Design and development of a double-row weeder for rice field: Eco-Friendly weed management solution

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Abstract: Agricultural mechanization and technology adoption are rapidly increasing in Bangladesh, particularly in the context of weed management. This study addresses the pressing need for efficient and labour-saving methods by designing and developing a manually operated double-row weeder tailored to the specific conditions of Bangladesh. The weeder is designed to clean weeds between field rows, optimizing the weeding and mulching processes. The hypothesis guiding the design includes a line-to-line distance of 20 cm, a push-pull action, and an operating condition of 3~5 cm of standing water to soften the field. The weeder incorporates essential elements such as a skid/float, float holder, main body frame, rotor, axel, bush, rotor holder, rotor holder adjuster, handle, handle holder, handle height adjuster, handle arm, handle arm jointer, nut, bolt, and more. For fabrication of the weeder, MS sheet, MS pipe, MS flat bar, MS nut-bolt, and other materials were used. The weeder features four rotors with six blades in each drum, strategically positioned for optimal weed uprooting and burial. The precise two mm-thick float assembly, set at a 20° angle, ensures smooth operation. With an efficient field capacity of 0.037 ha.h^{-1}, the weeder demonstrates an efficiency of 76.88%. The weeder weight is 7.5 kg, which helps pulverize the topsoil and enhance soil aeration. The developed weeder holds excellent potential for farmers in Bangladesh, offering improved comfort and reduced labour in weeding and mulching operations.

Keywords: Double-row Weeder; Weed; Rice; Field Capacity; Weeding Efficiency.

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1 Introduction

The staple crop of Bangladesh, rice, plays a vital role in the nation's food security and economic well-being (Gurung et al., 2016). However, a significant obstacle for rice farmers is managing weeds through mechanized farming (Nath et al., 2017). These unwanted plants compete fiercely with rice for crucial resources like water, nutrients, and sunlight, reducing yield substantially (Paul et al., 2022). Studies estimate that weeds can be responsible for up to 30% of all pest-related losses (Rana and Rana, 2016). Their presence not only hinders growth but can also negatively impact the quality of the harvest, ultimately affecting its market value (Nath et al., 2021). Effective weed control thus becomes essential to ensure food security for a growing global population (Paul et al., 2023).

Despite being a crucial step in rice production,

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weed control in Bangladesh remains a challenge due to its reliance on manual labor (Milovanovic and Smutka, 2018). This backbreaking work, requiring workers to bend for long periods, is time-consuming and leads to back problems. The rising costs associated with manual weeding further burden farmers facing difficulties (Hossen et al., 2011). Traditional methods often fall short, with manual options being labor intensive and chemical herbicides posing health and environmental risks, including developing herbicide-resistant weeds (Hossen et al., 2010).

While manual weeding remains the dominant practice for Bangladeshi rice farmers, it comes with drawbacks. Mechanical weeding, though beneficial for soil aeration and water absorption, can damage the topsoil (Ball and Crawford, 2009). In the 1960s, Japanese manual weeders were introduced, but their effectiveness is limited in heavy soils, and they are not widely accessible to women farmers. The Bangladesh Rice Research Institute (BRRI) has addressed these limitations by developing various weeder models like the BRRI weeder, BRRI Kishan weeder, BRRI wet and dry land weeder, and BRRI conical weeder, which have proven effective (Paul et al., 2022). Beyond these, Bangladeshi weed control methods encompass manual pulling, tools like the Niranee and locally made alternatives, and even chemical herbicides.

Faced with the limitations of backbreaking manual weeding and the environmental risks of herbicides, Bangladesh's agricultural sector urgently needs eco-friendly solutions. The double-row weeder emerges as a beacon of hope, offering a sustainable and efficient alternative. This innovative tool, specifically designed for Bangladeshi rice fields, surpasses traditional methods and single-row weeders by delivering affordability, efficiency, and sustainability – key elements for addressing both agricultural and environmental concerns.

The importance of weed removal, particularly during the early stages of rice growth, cannot be overstated. Weeds fiercely compete with rice plants for vital resources, significantly impacting crop yields (Kaur et al., 2022). The double-row weeder tackles this challenge head-on, promoting not just weed control but also soil health, water conservation, and biodiversity preservation. Furthermore, it aligns perfectly with global initiatives towards sustainable agriculture and climate resilience by minimizing the environmental damage associated with conventional weed management practices.

This introduction sets the stage for a deeper exploration of the double-row weeder's design and development process, highlighting its potential to transform Bangladesh's agricultural landscape. As a sustainable alternative, this technology holds the promise to empower rice farming communities, improve their livelihoods, and safeguard the environment for future generations.

2 Materials and methods

2.1 Materials required

The weeder was designed using readily available, cost-effective materials sourced locally. The engineering design was executed with Solid Works programming, and a prototype was constructed in the Farm Machinery and Postharvest Technology divisional research workshop at the Bangladesh Rice Research Institute (BRRI) in Gazipur, Bangladesh during Boro season,2022 (Latitude: 23°59'35.88"; Longitude: 90°24'27"). Most of the weeder's components were developed and fabricated within the workshop. Specifically, MS sheet (18 gages), MS flat bar, MS shaft, MS pipe, and nuts and bolts were utilized in the fabrication process. Following this, the fabricated weeder underwent rigorous testing in the BRRI research field.

2.2 Data were collected and calculated

Various metrics were assessed using the provided data, including walking speed (km h^{-1}), weeding effectiveness (%), plant damage (%), and field capacity (ha h^{-1}) (Hossen, et al. 2010). These calculations were based on specific criteria:

The time is taken to cover 100 m in the field during the weeding process.

The quantification of weeds in a one square meter plot of land before and after weeding.

The enumeration of plants in a one square meter plot before weeding and, subsequently, the tally of undamaged plants in a similar area post-wedding.

The determination of weeding duration in hours, accounting for any time losses, along with the area covered during weeding in decimal units.

Furthermore, operational comfort and trouble-free performance were essential during the operation.

2.3 Design considerations

The main functions of mechanical weeders are to uproot and trim weed plants, and then disseminate them on the soil surface or bury them in the soil. Manually operated weeders are the finest option for weeding operations in wetland paddy crops. In fabricating the conical weeder, the following considerations were considered:

Ease of weeding;

Easy and simple operation and maintenance;

Distance between rows of the rice field;

Least amount of force;

Locally accessible materials;

Lightweight and easy to handle;

Affordable cost.

2.4 Chronological development of the double-row weeder

The double-row weeder's design incorporates a versatile feature, allowing for individual use in two separate rows if desired. With an extra handle, this adaptation can be easily accomplished. This means that the double-row weeder can be disassembled and utilized as two distinct single-row weeders, providing flexibility and convenience in agricultural operations.

2.4.1 First version

A manually operated double-row weeder was engineered to effectively uproot weeds and mulch soil in two rows of rice fields. This weeder operates using a manual push-pull action, working back and forth within the top 3 centimeters of soil. The rotor, positioned on the periphery, has 21 'Y'-shaped blades strategically mounted alternately. To facilitate the operation of the double-row weeder, a handle is securely attached to the main frame, providing the necessary leverage for exerting push and pull forces. Detailed photographic and drawing views of the initial version of the double-row weeder are presented in Figures 1 and 2, offering a comprehensive visual representation of its design and functionality.

