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Design, fabrication, and performance evaluation of a multi-rows power operated weeder for line transplanted rice field in Bangladesh

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Abstract

This research was conducted to develop and assess the efficacy of a multi-row power operated weeder (PoW) to control weeds in line transplanted wetland rice fields. Power from a 6500 rpm engine was transferred to the rotors through a coupling device, spline-shaft, worm-gearing, and rotary-shaft connected with a power-involved detach facility ensuing 185 rpm rotation of the rotors. The spline-shaft was connected with the worm-wheel via worm-screw. Finally, engine power was transmitted to the weeder rotors from the worm-wheel to the shaft of the rotors. The weeder was tested in seven locations under different soil conditions. The treatments were- one mechanical-weeding by PoW succeeded by (sb) one hand-weeding (HaW), one mechanical weeding by BRRI (Bangladesh Rice Research Institute) manual weeder (BMW) sb one HaW, un-weeded, no-weed, and mulching sb two HaW (local practice). Average of seven locations, actual and theoretical capacity of area coverage by the multi-row power weeder were found 0.23 and 0.29 ha/h whereas the average field efficiency was found 78.74%. In all locations, significantly lower efficiency of weeding was recorded with manual weeder (69.28%) whereas the efficiency of weeding with the PoW was 78.93%. However, the weed control efficiency of the PoW was 73.18%. The unweeded treatment resulted in a significantly lower yield while there was no significant variation among the other treatments. Based on these preliminary findings, the newly-developed PoW was assessed to have good weed-control capacity and, therefore, might have the potential to herbicide applications.

Keywords: Field capacity, Rice, Weeding efficiency, Weeding cost, Yield

1. Introduction

Weed is one of the main agrarian enemies. The majority of the weeds contend more for their sustenance through the fast turn of events and sign by snappy advancement than the crop. For the serious competitive capacities, weeds have a significant negative impact on crop production and are liable for marked crop yield losses [1]. The plausible yield sacrifice for unhindered weed rivalry was 28.28% in broadcasted Aman rice [2]. Improper weed management is one of the main considerations for yield decrease of rice contingent upon the kind of weed verdure and its density [3]. Weed development diminished the paddy yield by 68-100% for directly cultivated Aus rice, 16-48% for transplanted irrigated wet season rice and 22.36 % for high-yielding irrigated dry season rice [4]. This loss then is a genuine danger for the staple food-deficit country. So appropriate weed control is fundamental for paddy cultivation in South-Asian countries like Bangladesh. Presently, the biochemical/chemical application for weed management is picking up fame everywhere in the world in light of its marvelous outcomes for controlling weed effectively. Traditional hand weeding needs an enormous workforce and records for around 26% of the all-out labor prerequisite (900-1200 worker hours/hectare) [5]. Moreover, the necessity of labor for weeding relies upon weed verdure, weed density, the season of weeding, and water condition during weeding operation and productivity of the labor. Repeatedly, a few weddings are important to maintain the harvest no-weed. Discount of yield because of weed solo is assessed to be 16-42 % relying upon crop, season, locations and includes 33% of the expense of production [6]. The weed should be controlled and killed at its early phase.

Maximum let down of weeding cost is consistently ideal considering the perspective of financial thought. Appropriate weeding science is also a significant element for the end-user of the nations. Density and intensity of weeds rely on the sources and accessibility of irrigation, soil condition, spot of the meadow, climatic conditions of the field, the profundity of plow-pan, and fertility of the soil, and so forth. In Bangladesh, three rice seasons (Aus, Aman, and Boro) cover about 8.35%, 30.75%, and 33.14% of gross production area and it subsidizes weight of value to 4.31%, 24.19%, and 27.63% of the entire production respectively [7] (BBS, 2020). However, the grain production is a lot lower than that of transplanted rice in other rice-developing nations of the world. Serious weed invasion comprises one reason for such low yield [8].

Weed invasion diminishes paddy production by 70-80% in rain-fed (Aus) season, 30-40% in irrigated wet (Aman) season, 22-36% in irrigated dry (Boro) season, and 80-82% in direct-seeded rice in wetland in Bangladesh [9-11]. Yield misfortunes because of the pervasion of weeds are more noteworthy than the joined misfortunes brought about by insects, and diseases in rice [12-13].

Manual weeding tools are still popular in Bangladesh. Hand pulling or by utilizing straightforward instruments like niranee, Japanese rice weeder, BRRI, and BARI (Bangladesh Agricultural Research Institute) introduced weeder are being used to control weeds which are tedious, time-consuming (less field capacity), and expensive too. Generally, a few hand weeding is accomplished for cultivating paddy contingent on the type of weeds and their density of invasion. Notwithstanding, these techniques are difficult, less agreeable, tedious, and costly too. BRRI has developed a power weeder suitable for manual transplanted rice fields under BRRI-KOICA collaborative project [14]. A limited study was conducted to evaluate the technology ergonomically under different soil conditions (silty and clay loam soil only) [14]. The majority of the ranchers of Bangladesh, transplant rice considering BRRI suggested spacing. It was found suitable in research and farmers' field. Now mechanical transplanting is expanding in Bangladesh due to different government programs for mechanization. It is now necessary to develop a multi-row power weeder suitable for both manual and mechanical transplanted rice fields with adjustable capacity. Under the proposed program, a multi-row power weeder was developed and evaluated to validate and adopted the developed power weeder to the end-users. The existing line spacing of the Bangladeshi farmers' is taken into consideration while designing the weeder. It can also be adjusting with line spacing ranging from 15-30cm. Therefore, a systematic study in farmers' participation was conducted to validate the power weeder comparing with the different weed management practices in Bangladesh.

