is crucial for both portability and efficient operation. Its weight was recorded after being measured with a balance in the FMPHT division's workshop at BRRI: 5.4 kg.

2.6.4 Pushing force measurement

In the field, three individuals, a spring balance, and a rope were used to determine the force necessary for the operation. While one person pulled the weeder, another recorded the spring balance data, and a third person just held the weeder's handle and guided the path of action while the weeder was being pulled (Figure 8).

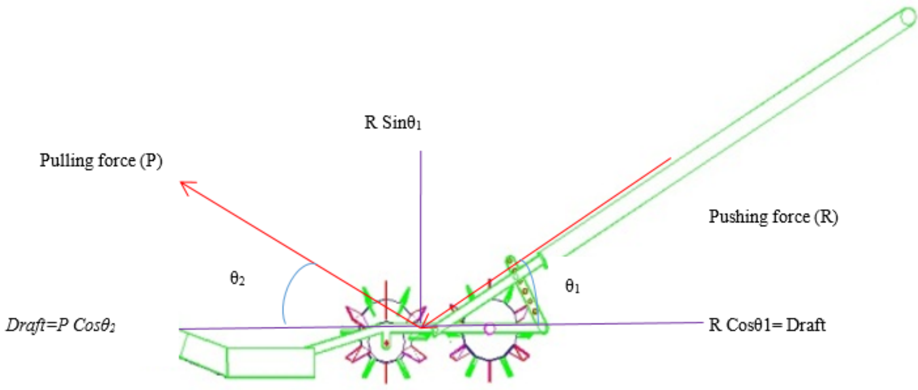

Figure 8 Force measurement of dual rotor weeder

$$Draft = Pulling\ force\ (P) \times cos\theta \quad (7)$$

$$Pushing\ force\ (R) = \frac{Draft}{Cos\theta} \quad (8)$$

2.7 General features and detailed specifications of the weeder

The general features and specifications of the weeder were presented in Tables 2 and 3, respectively.

Table 2 The general features of the BRRI dual rotor weeder

Sl.No.	Particulars	Specification
1	Function	For weeding in between rows of lines sowing paddy crop
2	Power	Manually operated
3	Number of operators	One person
4	Type of operation	Push Pull Operation
5	Operating Condition	Water must be more in the field at the time of weeding
6	Number of rows	Single Row
7	Weight	5.4 kg.
8	Width of operation	130-150 mm
9	Number of rotors	2 Nos.
10	Blades	Rotors are made of 20 gage M.S sheet. 1.2 mm thickness Each rotor has the following blades (20 gage M.S sheet) i) 6 numbers of plain blades & ii) 6 numbers of serrated blades
11	Rotor holder Spindle/ axle and nail	2 Nos. 12 mm diameter and 118 mm length with 24 mm diameter head on the top of the spindle/axle
12	Skid/float Assembly	1.2 mm thickness of 20 gage M.S sheet used Size: 220 ×121×62 mm with front 140 mm length of skid apex Float angle 25 Degrees.
13	Handle	Main Pipe: Diameter: 26 mm Length: 1363 mm Cross Bar: Diameter: 26 mm; Length: 303 mm
14	Height adjustment lever	2 Nos Length: 160 mm; width 20 mm; thickness: 4 mm
15	General Information	The BRRI dual rotor weeder has two cone-shaped rotors mounted in tandem with opposite orientations. Smooth and serrated blades are mounted alternately on the rotor to uproot and bury weeds when the rotors create a back-and-forth movement in the top 3 cm of soil.