Figure 1 Photographic view of the double-row weeder and its parts (First version)

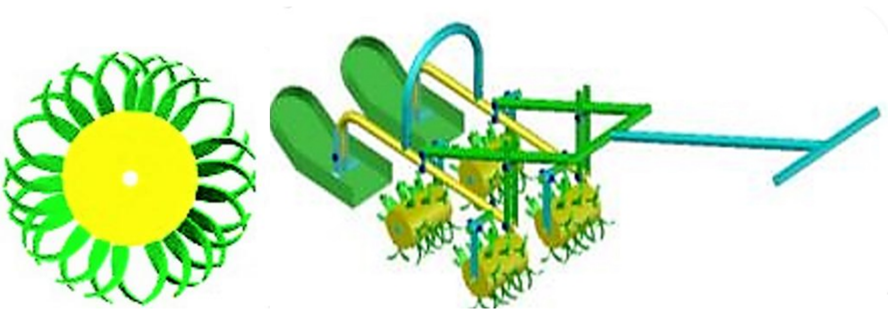
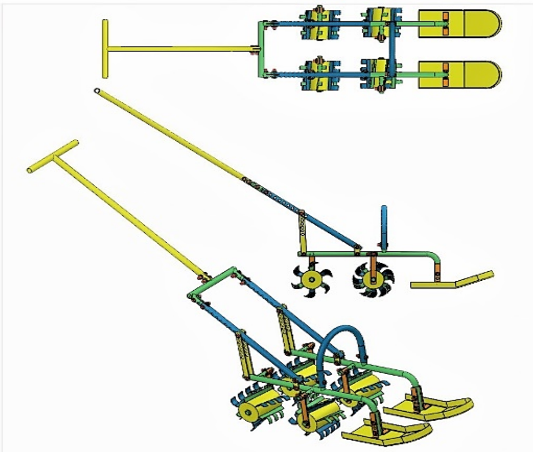


Figure 2 Drawing views of the double-row weeder (First version)

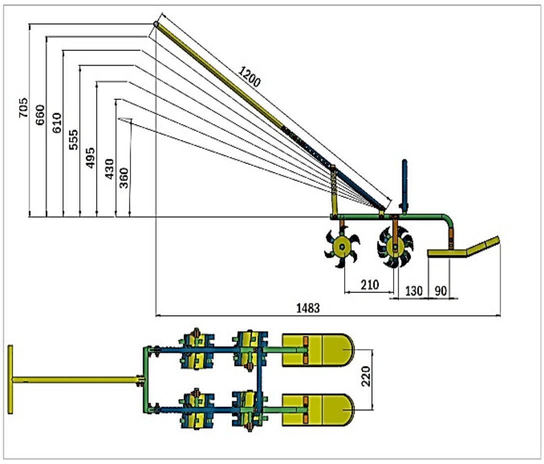
The weeder's initial test took place in the BRRI research field. During the evaluation, it was noted that the weeder successfully uprooted and buried approximately 60%- 70% of the weeds. The operator's feedback on the double-row weeder's performance was moderately positive. While it demonstrated a capability to uproot and suppress weeds in the field, its effectiveness fell short of expectations. As a result, there is a clear need to improve the weeder's uprooting capacity to enhance its overall performance and effectiveness in weed control.

2.4.2 Development and fabrication of different parts of the double-row weeder (Final version)

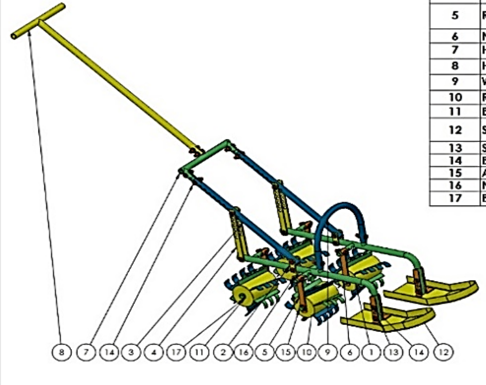
The weeder's width was meticulously designed with a 20 cm line-to-line spacing. In a single pass, the weeder effectively covered a width of 35~37 cm, while the overall width of the weeder itself was set at 40 cm. This selection was based on the row spacing (line-to-line distance) commonly used for transplanted and drum-seeded rice. As the weeder's effectiveness hinges on the width of its weeding tools, four rotary-type cylindrical rotors were employed for this purpose, as illustrated in Figure 3. The width of the rotor was specifically chosen to be 12.5 cm, a dimension calculated to minimize potential damage to the crops during the weeding process.



(a) Top, side, and Isometric view



(b) Views with dimensions



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Main Body Frame	MS Pipe	2
2	Handle Arm Holder	MS flat bar	4
3	Handle Arm	MS Pipe	2
4	Handle Arm Ht. Adjuster	MS flat bar	4
5	Rotor Holder	MS flat bar and pipe	4
6	Nut(Axel)	MS	4
7	Handle arm Adjuster	MS flat bar	1
8	Handle	MS pipe	1
9	Weeder lifter	MS pipe	1
10	Rotor	Sheet metal	4
11	Bush (Rotor)	MS	4
12	Skid	MS Sheet and flat bar	2
13	Skid Holder	MS flat bar	4
14	Bolt(10)	MS	24
15	Axel	MS shaft	4
16	Nut(10)	MS	24
17	Bush	MS pipe	2

(c) Bill of materials (BoM) of the designed double-row

Figure 3 Drawing views of the designed double-row weeder (Final version)

2.4.2.1 Skid or float

At the front end of the weeder, two skids or floats have been integrated, both crafted from mild steel sheets with a thickness of 2 mm. These skids serve a dual purpose - they prevent the weeder from sinking into soft, muddy soil while facilitating smooth movement. Additionally, they play a crucial role in distributing the weight of heavy loads carried by the weeder. The deliberate dimensions of the skid, measuring 312 mm in length and 120 mm in width, were carefully chosen to optimize performance. The inclination section of the skid extends to a length of 142 mm. This section and the skid holder constitute the complete skid component.

The front inclined portion of the skid is positioned at a 20-degree angle concerning the horizontal, a design choice to enhance the weeder's maneuverability. Moreover, the skid holder is affixed to the main body structure of the weeder, utilizing an "L" shaped flat bar with a length of 103 mm and a thickness of 3 mm, featuring three 10 mm diameter holes securely welded to the skid. A nut-bolt coupling in this skid holder firmly connects the mainframe and skid. To further enhance its functionality, the float features a sidewall height of 27 mm, effectively preventing mud entry from the sides, and a length of 310 mm, ensuring smooth floating action during operation.

Figures 4 and 5 provide a comprehensive visual representation of the skid from various perspectives. The skid's strategic placement and design contribute significantly to the weeder's ability to manage operation depth, easily navigate the soil, and reduce the demand for draft force.

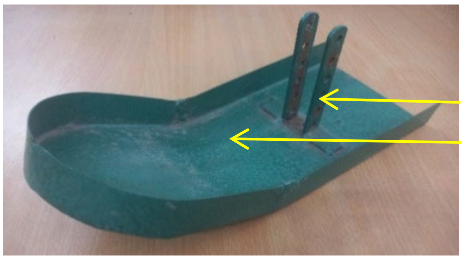
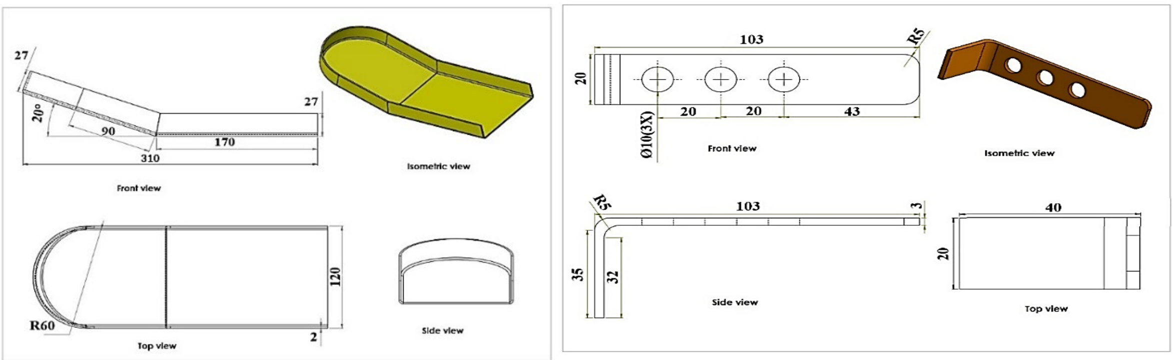


Figure 4 Photographic view of a skid of the weeder with skid holder



(a) Different views of float

(b) Different views of skid holder

Figure 5 Different views of the skid of the weeder

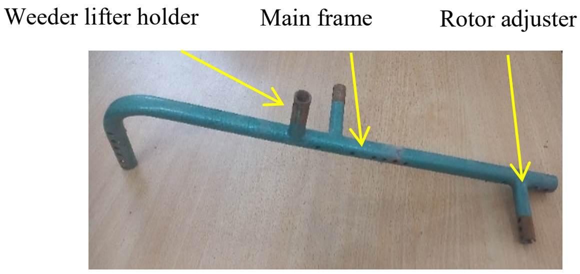
Note: All dimensions are in mm

2.4.2.2 Main body frame assemble

The frame is the foundational structure for accommodating various integral components, including the skids, handle, handle arms, weeder lifter, and weeder rotors. Within the mainframe, features such as the rotor holder adjuster and handle holder are incorporated (Figure 6). The weeder frame is constructed from a 26 mm diameter circular MS pipe, complete with four 10 mm diameter holes designed to adjust the handle pipe and skid holder heights. Additionally, three 10 mm diameter holes are strategically positioned on a 68 mm length of 16 mm round pipes of the mainframe to facilitate the assembly of the rotor holder (arms), enabling modifications to the required operation width.