2. Materials and methods

2.1 Design of the multi-row power weeder

2.1.1 Design considerations

The power weeder was designed and developed considering certain standards. Initially, it was considered to be a multiple rotor type (3 rotors and facility to add another 2 rotors) suitable for multi-row of the paddy field. It was also considered that the rotor size should be suitable for both manual and mechanical transplanted rice fields and the depth of weeding should be sufficient to uproot the weed (rotor spacing can be adjusted in the line spacing of 15 to 30cm). Spike and spike arrangement was considered in such a way to cover the whole area in between two lines (angle of the spike is selected in trials and error methods). An adjustable mechanism was considered for the rotor to fit with different line spacing of transplanted rice. The power transmission system was designed considering the simple engage and disengage facility using locally available materials to minimize the fabrication cost.

2.1.2 Design steps

The weeder design involved a series of steps that were followed to develop the final version. Firstly, a rotating propeller shaft was designed to convey the engine power to the main axle of the power weeder. Then, a simple gearbox was designed incorporating worm and worm gear at the end of the propeller shaft to reduce and change the direction of the rpm at 90o rotations. Clutch plate type coupling was used in between the engine main shaft and propeller shaft to ensure the engaged and disengaged facility with the rpm of the engine. Spike and spike arrangement mechanism was designed in such a way as to uproot the weeds during operation. All the components were assembled sequentially. Finally, it was evaluated the developed weeder in different soil conditions.

2.1.3 Multi-rows power operated weeder (PoW)

Multi-rows power-operated weeder was designed and fabricated in the divisional research of Bangladesh Rice Research Institute (Figure 1 and Table 1).

Table 1 Description of the weeder.

Items	Specification	
Dimensions	Total length × width × height (mm)	1417×762×807
	Total weight (kg)	20
	Full output kW/rpm	1.35/7000
	Type of Engine	Petrol engine
	Mode of engine start	Recoil
Traveling section	Crawling	Hand controlling system
	Rotor type	Spike in the rotor work as lug of the wheel
	Gearshift: Forward	Power engaged with the increase of engine rpm
Weeding section	Weeding mechanism	Rotary: spike used in the rotor for weeding
	Total rows in number	3
	Suitable for row to row distance (mm)	200 to 300 (adjustable)
	Field capacity (ha/h)	0.16-0.20

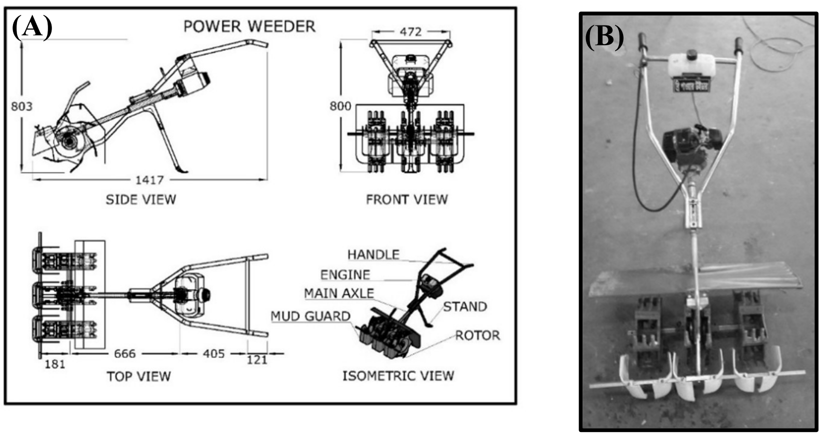

Figure 1 Multi-row power weeder; (A) drawing views and (B) fabricated view.

2.1.4 Power transmission system from engine to the rotor

The path of power transmission of the power weeder is shown in Figure 2. A coupling mechanism was used to transmit the engine power from the engine to the spline shaft. It is engaged and disengaged with the rate of rpm.

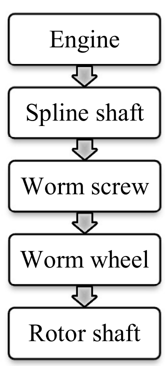

Figure 2 Power transmission diagram.

The worm gear was used to reduce the high rpm of the engine to a desired rate of the rotor rpm (Figure 3). The spline shaft (Figure 4) was directly connected with the worm screw which was connected with the worm wheel. Finally, power was transmitted to the weeder rotor from the worm wheel to the shaft of the rotors (Figure 5).

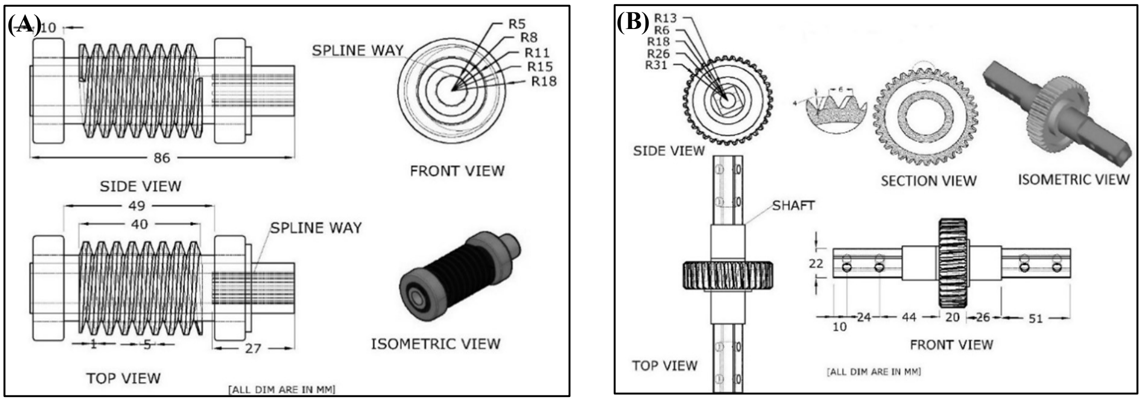

Figure 3 Worm-screw (A) and (B) worm-wheel of the worm-gearing.