Table 3 The detailed specifications of the BRRI dual rotor weeder

Sl. No.	Name of the components	Number	Size (mm)	Materials used
1	Handle	01	Length: 1363 and Diameter: 26	26 mm dia. G.I. pipe
2	Handlebar	01	Length: 303 and Diameter: 26	26 mm dia. G.I. pipe
3	Rotor	02	Length: 103, Larger Diameter: 140 and Smaller Diameter: 92	20-gauge M.S sheet
4	Rotor to Rotor distance	-	260	-
5	Blade in each rotor	12 (6 Plain blades and six serrated blades	Plain blade Length: one side 100 and another side 80, Width: 45 & Thickness: 1.2 Serrated blade length: 65, Width: 45	20-gauge M.S sheet
6	Blade angle	-	90 degrees toward motion from the vertical line	
7	The main axle or spindle in each rotor	01	Length (L): 118, Diameter of top: 24 & Diameter of axle/spindle: 12	M.S. Shaft
8	Bush in each rotor	02	Large bush Length:107, Inner diameter: 6 and Outer diameter:13 Smaller bush length: 12, Outer dia:13, Inner diameter: 6 with another side tapped.	M.S. Shaft
9	Height adjustment lever	02	Length=160, width 20 with 4 mm thickness	M.S. flat bar
10	Joint nut-bolt	06	Diameter 6 mm	-
11	Skidder	01	Width: 121, Length: 220, Front 140, 25 degrees up from baseline. Side wall height 62, front side wall 40, front radius 58	20-gauge M.S sheet

2.8 Cost estimation

The operational costs of the dual rotor weeder were calculated using a structured approach that considered both fixed and variable costs:

2.8.1 Fixed costs

Annual depreciation: calculated using the straight-line method:

$$D = \frac{P-S}{L} \tag{9}$$

Where:

P= the purchase price of the weeder;

S= salvage value (10% of purchase price);

L= working life in years;

Interest on investment:

$$I = \frac{P+S}{2} \times \text{ Interest rate} \tag{10}$$

where:

I = Interest on investment;

A standard annual interest rate of 12% was applied.

The total fixed cost was derived by summing depreciation and interest, then expressed on a per-hour and per-hectare basis based on annual working hours and field capacity.

2.8.2 Variable costs

(1) ***Labor Costs:*** Based on the labor rate (\$ day^{-1}) and converted to per-hour and per-hectare rates using the average workday of 8 hours and the field capacity.

(2) ***Repair and Maintenance:*** Assumed negligible for this calculation.

Total variable costs were the sum of labor costs and any repair and maintenance costs, expressed on a per-hour and per-hectare basis.

2.8.3. Operating costs

(1) ***Hourly Operating Cost:*** Sum of total fixed cost per hour and total variable cost per hour.

(2) ***Hectare Operating Cost:*** Sum of total fixed cost per hectare and total variable cost per hectare.

The calculations were based on an average field capacity and an 8-hour workday.

3 Results and discussion

3.1 Field performance of the weeder

An on-farm field trial was done in one unused research plot of the agronomy division, where many weeds were found. Weeder could properly uproot the weeds in the field (Figure 9). Seven days later, the weeding operation of that field found only a few weeds. Maximum weeds were uprooted and buried by the conical weeder. Another attempt was made to test the weeder in the research field of the IWM division to observe the performance of the weeder and determine whether it works well. The operator believed the BRRI conical weeder worked well and could properly uproot and bury the field's weeds. He also said that this weeder is needed for the field's weeding.

Figure 9 On-farm field test

Figure 10 Field performance of the dual rotor weeder

Tables 4 and 5 provide the weeder's (Figure 10) performance. The machine's output influenced person-to-person interactions. Calculations and tabulations were made on the specific area coverage (m^2), the time needed, theoretical field capacity, actual field capacity, field efficiency, weeding efficiency, and plant/leaf damage during a weeding operation using a single-row double rotor weeder.