The main body extends 150 mm from the float's center and spans a straight length of 520 mm. A 90-degree bend in the MS pipe facilitates the connection to the float and the mainframe. Exact adjustments in weeder height and width are achieved through the presence of three strategically placed holes, ensuring precision in the setup. The mainframe is securely fastened with skids and rotors using nuts and bolts, while the handle holder, measuring 50 mm in length, features a single 10 mm diameter hole for the welded nut-bolt connection on the mainframe.

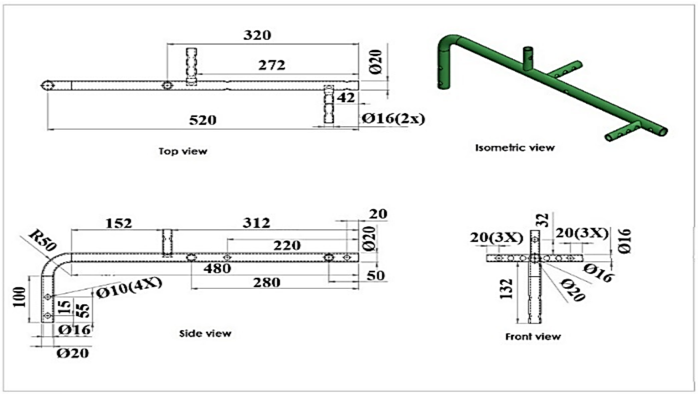
Figure 7 provides detailed visual representations of the main body frame from various angles. To affix the handle to the mainframe, a 10 mm nut-bolt joint is employed, ensuring secure and stable integration.



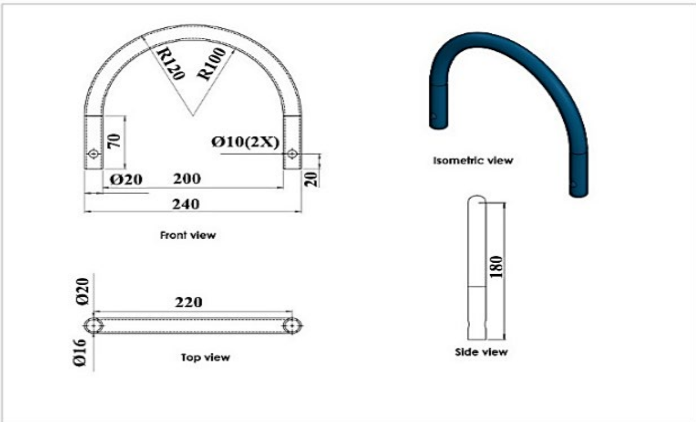
(a) Photographic view of the main

(b) Photographic view of the weeder lifter

Figure 6 Photographic view of the main body frame and the lifter of the weeder



(a) Different views of the main frame of the weeder



(b) Different views of the weeder lifter

Figure 7 Different views of the main body frame assemble the weeder*Note: All dimensions are in mm*

2.4.3 Rotor assemble (Drum, serrated blades, axle/spindle, bush)

The weeder is outfitted with a set of four rotors positioned in a sequential arrangement. Each rotor assembly encompasses essential components such as the rotor drum, serrated blades, axle or spindle, bush, and nut, among others. These cylindrical rotors feature detachable serrated blades (three- and four-toothed) securely welded around their circumference. During the development of the rotating drums, careful consideration was given to factors such as the extent of soil manipulation and achieving optimal coverage between two rows.

The drum was crafted from mild steel (MS), while the blades were also fashioned from the same durable material. To construct the drum, an MS sheet was initially cut to the desired size and then shaped into a cylindrical form, resulting in a drum diameter of 80 mm, as depicted in Figure 11. The sheet metal rotors were intentionally designed with a hollow interior to enhance buoyancy on softer soil. The roller, fashioned from a 125 mm wide MS sheet, necessitated careful precision during the cutting process to ensure proper alignment. Serrated blades, vital for effective weeding, were cut and meticulously positioned on the rotor.

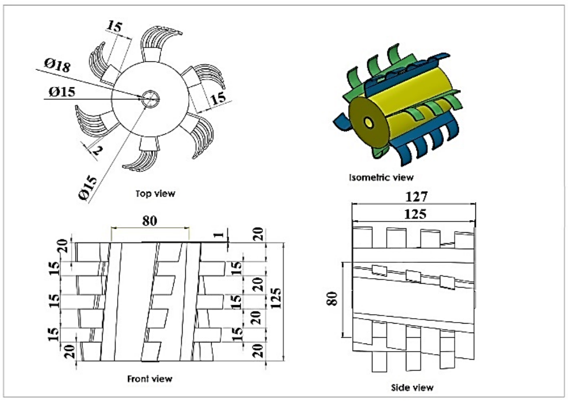
These alternating blades, affixed to the rotor, serve to uproot and bury weeds in the soil as the rotor advances. This design feature enables the manual weeder to weed efficiently in a single forward pass, eliminating the need for a push-pull motion. The blades were forged from a 2 mm thick MS sheet, measuring 125 mm in length and 36 mm in width, as illustrated in Figure 8.

Four axles (spindles) and corresponding bushes were engineered and integrated to complement the rotor system. The spindles boasted a diameter of 15 mm and a length of 140 mm, with a head diameter of 20 mm, as indicated in Figure 9. The bushes, integral components of the rotor assembly, were meticulously designed to fit snugly. Their outer diameter measured 18 mm (with an inner diameter of 15 mm), and their length extended to 127 mm. The bushes were securely welded, ensuring stability and longevity in the rotor's operation.

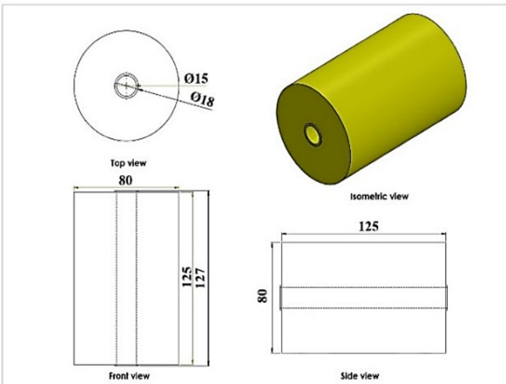
2.2.4 Handle assemble (Handle, handle arm, arm jointer, handle height adjustment leaver)

The length of the handle and its angle of inclination concerning the horizontal surface are intricately connected. The functional design and geometric considerations of the tool determines these factors. To cater to the varying standing elbow heights of male and female workers, an adjustable handle was designed to ensure that the weeder's length aligns with the ideal height, minimizing strain on the operator's back and ensuring continuous operation in a standing position. The handle arm, constructed from a 2 mm thick MS pipe, featured a 690 mm long MS pipe welded at the center of a 250 mm long handle crossbar made of a 20 mm diameter MS pipe, creating a precise 90° angle between them, as depicted in Figure 10. The handle grip was fashioned from the same MS pipe material. Figure 14 provides detailed visual representations of the handle's design.