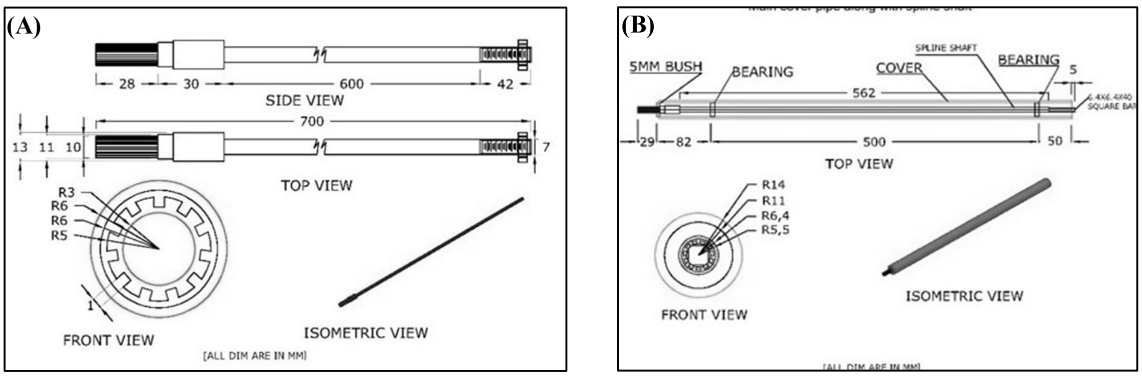

Figure 4 Spline shaft (A) and (B) shaft cover**.**

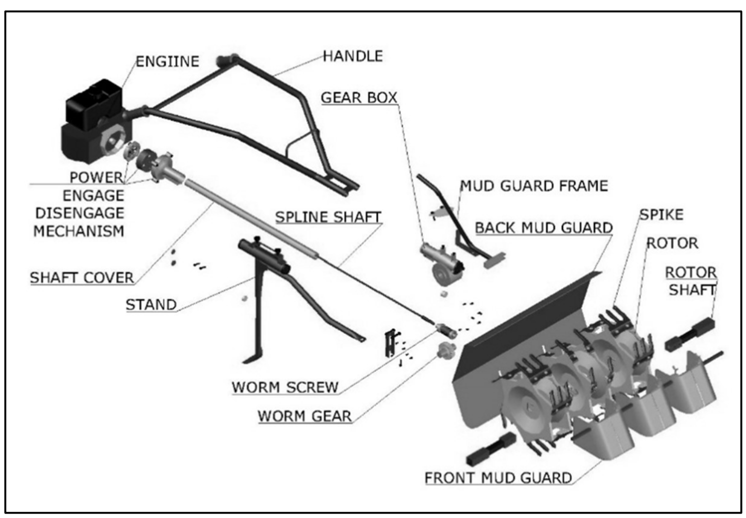

Figure 5 Exploded view of power transmission of power weeder.

2.1.5 Main frame

Stand, handle, mudguard frame, and front mudguard cover along frame were the main components of the power weeder. SS (stainless steel) materials were castoff to build the frame (Figure 6 and 7).

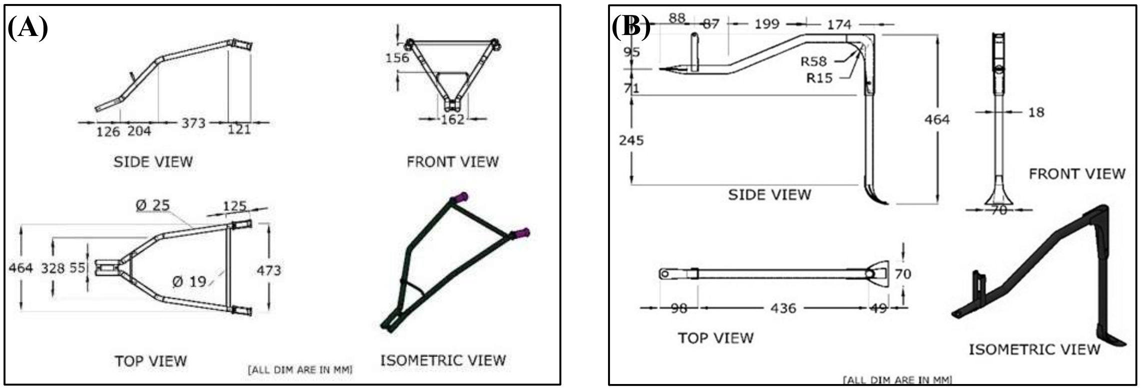

Figure 6 Stand (A) and (B) mud guard frame of the power weeder.