3.2 Capacity of the weeder

The comparison of theoretical and actual field capacities in Jogitola and the BRRI research field in Gazipur reveals that the developed weeder performed efficiently in both locations. The actual field capacity in Jogitola (0.0204 ha h^{-1}) was slightly lower than in the BRRI research field (0.0206 ha h^{-1}), indicating that controlled conditions, such as lower weed density and more favorable soil texture at BRRI, contributed to improved efficiency (Figure 11). These results align with findings from Chauhan et al. (2017), who reported that mechanical weeder capacity ranged from 0.017 to 0.023 ha/h, depending on operational factors such as soil conditions and weed density. Similarly, Chakraborti et al. (2016) found capacity between 0.018 to 0.021 ha h^{-1}, with variations based on field conditions. The slight difference between theoretical and actual capacities reflects real-world challenges such as turning time and soil softness. Compared to manual weeding, which has lower field capacities (0.014 to 0.019 ha h^{-1}), as Rahman and Uddin (2019) reported, the mechanized weeder showed clear advantages. The field capacity results from the BRRI research field also align with Singh and Srivastava (2017), who reported optimal capacities of up to 0.023 ha h^{-1} under favorable conditions. This highlights the weeder's consistent and effective performance across varying environments.

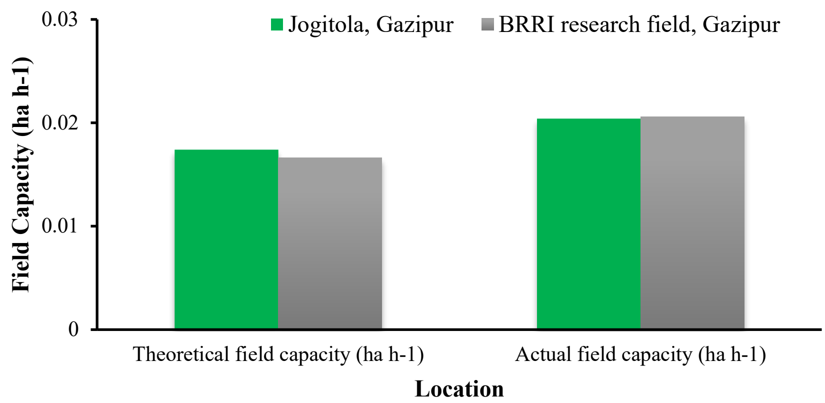

Figure 11 Capacity of the dual rotor weeder

Table 4 Field performance of the developed weeder

Sl. No.	Actual/Effective field capacity (ha h^{-1})	Degree of weeding / weeding efficiency (%)	Plant damage (%)	Walking speed (km h^{-1})
		Operation in Jogitola, Gazipur		
01	0.017	82.41	2.2	1.2
02	0.021	83.55	1.94	1.32
03	0.019	82.23	1.57	1.23
04	0.022	81.26	2.03	1.57
05	0.023	83.96	1.46	1.37
Average	0.0204	82.682	1.84	1.338
		Operation in BRRI research field, Gazipur		
01	0.018	82.18	1.45	1.28
02	0.023	79.85	1.80	1.37
03	0.021	82.21	2.22	1.16
04	0.022	81.96	2.15	1.24
05	0.019	82.82	2.16	1.35
Average	0.0206	81.804	1.96	1.28

Table 5 Field capacity and efficiency of the dual rotor weeder

Sl no.	Location	Theoretical field capacity (ha h^{-1})	Actual field capacity(ha h^{-1})	Field Efficiency %)
1	Jogitola, Gazipur	0.0174	0.0204	85.29
2	BRRI research field, Gazipur	0.0166	0.0206	80.58
	Average	0.017	0.0205	82.935

3.3 Field efficiency

The observed variations in field efficiency between Jogitola, Gazipur, and the BRRI research field can be significantly attributed to turning time losses. In the BRRI research the field efficiency of the dual rotor weeder was recorded at 80.58%, and it increased to 85.29% in the farmer's field at Jogitola (Figure 12). This discrepancy suggests that field conditions and the nature of turning operations significantly impact efficiency. Similar patterns have been noted in other studies, where field efficiency is affected by operational speed and turning times. Karim et al. (2020) highlighted that field efficiency tends to decrease in more structured research environments due to frequent turning losses, with efficiencies averaging around 78% to 82%. On the other hand, in real-world farming conditions, efficiency can be higher due to more open spaces and less restricted turning requirements. Ali and Rahman (2019) observed that mechanized weeders in farmer fields could exhibit up to 86% efficiency under optimal conditions, supporting the current findings. When averaging the efficiencies from both locations, the overall field efficiency was 82.935%, which highlights the need to reduce turning time losses and improve operational effectiveness across varying field conditions.