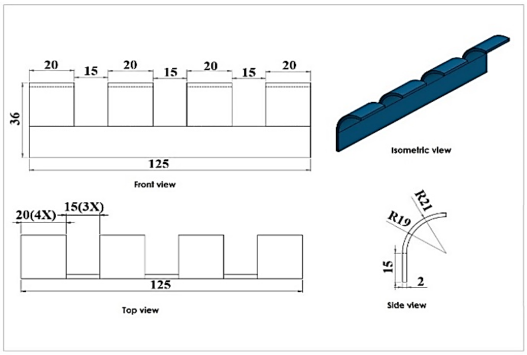
Figure 8 Photographic view of the rotor of the weeder with serrated blades, axle or spindle, and bush



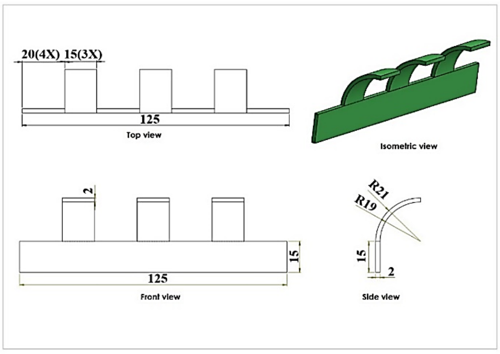
(a) Different views of the rotor



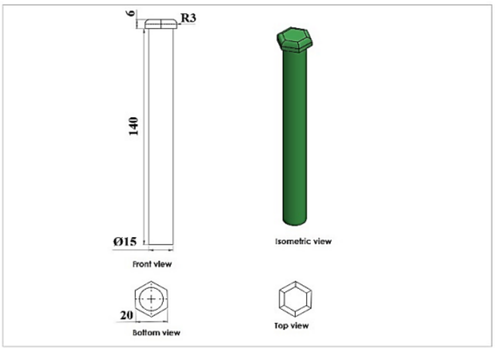
(b) Different views of the drum



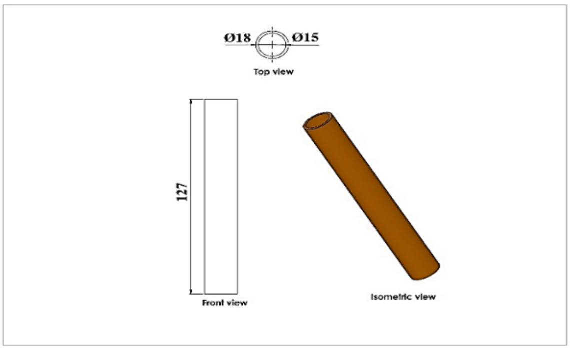
(c) Different views of the four-teethed



(d) Different views of the three-teethed



(e) Different views of axle/spindle



(f) Different views of the bush

Figure 9 Different views of the rotor assembly of the weeder

Note: All dimensions are in mm

The weeder's handle, constructed from a 20 mm diameter MS pipe, was securely attached to the frame. Its maximum height was fixed at 705 mm, with the flexibility for adjustment based on the operator's preference. A lever with seven distinct settings was employed to regulate the handle's height from ground level. In its lowest position, the handle's height from the ground measured 560 mm (Figure 11). Conversely, when the adjustment lever was elevated to the highest setting, it reached a height of 905 mm. The entire length of the handle (1260 mm) and its height from ground level were meticulously calculated to strike a balance between the force required for operation and the operators' comfort. These considerations were crucial in optimizing the ergonomic aspects of the weeder's design.

Handle

(a) Handle

Handle arm jointer

(b) Handle arm jointer

Handle arm

(c) Handle arm

Handle ht. adjustment leaver

(d) Handle ht. adjustment lever

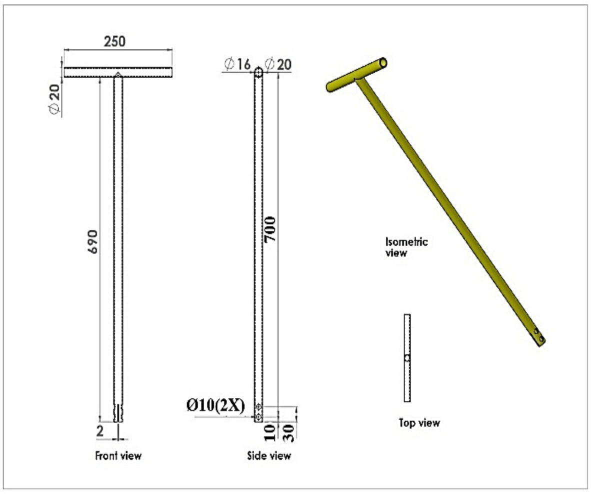
Figure 10 Photographic view of the handle assemblies of the weeder

2.2.5 Rotor Holder

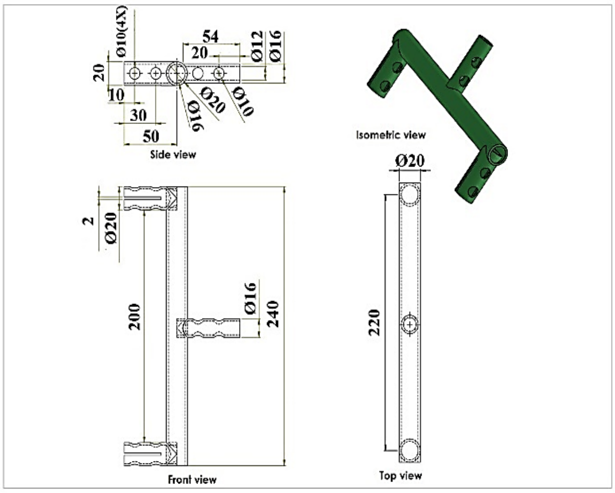
The mounting rotor holder of the weeder played a pivotal role in affixing the weeding unit to the mainframe. In this regard, four-rotor holders, each measuring 140 mm in length, were expertly crafted from a 4 mm thick MS flat bar. Additionally, 26 mm diameter MS tubing, measuring 26 mm in length, was skillfully welded to a 120 mm long flat bar, as shown in Figure 12. To allow for adjustments in the width of operation, a 10 mm hole was created at the upper end of each arm. In contrast, a 15 mm hole was positioned at the lower back, providing the necessary accommodation for the weeding drums at a precise 90° angle. This configuration allows for optimal customization and adaptability in the weeder's operation. Figure 16 offers isometric views of the mounting rotor holder, clearly representing this critical component in the weeder's design.

2.3 General specifications

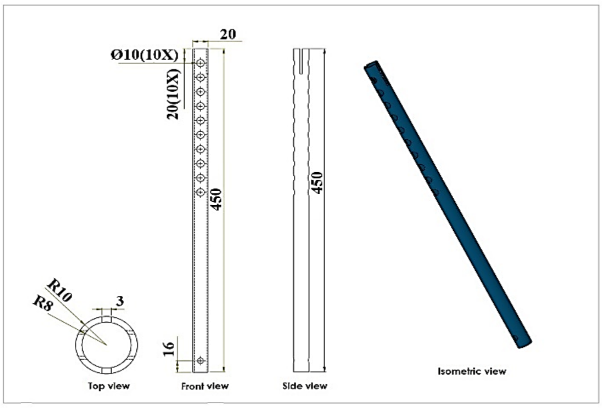
The newly developed double-row weeder weighs 7.5 kg, making it effortlessly maneuverable between four rows in a rice field. This lightweight design ensures that both men and women can easily handle the weeder. Additionally, the fabrication process for this weeder is straightforward and uncomplicated. For detailed information on its general features and specifications, please refer to Tables 1 and 2, respectively.



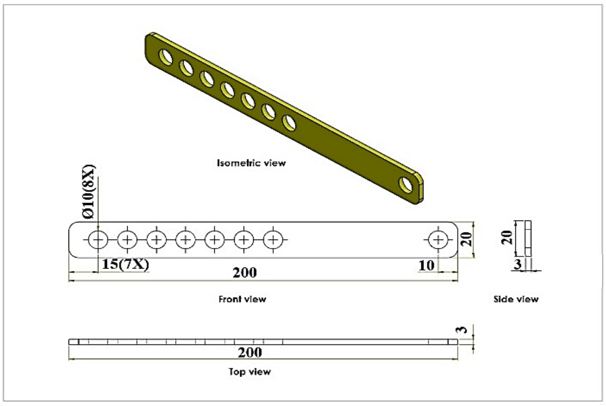
(a) Different views of handle



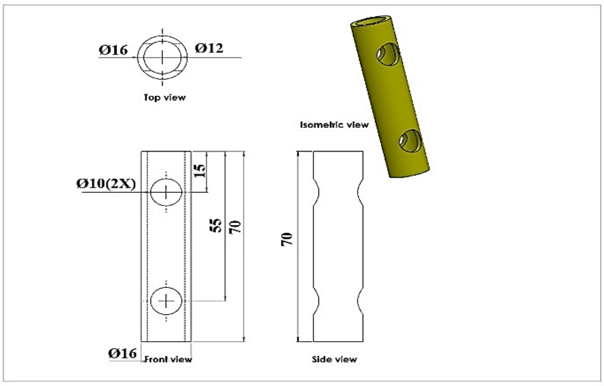
(b) Different views of handle arm jointer