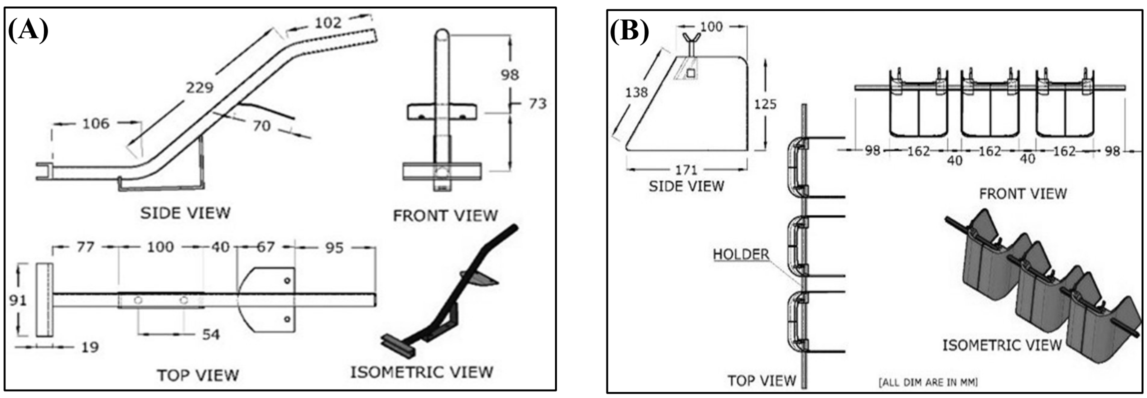

Figure 7 Front mud guard frame (A) and (B) cover of the power weeder.

2.1.6 Spikes arrangement

Spike angle and arrangement were designed critically considering the effective depth of weeding and the total area of coverage in between two lines. A total of 18 spikes were attached to each side rotor whereas six spikes were attached to each middle rotor (Figure 8).

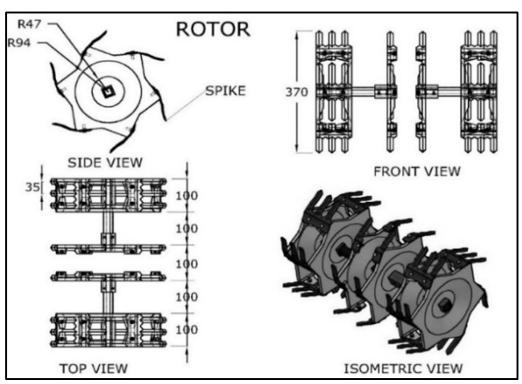

Figure 8 Spikes arrangement of the power operated weeder.

2.2 Field evaluation

2.2.1 Location of the study

The developed power-operated weeder was evaluated in the farmer’s field at Sadar, Habigang; Sadar, Gazipur; Sreepur, Gazipur; Sadar, Rangpu r; Sadar, Netrakona; BRRI R/S Cumilla and Bhaluka, Mymensingh Bangladesh in Boro 2018-19 season.

2.2.2 *Soil sample collection and analysis*

A SS metal core of 50 mm height and 49.8 mm diameter was used to collect samples of soil from three different locations of the studied field at the depth of 0-150 mm to analyze soil type, pH, and organic matter. The soil of the experimental locations Sadar, Habigang; Sadar, Gazipur (1); Sreepur, Gazipur (2); Sadar, Rangpur; Sadar, Netrakona; BRRI R/S Cumilla and Bhaluka, Mymensingh represented the Loam Soil (LS), Silt Loam Soil (SiLS), Clay Loam Soil (CLS), Sandy Loam Soil (SLS), Sandy Clay Loam Soil (SCLS), Silt Clay Loam Soil (SiCLS) and Sandy Clay Soil (SCS), respectively (Table 2). The USDA Soil Texture Triangle was used to determine soil type [15].

Table 2 Soil texture classes of the experimental fields of different locations.

Sl no.	Location	Particle Distribution (%)			Textural Class	pH	Organic matter (%)
		Sand	Silt	Clay			
1	Habigang	40.47	46.97	12.56	Loam (L)	5.06	1.34
2	Gazipur (1)	29.92	50.84	19.24	Silt Loam (SiL)	5.66	2.48
3	Gazipur (2)	33.33	40.00	26.67	Clay Loam (CL)	5.33	1.61
4	Rangpur	50.00	44.70	5.30	Sandy Loam (SL)	5.36	2.68
5	Netrakona	46.69	32.81	20.50	Sandy Clay Loam (SCL)	6.93	1.68
6	Cumilla	19.75	49.50	30.75	Silt clay Loam (SiCL)	5.12	2.68
7	Mymensingh	47.00	17.50	35.50	Sandy Clay (SC)	7.05	1.41

2.2.3 *Experimental design and treatments*

The experiment was laid out following a randomized complete block design (RCBD) with three replications. Approximately 1.0 m obstruction separating was kept among the sub-plots while contemplated field area was 0.28, 0.23, 0.34, 0.14, 0.15, 0.26 and 0.12 ha at Sadar, Habigang; Sadar, Gazipur; Sreepur, Gazipur; Sadar, Rangpur; Sadar, Netrakona; BRRI R/S Cumilla and Bhaluka, Mymensingh, respectively. The treatments were –

Treatments

- T_1 = One weeding by developed power operated weeder (PoW) succeeded by (sb) one hand-weeding (HaW)
- T_2 = One weeding by BRRI manual weeder (BMW) sb one HaW
- T_3 = Unweeded
- T_4 = No-weed and
- T_5 = Mulching sb two HaW (Local practice)

Weeds of the studied fields were managed according to the pre-designed treatments of the experiments. PoW and BMW were operated at 25 dates after transplanting in T_1 and T_2. A single physical weed cleaning operation was conducted at 45 dates after transplanting to rheostat the weeds of T_1, T_2, and T_5. Treatment T_3 (no weeding) was not weeded during the whole crop growing periods. Contrary, treatment T_4 (no-weed) was cleaned at 25, 35, 45, and 55 dates after transplanting to retain the treatment no-weed in full cultivating season. By the virtue of treatment T_5, weeds were overseen utilizing nearby acts of the ranchers physically at 15, 25, and 45 dates after transplanting.