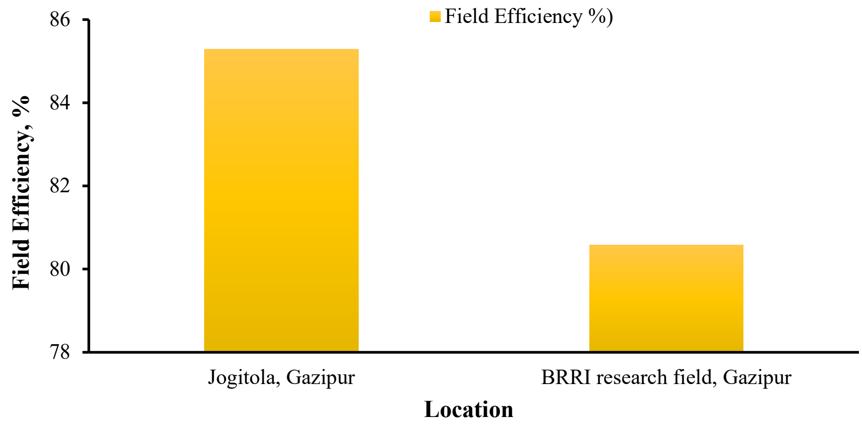

Figure 12 Field efficiency of the dual rotor weeder

3.4 Weeding efficiency or degree of weeding of the weeder

The weeding efficiency (WE) of the developed weeder, evaluated across the BRRI research field and farmer fields in Jogitola, Gazipur, was 82.68% and 81.80%, respectively (Figure 13). These results reflect the influence of several operational and environmental factors, including weed density, soil moisture, weeding regime, and the conditions of the operator and soil. The slight variation in efficiency between the two locations can be attributed to differences in field conditions, which tend to impact the weeder's effectiveness. As Roy et al. (2018) noted, soil moisture and weed severity play crucial roles in determining the effectiveness of mechanical weeders. High soil moisture can cause the weeder to be less effective in uprooting weeds, which may explain the slightly lower efficiency in the farmer’s field. Similarly, Kumar and Patel (2019) noted that weeding efficiency decreases as weed density increases, further highlighting the importance of maintaining optimal field conditions for effective mechanical weeding. The weeder achieved an efficiency level above 80% in both locations, demonstrating its capacity for effective weed control in varying environments. These findings suggest that while mechanical weeders can be highly efficient, managing variables such as weed severity and soil conditions remains crucial to maximizing their potential.