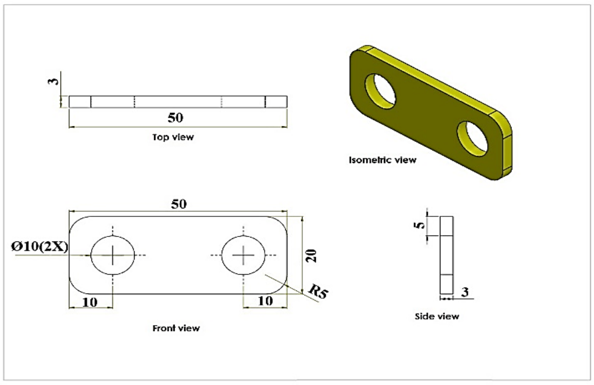
(c) Different views of handle arm



(d) Handle height adjusting lever



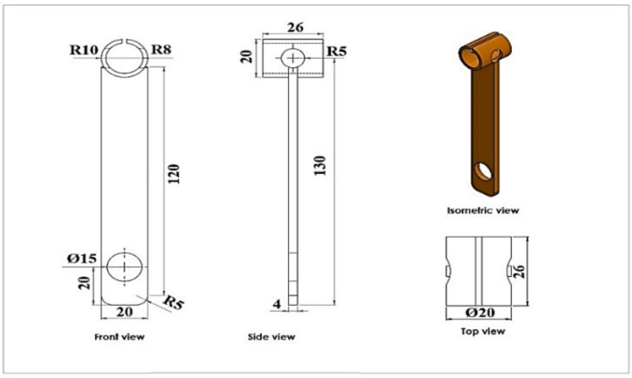
(e) Handle arm joining bush



(f) Handle arm holder

Figure 11 Different views of the handle of the weeder

Note: All dimensions are in mm



(a) Drawing views of the rotor holder

(b) Photographic view of the rotor holder

Figure 12 Rotor holder of the weeder

Note: All dimensions are in mm

Table 1 The general features of the BRRI double-row weeder

S.NO.	Particulars	Specification
1	Function	For weeding in between two rows of line 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	Two rows
7	Weight	7.5kg
8	Width of operation	35-37 cm
9	Number of rotors	4 Nos. Rotors are made of a 20-gauge MS sheet
10	Blades	2 mm thickness Each rotor has the following blades (18 gages MS sheet) i) 12 numbers of three-teethed blades ii) 12 numbers four-teethed blades
11	Rotor holder	4 Nos.
	Spindle/ axle	15 mm dia and 140 mm length with 20 mm diameter head on the top of the spindle/axle
12	Skid/float Assembly	2 mm thickness of 18-gauge M.S sheet used Size: 312 ×120×27 mm with front 142 mm length of skid apex Float angle 20 Degrees.
13	Handle	Main Pipe: Diameter 20 mm; Length 690 mm Griper/Cross Bar: Diameter 20 mm; Length 250 mm
14	Height adjustment lever	4 Nos Length 200 mm; width 20 mm; thickness 3 mm
15	General information	The BRRI double-row weeder has four rotary drums mounted in tandem. Three-teethed and four-teethed blades are mounted alternately on the drum to uproot and bury weeds when the rotors create a back-and-forth movement in the top 3 cm of soil.

Table 2 The detailed specifications of the BRRI double-row weeder

Sl. No.	Name of the components	Number	Size (mm)	Materials used
1	Handle	01	Length: 690, diameter: 20	20 mm diameter MS pipe
2	Handlebar/ griper	01	Length: 250, diameter: 20	20 mm diameter MS pipe
3	Rotor	04	Length: 125, diameter: 80	18-gauge MS sheet
4	Rotor to Rotor distance	-	230	-
5	Blade in each rotor	24	12 Three-teethed and 12 four-teethed blades. Blade length: one side 125, width: 36, thickness: 2	18-gauge MS sheet
6	Blade tip radius	-	21 mm	
7	The main axle or spindle in each rotor	01	Length: 140, diameter of top: 20, diameter of axle/spindle: 15	MS Shaft
8	Bush in each rotor	01	Bush length:127, inner diameter: 15, outer diameter:18	MS Shaft
9	Height adjustment lever	02	Length: 200, width: 20, thickness: 4	MS flat bar
10	Joint nut-bolt	26	Dia 10	-
11	Skid	02	Width: 120, length: 310, front: 142, degrees up from the baseline: 20, sidewall height: 27	18-gauge MS sheet

2.4 Working principles of developed weeder

The push-type weeder's design involves two cylindrical-shaped rotors affixed to each row's right and left sides of the mainframe. A float is installed at the front end to prevent the weeder from sinking into wet soil. An extendable handle provides additional height adjustment capabilities. Before operation, the handle height must be set to ensure optimal comfort for the operator. This adjustment is crucial, considering the operator's height, required force, and ease of use.

This hand-operated manual weeder significantly simplifies the weeding process, allowing for the potential of weeding an entire double row at once. It's important to note that this weeder is designed for wetland use, necessitating an area with ample water. The four six-bladed rotors of the weeder oscillate back and forth, effectively uprooting and burying weeds in the process. Additionally, a 2 mm thick float assembly with a precise angle of 20° ensures its proper functionality. The weeder's blades successfully uproot weeds, which are then buried in the muddy soil through push-pull. This process disturbs the topsoil, promoting improved aeration and creating a more conducive environment for crop growth. It is recommended that the weeder be used in damp and compact soil conditions.

Figure 13 provides a photographic representation of the final version of the developed double-row weeder. This visual reference showcases the weeder's design and features, illustrating its potential impact on effective weed management in agricultural fields.

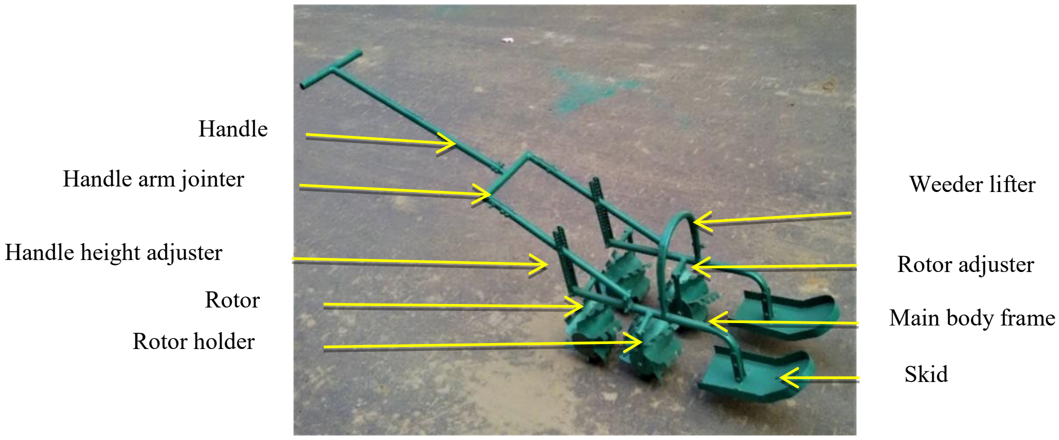


Figure 13 Photographic view of the final version of the designed weeder

2.5 Theoretical considerations

When assessing the performance of a double-row weeder, various factors come into play. These include considerations such as its weight, capacity, blade depth in the soil, effectiveness in cutting leaves, walking speed during operation, overall field capacity, condition of the field being worked on, ease of operation, adjustability of the weeder, soil type, the topography of the land, as well as the size and shape of the field. These elements contribute to the weeder's overall functionality and effectiveness in weed control within a given agricultural setting.

2.6 Evaluation procedure

2.6.1 Site characterization and experimental setup

The field experiment took place in Tarotpara, Gazipur (Latitude and longitude coordinates are: 23.999941, 90.420273), Bangladesh, and at the Bangladesh Rice Research Institute (Latitude: 23°59'35.88"; Longitude: 90°24'27") during Boro season, 2022. The soil composition in the area was identified as clay loam (Table 3) (Hossen et al., 2017).