2.2.4 *Rice varieties and date of operations*

Rice variety of BRRI dhan28 at Sadar, Gazipur; Sreepur, Gazipur; Bhaluka, Mymensingh, BRRI Dhan89 at Sadar, Netrakona; BRRI dhan29 at Sadar, Habigang; BRRI dhan89 at BRRI R/S Cumilla and BRRI dhan58 at Sadar, Rangpur respectively [16]. The date of different operations was done based on guidelines of the respective variety (Table 3). The actual growth duration of the varieties is presented in the table while the growth period of BRRI dhan28, BRRI dhan29, BRRI dhan58, and BRRI dhan89 are 140, 160, 150-155, and 154-158 days, respectively [16].

Table 3 Rice varieties and date of different operations during study.

Sl. no.	Place	Area in ha	Variety	D/S	D/T	D/W (1st)	D/W (2nd)	D/H	G/D
1	Gazipur (1)	56.2	BRRI dhan28	27-11-18	27-01-19	24-02-19	14-03-19	02-05-19	156
2	Gazipur (2)	85.0	BRRI dhan28	13-12-18	17-01-19	16-02-19	19-03-19	03-05-19	142
3	Mymensingh	60.3	BRRI dhan28	12-12-18	23-01-19	13-02-19	09-03-19	01-05-19	140
4	Netrakona	35.8	BRRI Dhan89	03-12-18	03-02-19	27-02-19	14-03-19	21-05-19	169
5	Habigang	52.0	BRRI dhan29	01-12-18	26-01-19	22-02-19	17-03-19	27-05-19	177
6	Cumilla	70.0	BRRI dhan89	01-12-18	26-01-19	24-02-19	10-03-19	13-05-19	163
7	Rangpur	64.0	BRRI dhan58	06-12-18	12-01-19	14-02-19	01-03-19	11-05-19	156

Note: D/S-Date of seedling, D/T-Date of transplanting, D/W (1st)-Date of 1st weeding, D/W (2nd) – Date of 2nd weeding, D/H- Date of harvesting and G/D-Growth duration.

2.2.5 Weeds management

Weeds of the experimental field were handled as per pre-designed actions. PoW and BMW were maneuvered at 25 dates after transplanting in T1 and T2. A single physical weeding was conducted at 45 dates after transplanting to rheostat the weeds of T_1, T_2, and T_5. Treatment T_3 (unweeded) was not weeded during the crop growing periods. Opposite in treatment T_4 (no-weed), cleaning operation was made at 25, 35, 45, and 55 dates subsequent to transplanting to hold the field no-weed in full cultivating season. On account of treatment T_5, weeds were taken care of by the nearby ranchers' practices physically at 15, 25, and 45 dates subsequent to transplanting.

2.2.6 Field capacity of the weeder

Both theoretical and actual field capacities of the developed power weeder were measured during operation in different locations. Weeder operation period included the time for turning of the weeder at the end, operator's personal time during operation, rotors adjustment time, weeder re-starting time, etc. were quantified to estimate the weeder's actual field capacity, which is the weeding area covered in hector (ha) divided by the total operation time of the weeder for the respective area (h). The field efficiency of the weeder was calculated based on the actual operating speed and theoretical operation speed of the weeder.

2.2.7 Efficiency of weeding

The efficiency of weeding (%) of the different weeding practices was measured during the first weeding using the following equation [17]. The sum of weeds of the pre-stamped region was tallied both pre- and post-weeding activity. A frame of 0.5 m × 0.5 m for every replication was situated nonchalantly in each field, and weeds were checked and gathered from every frame both pre- and post-weeding activity.

$$E_W = \frac{W_1 - W_2}{W_1} \times 100$$

where,

E_W = Efficiency of weeding (%)
W_1 = Population of weeds before weeding
W_2 = Population of weeds after weeding

2.2.8 Weed-control efficiency

Weed-control efficiency (%) of the different weeding practices was measured based on the number of weeds of the unweeded plots using the following equation [18]. Total numbers of weeds of the other treatments were calculated after weeding operation from the pre-marked area. A frame of 0.5 m × 0.5 m for every replication was situated nonchalantly in each field, and weeds were checked and gathered from every frame both pre- and post-weeding activity.

$$E_{CW} = \frac{W_c - W_t}{W_c} \times 100$$

where,

E_{CW} = Weed control efficiency (%)
W_c = Population of weeds of the unweeded plots
W_t = Population of weeds after weeding of the other treatments

2.2.9 Yield and yield attributes

Yield and yield contributing parameters were collected from the study field using the standard procedure [19].

2.3 Operating cost of the developed weeder

Depreciation over the time of the weeder use, interest on weeder purchase price, tax & insurance cost, and weeder keeping cost are the parts of the overheard cost which was estimated as per procedure used by Hossen [19]. The field operation cost (Tk/h) of the developed weeder was determined on the basis of overhead (Tk/h) and flexible (Tk/h) cost following the procedure described in Hunt [20].

2.4 Data analysis

Exploratory information was examined as a solitary factorial plan as per Gomez and Gomez [21] utilizing Statistix 10 program [22]. The least significant difference (LSD) tests were used to contrast the means. A straightforward correlation investigation was done with Excel 2010 to decide the relationship of grain respect yield credits.

3. Results and discussion

3.1 Development of multi-row power weeder

3.1.1 Engine

A lightweight (1.5 Kg only) 2-stock petrol engine (Model: BG-328, Brand-SAIMAC, Country-China, power: 1.35 Kw, starting mode: recoil type, and RPM: 6500) was used as a power source to operate the weeder (Figure 9).