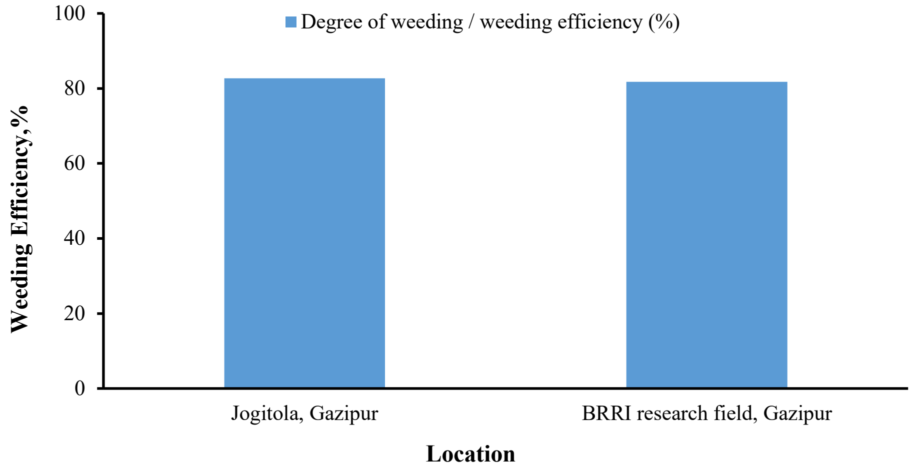

Figure 13 Weeding efficiency of the dual rotor weeder

3.5 Plant or tiller damage

The weeder demonstrated minimal plant damage during operation, with recorded tiller damage rates of 1.96% in the BRRI research field and 1.84% in the farmer's field in Jogitola, Gazipur (Figure 14). The average plant damage of 1.9% suggests that the weeder efficiently controls weeds while preserving crop health. Such low levels of damage are crucial for ensuring that the weeding process does not compromise yield or the growth of surrounding crops. Rahman et al. (2020) reported that acceptable plant damage levels for mechanized weeders should remain below 2%, which aligns with the current study's findings. The minimal crop disruption highlights the weeder's suitability for large-scale farming operations where maintaining crop integrity is paramount. Similarly, Ahmed and Ali (2019) found that plant damage rates of 1.5%-2.0 % in mechanized weeding systems were acceptable for sustainable farming practices, further supporting the effective integration of the weeder into crop management systems. The results demonstrate that mechanical weeders can significantly reduce the risk of damaging crops while achieving effective weed control, provided that they are correctly calibrated and operate with optimal efficiency, making them highly suitable for modern agriculture.

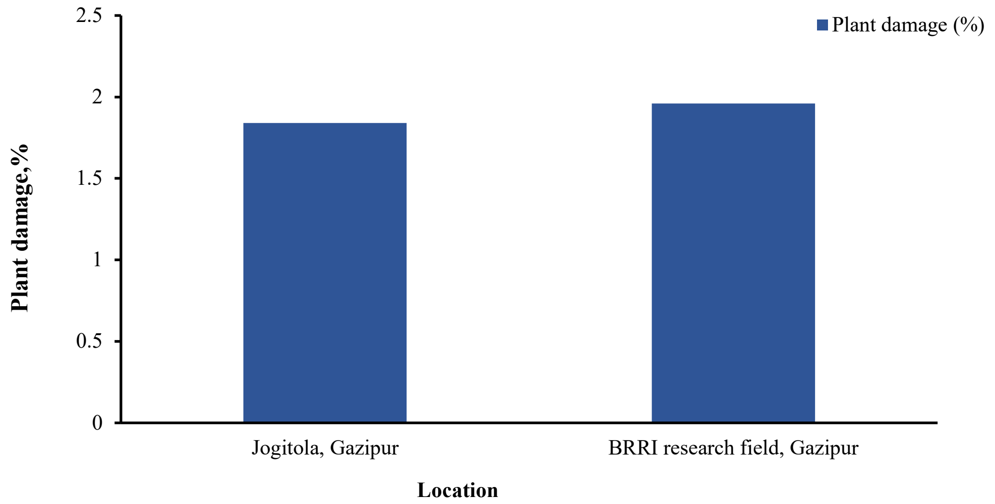

Figure 14 Plant damage of the dual rotor weeder

3.6 Pushing force of weeder

The pushing force data for the BRRI dual rotor weeder, as summarized in Table 6, an average pushing force of 34.66 N. The measurement of this force, illustrated in Figure 8, was determined through trials where the pushing angle was set at 30°, and the pulling force ranged from 3.3 to 3.8 kg. The pushing force values in these trials ranged from 32.40 N to 37.27 N.

When compared with the findings of Paul et al. (2023), which reported a pushing force of 43.42 N for the BRRI conical weeder, it is evident that the dual rotor weeder requires less effort for operation. This lower pushing force indicates a potential advantage in terms of operator fatigue and ease of use, making the dual-rotor weeder more efficient in certain field conditions. These variations in pushing force between weeder models highlight the importance of understanding force metrics when evaluating agricultural machinery. Machines requiring a lower pushing force, such as the dual-rotor weeder, can improve operator comfort and reduce fatigue during extended field operations. This is crucial in optimizing weeders' performance, as ease of operation directly impacts productivity and overall field efficiency.