Table 3 Soil conditions of the experimental fields (0-15 cm)

Characteristics	East bide, BRRI, Gazipur
Soil texture	Clay loam
pH (H_2O)	6.2
Organic matter (%)	1.94
Bulk density, g cm^{-3}	1.22
Particle density, g cm^{-3}	2.56
Soil porosity (%)	47.7

Note: The soil of the research field of east-bide, FMPHT divisional experimental plots, contains 45% sand, 37% clay, and 18% silt.

Manual Transplanting was conducted with a row spacing of 20 cm to evaluate the efficacy of weeding in rice fields. In the designated experimental field, grassy weeds were notably more abundant than other types. The field maintained a water level of 3~5 cm. The rice plants measured between 15 and 20 cm in height, as detailed in Table 4.

Table 4 Condition of the field

Parameters/ Items	Tarotpara, Gazipur	BRRI, Research field
Type of Soil	Clay Soil	Clay loam Soil
Depth of standing water (cm)	3-4	3-5
Type of predominant weed	*Scirpus maritimus*	*Scirpus maritimus*
Size of weeds (cm)	10-15	10-16
Stage of maturity of crop, days	22	25
Row spacing of crop, cm	20	20
Plant height (cm)	15-20	16-20

2.6.2 Machine parameters

An experienced operator was carefully selected to ensure the effective operation of the designed weeder in the field. Weeding activities were carried out approximately 22 to 25 days after the initial crop planting. The study investigated the influence of factors such as blade width, operational speeds, and depth of operation on field capacity, plant damage, and weed control effectiveness, employing relevant mathematical equations for analysis.

To determine the weeder's theoretical field capacity, walking speed was measured without any time losses considered. The computation of the weeder's actual field capacity involved a comprehensive assessment of total field operation time, factoring in turning loss, operator-related time losses, and any additional time spent on system adjustments and troubleshooting. Before and following each field operation, meticulous counts of weeds and tillers were conducted within a pre-selected 1(one) m^2 area. The formula utilized for these assessments allowed for calculating wounded tillers and hills and quantifying weeding capacity and efficiency. This rigorous methodology comprehensively evaluates the weeder's performance in real-world agricultural applications.

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

The time taken to cover a 10 m row length was noted to assess the machine travel speed during the weeding operation. Five measurements were made for each procedure, and the average value was calculated. The time was measured in seconds using a digital stopwatch.

2.6.4 Effective working width (mm)

The effective width of the weeder and the weeding are the same. The actual working width of the tested weeder was 345 mm, although the effective width was slightly smaller than the actual theoretical width. The precise weeding width was determined using a 5 m steel tape.

2.6.5 Actual field capacity

The designed weeder's actual field capacity was measured while operating in the study areas. The machine working period, which included the time required during the weeder's turning, the operator's time, adjustment time, re-starting time, and so on, was used to calculate the weeder's actual field capacity. It is the machine's accurate average field coverage rate ratio to the total time spent in operation (Hunt, 1995). Therefore,

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

Where,

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

A =Area of weeding in ha;

T = Time of weeding in h.

2.6.6 Theoretical field capacity (ha h^{-1})

The theoretical field capacity is the rate of field coverage that would be obtained if the weeder operated continuously. It is determined by theoretical width and speed. The theoretical field capacity was derived using the following relationship:

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

2.6.7 Field efficiency (%)

The field efficiency was calculated using the equation:

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

2.6.8 Weeding efficiency

The average number of weeds present per square meter area before the wedding should be determined. Similarly, the number of weeds left out per square meter can be counted. Five days after the wedding, the test was done. The difference between the two will give the number of weeds eradicated, and the efficiency of the weeder can be calculated using the following formulae (Remesan et al., 2007).

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

$$WE = \frac{W_1 - W_2}{W_1} \times 100 \quad (5)$$

Where,

WE = Efficiency of weeding in percentage;

W_1 = Population of weeds before the operation;

W_2 = Population of weeds after the operation.

2.6.8 Damaged tiller rate

The percentage of rice tiller breakage was determined using the following equation:

$$DTR = \frac{T_1 - T_2}{T_1} \times 100 \quad (6)$$

Where,

DTR = Damage of tiller in percentage;

T_1 = Tiller number before weeding;

T_2 = Tiller number after weeding.

2.6.9 Operational cost

The machine's operating cost (Tk hr-1) was calculated using the method mentioned in Hunt (1973), considering the fixed cost (Tk hr-1) and variable cost (Tk hr-1).

3 Results and discussion

3.1 Field performance of the weeder

This weeder offers the advantage of adjustability, allowing it to function as either a single-row or double-row implement. The performance of the weeder (Figure 14) is presented in Table 5 and Table 6. The effect of the machine's output varied from person to person.

Figure 14 Field performance of the double-row weeder (Final version)

Table 5 Field performance of the double-row weeder

Sl. No.	Actual field capacity, ha h^{-1}	Degree of weeding/weeding efficiency (%)	Plant damage (%)	Walking speed, km h^{-1}
Operation in BRRI research field, Gazipur				
1	0.0368	74.40	2.35	1.131
2	0.0373	76.20	2.12	1.142
3	0.0378	78.34	1.98	1.138
4	0.0370	79.28	2.25	1.136
5	0.0381	78.42	2.15	1.148
Average	0.0374	77.33	2.17	1.139
Operation in Toratpara, Gazipur				
1	0.0366	79.35	2.7	1.134
2	0.0372	79.65	1.83	1.132
3	0.0368	78.34	2.45	1.128
4	0.0376	77.56	2.15	1.134
5	0.0377	78.62	1.96	1.140
Average	0.0372	78.70	2.22	1.134

Table 6 Field capacity and efficiency of the weeder

Sl. no.	Location	Theoretical capacity, ha h^{-1}	Actual field capacity, ha h^{-1}	Field Efficiency (%)
1	BRRI research field, Gazipur	0.0452	0.0374	82.74
2	Toratpara, Gazipur	0.0454	0.0372	81.93
	Average	0.0453	0.0373	82.34

3.2 Capacity of the weeder

The field capacity of the newly developed weeder was meticulously assessed in two distinct locations within the Gazipur district. This evaluation included measuring both theoretical and actual field capacity during operational use, enabling the calculation of field efficiency. The theoretical field capacity was observed to vary in the forward speed of the weeder's operation. Conversely, the actual field capacity demonstrated fluctuations dependent on factors such as soil condition, soil softness, weed density, forward speed, and any turning time loss, among others.

The recorded traveling speed of the double-row weeder ranged from 1134 to 1139 m h^{-1}. In practical terms, the weeder exhibited an effective field capacity of 372 m^2 h^{-1} in the farmer's field, while in the BRRI research field, it demonstrated a capacity of 374 m^2 h^{-1}. Considering these findings, the average field capacity was calculated to be 373 m^2 h^{-1}, as illustrated in Figure 15. This data is a valuable indicator of the weeder's operational efficiency in real-world agricultural applications.