Figure 9 Petrol engine used as power source in the power weeder (Model-BG-328, Brand-SAIMAC, Country-China).

3.1.2 Worm gear

Worm-gearing was designed using the guideline prescribed by Oberg & Jones, 1969 [23] and Khurmi & Gupta, 2005 [24]. It was used to decrease the rpm of the rotor shaft of the weeder at a ratio of 35:1 (Figure 10). Therefore, the velocity ratio of the worm-gearing is 35. The worm gear is directly received engine rpm through the spline shaft. Hence the rpm of the worm gear is the same as engine rpm which is NG = 6500 rpm and the number of the start of the worm gear is n=4 and teeth of worm wheel, Tw=35. Hence the rpm of the worm wheel is

$$N_w = 742$$

$$(Nw = \frac{4}{35} \times 6500 = 742)$$

which is equal to the rpm of the weeder rotor. Gear body is made of aluminum alloy making dice for the purpose of easy replication.

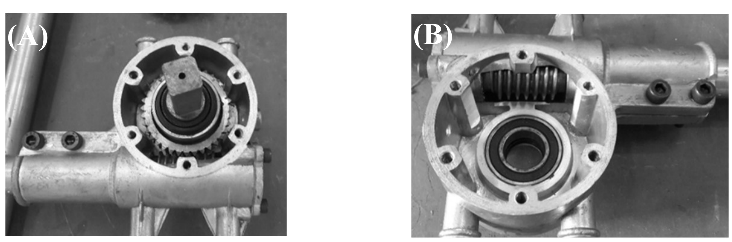

Figure 10 Worm gearing showing the worm wheel (A) and (B) worm screw.

3.1.3 Spline shaft

Engine power was directly conveyed to the worm gear with a coupling and spline mechanism using a shaft called a spline shaft. One end of the shaft is the outer spline which is connected with the inner spline of the worm gear and another end was directly connected with the engine with a coupling mechanism. It was made of high carbon material with proper heat treatment. The total length of the spline shaft is 700 mm where 28 mm is a spline.

3.1.4 Rotor and rotor arrangement

A total of three rotors were used in the power weeder. Double rotors were used on both sides of the weeder whereas the middle rotor was split into two single rotors for the gear set up in between two single rotors. Two shafts were connected with both ends of the worm wheel shaft to convey the power from the worm wheel to the rotors (Figure 11). It was made of a 20-gauge MS sheet. The diameter and width of coverage of each rotor are 290 and 100 mm, respectively.

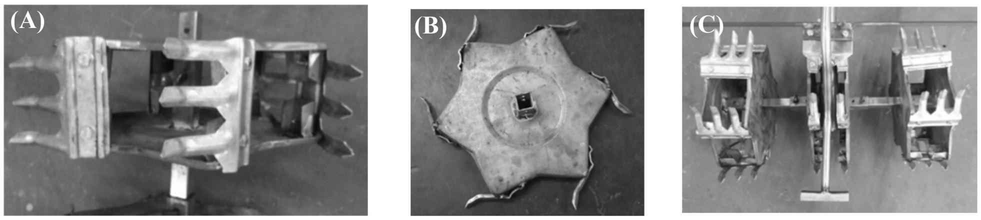

Figure 11 Rotor and rotor arrangement showing; double rotor (A), single rotor (B) and single and double rotor (C).

3.1.5 Spike and spike arrangement

The Spike arrangement is shown in the following figure. It was made of a 20-gauge MS sheet using dice, jig, and fix to maintain the same size. A total of 18 spikes were attached in each side rotor whereas 06 spikes were attached in each middle rotor of the weeder (Figure 12). In the rotor, spikes were arranged alternatively in left and right alignment to cover the weeding area for effective weeding.

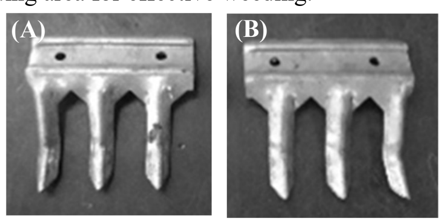

Figure 12 Spike arrangement of the power weeder; left alignment (A) and (B) right alignment.

3.1.6 Frame and others

Different components were fabricated according to the design and specification of the weeder (Figure 13). The front mudguard was made of plastic material. Dice was made for these components. Dice also made for the gear body. The mudguard holder, stand, mainframe, and handle were made using stainless steel (SS) pipe of 1.5 mm thickness. SS square bar was used to fabricate the main shaft of the rotor connected in the worm wheel of the gear. SS pipe of 1.5 mm thickness was also used for fabricating the main cover pipe of the spline shaft.

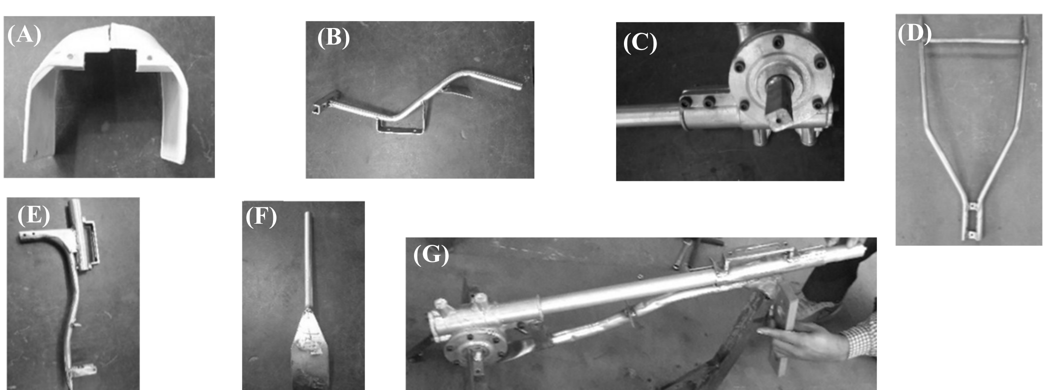

Figure 13 Different components of the power weeder showing; front mud guard (A), mud gurd holder (B), gear body (C), stand (D), main frame (E), handle (F) and cover pipe of the spline shaft (G).