Table 6 Pushing force measurement of the weeder

Obs. No.	Pulling force (kg)	Pulling angle (°)	Pushing angle (°)	Draft (kg)	Pushing force (N)	Average pushing force (N)
1.	3.8	0	30	3.29	37.27	
2.	3.5	0	30	3.03	34.32	34.66
3.	3.3	0	30	2.86	32.40	

Table 7 Cost items and operating cost of single-row dual rotor weeder

Items	Parameter	Amount	
		Tk	USA $
Fixed cost items	Purchase price of weeder (P), Tk or US$	1500	13.64
	Salvage value(S), Tk (10% of P), Tk or US$	150	1.36
	Working life (L), yr	5	
	Average working hours per year	480	
Variable cost items	Labour (Tk or US$ h^{-1})	62.5	0.57
	Repair and maintenance (Tk or US$ yr^{-1})	0	
	Field capacity (ha/h)	0.0205	
	Calculations		
Fixed costs	Annual depreciation, $D=(P-S)/L$, (Tk or US$ yr^{-1})	270	2.45
	Interest on investment, $I=(P+S)/2$*I, where rate of interest is 12%	99	0.9
Total fixed cost	(Tk or US$ yr^{-1})	369	3.35
Total fixed cost	(Tk or US$ h^{-1})	0.77	$7x10^{-3}$
Total fixed cost	(Tk or US$ ha^{-1})	37.56	0.34
Variable cost	Labour (Tk or US$ h^{-1})	62.5	0.57
	Repair and maintenance (Tk or US$ h^{-1})	0	
Total variable cost	(Tk or US$ h^{-1})	62.5	0.57
Total variable cost	(Tk ha^{-1})	3,048.78	27.72
Operating cost	(Tk or US$ h^{-1})	63.27	0.58
Operating cost	(Tk or US$ ha^{-1})	3,112.05	28.29

Note: Average workday = 8 h at 0.0205 ha per h; Labor/operator charge = 500 Tk day^{-1}, 1 USA $ = 110 BD TK.

3.7 Cost of operation

The pricing of the dual rotor weeder is subject to variations influenced by factors such as the quality of materials used, including MS pipe, MS flat bar, MS sheet, plain sheet, and nut-bolt specifications. Typically, the estimated cost of the developed weeder is around $ 3.64. To further assess its economic viability, the operational cost of the dual rotor weeder was evaluated in terms of field capacity and area coverage. As outlined in Table 7, the total operating cost, incorporating fixed and variable expenses, was calculated at 0.58 USA $ h^{-1} for the conical weeder. When expressed in terms of USA $ ha^{-1}, the operating cost for the weeder amounts to 28.29. These figures offer valuable insights into the economic considerations associated with deploying the weeder, aiding stakeholders in decision-making regarding its adoption and integration into agricultural practices.

4 Conclusion

The study successfully developed and tested a manually operated, push-pull single-row, double-rotor weeder designed specifically for rice fields in Bangladesh. The weeder, fabricated using locally available materials, demonstrated significant potential in improving weeding efficiency while reducing the labor and time required for manual weeding. It offers a practical solution for farmers with a weeding efficiency of 81%-82% and an effective field capacity of 0.0205 ha h^{-1}. The low operating cost of Tk 3,112 per hectare further highlights its economic viability for small and medium-scale farmers. The conical rotors, combined with plain and serrated blades, ensure effective weed uprooting and burial, while the push-pull design makes it easy to operate and maintain. This innovation addresses the need for more efficient weed control methods in rice farming, providing a sustainable alternative to traditional manual weeding and herbicide use. The weeder's adaptability to various field conditions and ease of use suggests its potential for widespread adoption, contributing to the modernization of agricultural practices in Bangladesh. Overall, the dual rotor weeder represents a significant advancement in farm mechanization, offering a cost-effective and user-friendly solution to enhance productivity in rice cultivation.

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