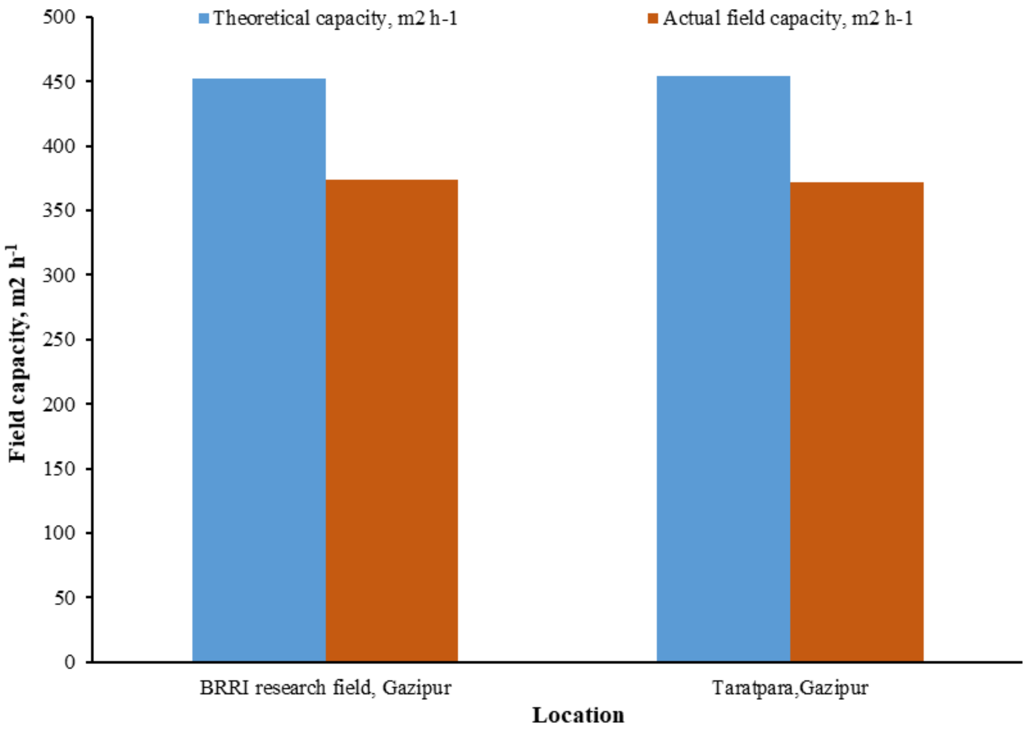


Figure 15 Capacity of the double-row weeder

3.3 Field efficiency

The field efficiency of the different technologies showed variations attributed to total turning time losses. Specifically, when employing a double-row weeder, the field efficiency was 82.74% in the BRRI research field and slightly lower at 81.93% in the farmer's field, as depicted in Figure 16. Considering these results, the average field efficiency across both settings was 82.34%. This data serves as a valuable benchmark for assessing the operational effectiveness of the double-row weeder in real-world agricultural scenarios.

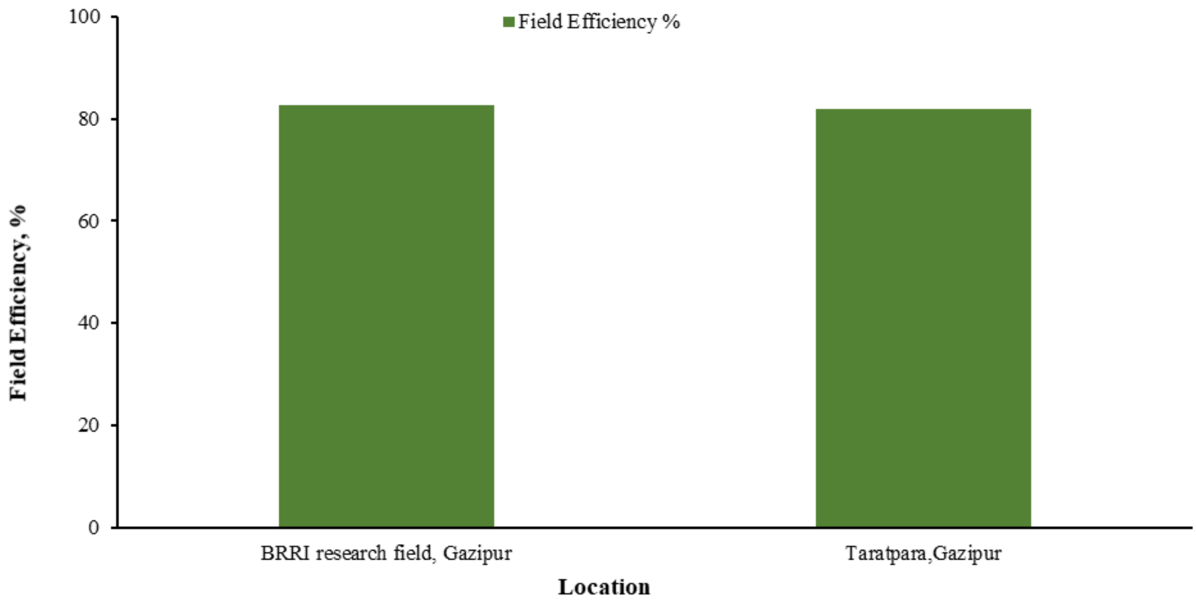


Figure 16 Field efficiency of the double-row weeder

3.3 Weeding efficiency or degree of weeding of the weeder

The efficiency of the weeding process, quantified as weeding efficiency (WE), is influenced by various factors, including weed severity, soil moisture levels, the chosen wedding regimen, operator conditions, and soil characteristics. In both the farmer's field and the BRRI research field, the weeder demonstrated notable effectiveness, achieving a degree of weeding at 78.70% and 77.33%, respectively, as illustrated in Figure 17. These results underscore the weeder's capacity to manage weed populations across different agricultural settings effectively.

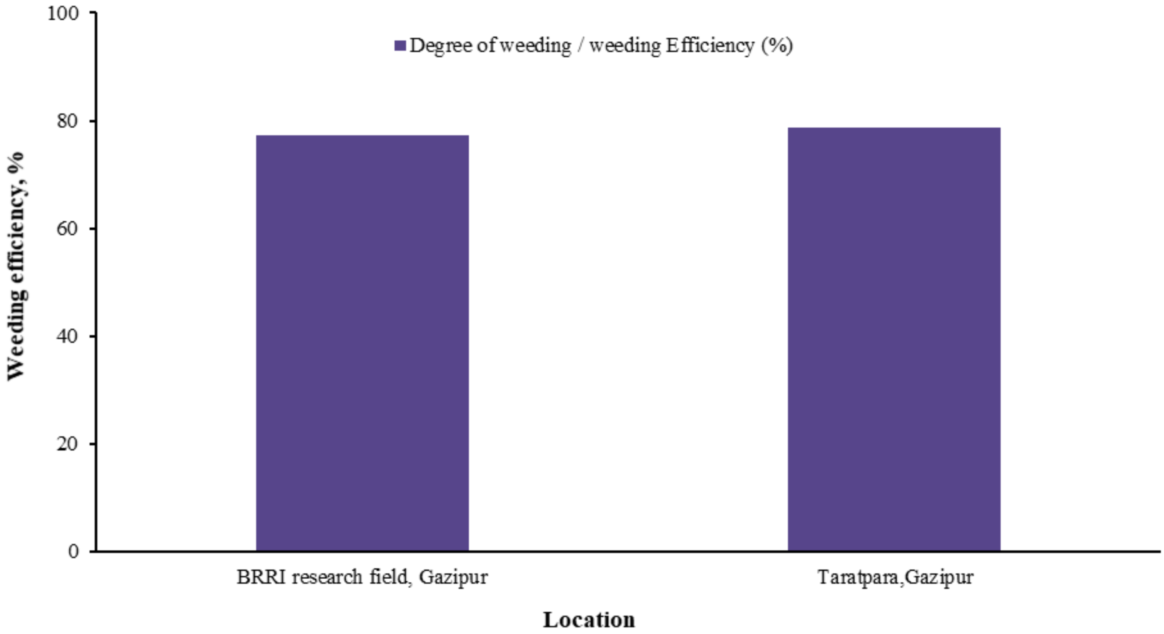


Figure 17 Weeding efficiency of the double-row weeder

3.4 Plant or tiller damage

The weeder's plant or tiller damage was 2.22% and 2.17% in the farmer's and BRRI research fields, respectively. The average tiller damage was 2.2% (Figure 18).