All components of the power weeder were assembled in the divisional laboratory. Jig and fixture were used to main the accuracy of assembling.

3.2 Operational procedure

The BRRI multi-rows power weeder was designed and developed considering the line transplanter wetland rice field. During the field operation of the weeder, it should be placed accurately among the lines at the right end of the transplanted rice field for ease of turning maintaining the rotor position in the middle of two lines. Then, the power weeder engine has to start and engage the power of the engine to the rotor increasing engine speed. It is essential to control the alignment of operation carefully avoiding plant tiller damage. At the end of the field, again reduce the engine speed to disengage the engine power from the rotor and place the weeder in the lines in the opposite direction. Minimum standing water has to maintain during operation. For effective weeding, the minimum walking speed of the operator should be maintained. It is essential to check the lubricant of the gear before weeder operation.

3.3 Field evaluation of the multi-row power weeder

3.3.1 Weed density before 1st weeding at 25 dates after transplanting

Weeds density was counted at 25 dates after transplanting (Table 4). Weeds type and density varied with soil conditions, locations, and irrigation conditions. Two-ways interaction was not found significant whereas the single effect of soil type and weeding methods were significant on weeds density. Weeds density was significantly higher in silt clay loam followed by loam whereas lower weeds density was observed in clay loam, sandy clay loam, and sandy loam. Gaston et al [25]; Nordmeyer et al [26]; and Korres et al. [27] stated that soil organic carbon (SOC), soil texture, and nutrient status of the soil mainly affect weed occurrence.

Table 4 Weeds density (no. m^2) as affected by different weeding methods and locations.

Treatment	Weeds density (no./m^2)							Mean
	SiLS	CLS	SCS	SCL	LS	SiCLS	SLS	
T_1	178	108	246	94	206	460	94	198.0^{ab}
T_2	158	78	120	98	260	272	152	162.6^{c}
T_3	196	72	96	80	226	366	120	165.1^{bc}
T_4	158	66	102	74	222	402	112	162.3^{c}
T_5	192	138	222	116	238	374	128	201.1^{a}
Mean	176.4^{c}	92.4^{e}	157.2^{cd}	92.4^{e}	230.4^{b}	374.8^{a}	121.2^{de}	-
CV	30.9							
LSD	L=40.03 and T=33.83							
LoS	$L=^{**}$, $T=^{*}$ and L × T = ns							

T_1 - One weeding by power-operated weeder (PoW) sb one hand-weeding (HaW), T_2 - One weeding by BRRI manual weeder (BMW) sb one HaW, T_3 - Unweeded, T_4 – no-weed and T_5 - Mulching sb two HaW (Local practice), NS-Not significant, *-significant at 5 %, **-significant at 1 %, LoS-Level of significance, L-Locations, T- Weeding methods, SiLS-Silty loam soil, CLS-Clay loam soil, SCS-Sandy clay soil, SCLS-Sandy clay loam soil, LS-Loam soil, SiCLS-Silty clay loam soil and SLS-Sandy loam soil. Means followed by a common letter (s) or without a letter in the same row and column are not statistically significant whereas means with different letters differ significantly at a 5% level of probability.

3.3.2 Weeds biomass before 1st weeding at 25 dates after transplanting

Weeds biomass was measured at 25 dates after transplanting (Table 5). Weeds biomass varied with weeds type, density, and age of the weeds. Two-ways interaction was found significant on weeds biomass as were single effects of location was significant on weeds biomass. Weeds biomass was significantly higher in silt loam, loam, silt clay loam, and sandy loam soil. Significantly higher weeds biomass was observed at silt clay loam under T1, T3, and T5, at silt loam under T2, at loam under T2 and T4, and at sandy loam under T5.

Table 5 Weeds biomass per m^2 as affected by different weeding methods and locations.

Treatment	Weeds Biomass (g/m^2)							Mean
	SiLS	CLS	SCS	SCLS	LS	SiCLS	SLS	
T_1	63.0	31.5	17.5	22.8	57.8	82.3	66.5	48.8
T_2	78.8	29.8	24.5	26.3	75.3	21.0	61.3	45.3
T_3	47.3	33.3	49.0	29.8	66.5	75.3	59.5	51.5
T_4	52.5	31.5	42.0	31.5	84.0	50.8	63.0	50.8
T_5	47.3	36.8	36.8	21.0	49.0	92.8	73.5	51.0
Mean	57.767^{a}	32.587^{b}	33.973^{b}	26.287^{b}	66.527^{a}	64.413^{a}	64.753^{a}	
CV	34.55							
LSD	L=12.45 and L × T = 27.85							
LoS	$L=^{**}$, T=ns and L × T = *							

T_1 - One weeding by power weeder (PoW) sb one hand-weeding (HaW), T_2 - One weeding by BRRI manual weeder (BMW) sb one HaW, T_3 - Unweeded, T_4 – no-weed and T_5 - Mulching sb two HaW (Local practice), NS-Not significant, *-significant at 5 %, **-significant at 1 %, LoS-Level of significance, L-Locations, T- Weeding methods, , SiLS-Silty loam soil, CLS-Clay loam soil, SCS-Sandy clay soil, SCLS-Sandy clay loam soil, LS-Loam soil, SiCLS-Silty clay loam soil and SLS-Sandy loam soil.
Means followed by a common letter (s) or without a letter in the same row and column are not statistically significant whereas means with different letters differ significantly at a 5% level of probability.