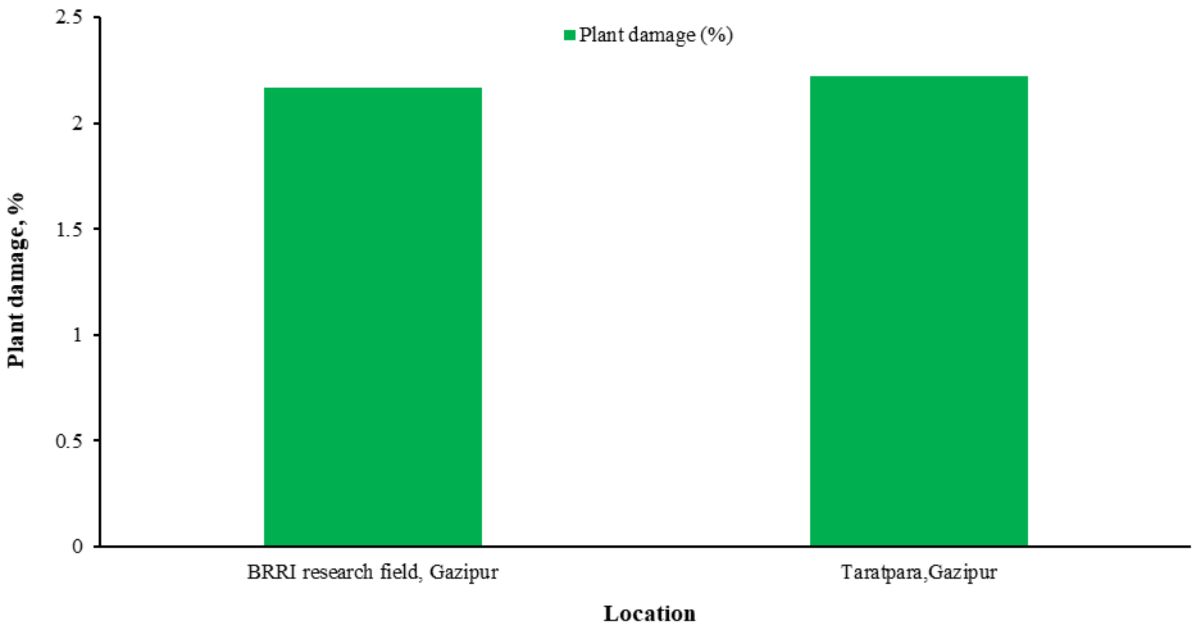


Figure 18 Plant damage of the double-row weeder

3.6 Cost of operation

The cost of the double-row weeder is contingent on the quality of materials used, including M.S. pipe, M.S. flat bar, M.S. sheet, plain sheet, and nut-bolt components. As estimated, the double-row weeder is priced at approximately Tk. 2500 (24 US$). To further assess its economic viability, the operational expenses of the developed weeder were calculated based on its field capacity. The results, detailed in Table 7, indicate a total operating cost of 76.28 Tk h^{-1}

(0.726 US$ h^{-1}), encompassing fixed and variable expenses for the double-row weeder. Furthermore, when evaluated on a per-hectare basis, the operating cost for the double-row weeder amounts to 2,062 Tk ha^{-1} (20 US$). This data provides valuable insights into the economic considerations of adopting this innovative agricultural technology.

Table 7 Cost items and operating cost of double-row weeder

Items	Parameter	Amount	
		Tk	US$
	Purchase price of weeder (P)	2500	24
	Salvage value(S), (10% of P)	250	2.4
Fixed cost items	Working life (L), yr	5	
	Average working hours per year	480	
	Labour, Tk or US$ hr^{-1}	75	0.71
Variable cost items	Repair and maintenance, Tk or US$ yr^{-1}	0	
	Field capacity, m^2 hr^{-1}	373	
	Calculations		
Fixed costs	Annual depreciation,	450	4.29
	D=(P-S)/L Tk or US$ yr^{-1}		
	Interest on investment, *I=(P+S)/2*I*, where the rate of interest is 12%	165	1.57
Total fixed cost	Tk or US$ yr^{-1}	615	5.86
	Tk or US$ hr^{-1}	1.28	0.012
	Tk or US$ ha^{-1}	27.28	0.26
Variable cost	Labour, Tk hr^{-1}	75	0.71
	Repair and maintenance, Tk hr^{-1}	0	
Total variable cost	Tk or US$ hr^{-1}	75	0.71
	Tk or US$ ha^{-1}	2,027.03	19.31
Operating cost	Tk or US$ hr^{-1}	76.28	0.73
	Tk or US$ ha^{-1}	2,061.62	19.63

Note: Average workday = 8 hr at 0.037 ha per hr.; Labor/operator charge = 600 Tk day^{-1}, 1 US$ = 105 BD TK.

4 Conclusion

This study highlights the growing trend of agricultural mechanization in Bangladesh, particularly for weed management. A novel manually operated double-row weeder was designed specifically for Bangladeshi rice fields to address the need for efficient and labor-saving methods. This innovative tool tackles weeds between rows, optimizing weeding and mulching processes.

The design considerations included a 20 cm line-to-line distance, a push-pull operation, and functionality in 3-5 cm of standing water for softened soil. The weeder incorporates a robust build with a skid/float, frame, rotors, axles, and adjustable handle for ergonomic operation. Fabrication materials included MS sheets, pipes, and flat bars, ensuring affordability and durability.

The weeder boasts four rotors, each equipped with six strategically positioned blades for efficient weed uprooting and burial. A precisely angled two mm-thick float assembly facilitates smooth operation across wet fields. This weeder proves its effectiveness by delivering an impressive field capacity of 0.037 ha h-1 and a commendable efficiency of 76.88%. Its 7.5 kg weight also contributes to top-soil pulverization and improved soil aeration.

This double-row weeder presents a significant advancement for Bangladeshi rice farmers. By reducing manual labor and offering improved comfort during weeding and mulching, this technology can empower farmers, enhance their livelihoods, and contribute to a more sustainable agricultural future.

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Declarations

Conflict of Interest: The authors declare no competing interests.

Ethical Approval: Not applicable.

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References

Ball, B. C., and C. E. Crawford. 2009. Mechanical weeding effects on soil structure under field carrots (*Daucus carota* L.) and beans (*Vicia faba* L.). *Soil Use and Management*, 25(3): 303-310.

Gurung, K., H. Bhandari, and T. Paris. 2016. Transformation from rice farming to commercial aquaculture in Bangladesh: Implications for gender, food security, and livelihood. *Gender, Technology and Development*, 20(1): 49-80.

Hossen, M. A., M. S. Islam, M. D. Huda, M. A. Zami, M. G. K. Bhuyan, and B. C. Nat. 2011. Design and development of a weeder for both lowland and upland conditions. *AMA-Agricultural Mechanization in Asia Africa and Latin America*, 42(2): 56-62.

Hossen, M. A., B. C. Nath, A. T. M. Raihan, M. A. Haque, and M. S. Islam. 2010. Performance evaluation of the BRRI development wet and dry land weeder. *International Journal of BioResearch*, 8(1): 27-34.

Hossen, M. A., M. M. Hossain, R. W. Bell, and M. E. Haque. 2017. Effects of inundation period and tillage option onfield performance of self-propelled rice transplanter. *Agricultural Engineering International: CIGR Journal*, 19(4): 1–12.

Hunt, D. (1995). *Farm Power and Machinery Management, Cost determination (9th edition)*, Iowa State University Press, USA.

Hunt, D. 1973. *Farm Power and Machinery Management (9th edition)*, Laboratory manual and workbook. seventh edition, Iowa State University Press, Ames, Iowa.

Kaur, S., S. Dhanda, A. Yadav, P. Sagwal, D. B. Yadav, and B. S. Chauhan. 2022. Current status of herbicide-resistant weeds and their management in the rice-wheat cropping system of South Asia. *Advances in Agronomy*, 172: 307-354.

Milovanovic, V., and L. Smutka. 2018. Cooperative rice farming within rural Bangladesh. *Journal of Co-operative Organization and Management*, 6(1): 11-19.

Nath, B. C., Y. S. Nam, M. D. Huda, M. M. Rahman, P. Ali, and S. Paul. 2017. Status and constrain for mechanization of rice harvesting system in Bangladesh. *Agricultural Sciences*, 8(6): 492-506.

Nath, B. C., M. D. Huda, M. M. Rahman, and S. Paul. 2021. Essential steps for developing rice harvest mechanization in Bangladesh. *In Cutting-edge Research in Agricultural Sciences Vol. 7*, 1st ed., ch. 11, 109-125. BP International, 27 Old Gloucester Street, London WC1N 3AX, UK.

Paul, S., B. C. Nath, A. Hossen, K. Pintu, H. Paul, S. Islam, A. U. Khan, and M. Ahmmed. 2023. Development and fabrication of manually push-pull type conical weeder for Bangladesh condition. *Agricultural Sciences*, 14(5): 685-709.

Paul, S., M. A. Rahman, H. Paul, M. M. Rahman, B. C. Nath, M. D. Huda, and M. G. K. Bhuiyan. 2022. Fabrication and field performance of power weeder for mechanized rice cultivation in Bangladesh. *Bangladesh Rice Journal*, 26(1): 47-57.

Rana, S. S., and M. C. Rana. 2016. *Principles and Practices of Weed Management.* 3rd ed. Department of Agronomy, College of Agriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, 138, India.

Remesan, R., M. S. Roopesh, N. Remya, and P. S. Preman. 2007. Wet land paddy weeding-A comprehensive comparative study from south India. *CIGR Journal*, IX: PM 07 011.