3.4 Machine operation

3.4.1 Capacity of area coverage of the developed power weeder

Both the actual and theoretical capacity of area coverage of the developed power weeder was estimated in seven locations of the country (Table 6). The theoretical capacity of area coverage related with the speed of operation of the weeder without any losses in the field whereas the actual capacity of area coverage related alongside the rate of operation, turnoff loss at the end of the field, weeder placing time in between rows, etc. In all cases, the theoretical and actual capacity of area coverage of the power weeder were observed more in the SL and SC soil compared to SL and CL soil. Both the capacities of area coverage were observed more in SL and less in SL soil due to penetration differences during operation. The efficiency of the weeder in operation was found in the range of 68.2 to 83.5% notwithstanding of land and sites. Mean of seven sites and three replications, actual and theoretical capacity of area coverage of the multi-rows power weeder was found 0.229 and 0.290 ha/h whereas average field efficiency was found 78.74%.

Table 6 Field performance of the multi-row power weeder.

Sl. no.	Place	Area (m^2)	Operational time (m)	Forward speed (km/h)	AFC (ha/h)	TFC (ha/h)	FE (%)
1	Silt Loam	1374	39.44	4.44	0.209	0.266	78.5
2	Clay Loam	1085	32.39	4.91	0.201	0.295	68.2
3	Sandy Clay	1250	30.86	4.93	0.243	0.296	82.1
4	Sandy Clay Loam	1050	26.81	4.87	0.235	0.292	80.4
5	Loam	1080	27.34	4.84	0.237	0.290	81.6
6	Silt clay Loam	1400	37.00	4.92	0.227	0.295	76.9
7	Sandy Loam	1280	30.60	5.01	0.251	0.301	83.5

Note: Mean of three replications, range of coverage in a single pass of the weeder: 0.6 m, AFC-Actual capacity of area coverage, TFC-Theoretical capacity of area coverage and FE- Efficiency of the weeder in operation.

3.4.2 Capacity of area coverage of the BRRI manual weeder

The capacity of area coverage of the BRRI manual weeder was also determined during field operation in seven locations of the country (Table 7). The theoretical capacity of area coverage related with the rate of weeder operation whereas the actual capacity of area coverage related to soil condition, soil softness, weeds density, forward speed, turning time loss, etc. In all cases, the theoretical and actual capacity of area coverage of the weeder were also found higher in the LS compared to SL and CL soil. Both the field capacities of area coverage were observed more in SL and less in SL and SCL due to penetration differences during operation. Efficiency in operation varied from 45 to 85% regardless of land and sites. Mean of seven sites and three replications, actual and theoretical capacity of area coverage of the manual weeder was obtained 0.038 and 0.05 ha/h whereas average field efficiency was found 76.25%. Manual weeding capacity varied with weeds type, density, soil condition, and water condition. Average of seven locations, manual weeding capacity was found 62.5 m^2/h.

Table 7 Field performance of the BRRI manual weeder and hand weeding capacity.

Sl. no.	Place	Area (m^2)	Operational time (m)	Forward speed (km/h)	AFC (ha/h)	TFC (ha/h)	FE (%)	MWC (m^2/h)
1	Silt Loam	460	86.25	0.73	0.032	0.044	72.9	60.00
2	Clay Loam	320	50.53	0.92	0.038	0.055	69.2	70.00
3	Sandy Clay	400	60.00	0.81	0.04	0.049	82.3	45.00
4	Sandy Clay Loam	350	59.66	0.74	0.0352	0.044	79.5	80.00
5	Loam	320	43.64	0.94	0.044	0.056	78.2	52.50
6	Silt clay Loam	425	79.69	0.82	0.032	0.049	65.4	45.00
7	Sandy Loam	425	55.43	0.89	0.046	0.053	86.3	85.00

Note: Mean of three replications, range of coverage in a single pass of the weeder: 0.6 m, AFC-Actual capacity of area coverage, TFC-Theoretical capacity of area coverage and FE- Efficiency of the weeder in operation and MWC- Manual weeding capacity.

3.4.3 Efficiency of weeding

The efficiency of weeding (E_W) of weeder varied significantly due to density of weeds, irrigation water condition in the field, BMI index of the operator, soil and field conditions also. Two-ways interaction of weeding methods and locations showed a significant effect on the efficiency of weeding of the weeder as were weeding methods were significant (Table 8). Manual weeding practices showed significantly higher efficiency of weeding over the mechanical efficiency of weeding due to weeds uprooted in between two plants hills followed by a power weeder. In all cases, significantly lower efficiency of weeding was observed for BRRI manual weeder. Alizadeh (2011) obtained 84.33% weeding efficiency in paddy field weeded by 3 rows mechanical power weeder [28].

Table 8 Efficiency of weeding as affected by different weeding methods over the locations.

Treatments	SiLS	CLS	SCS	SCLS	LS	SiCLS	SLS	Mean
T_1	74.67	77.41	81.59	80.93	85.47	75.21	77.25	78.93^b
T_2	68.90	75.83	69.75	73.73	67.61	61.13	68.04	69.28^c
T_5	92.87	87.33	76.67	82.00	89.37	94.71	85.00	86.85^a
Mean	78.811	80.19	76.00	78.89	80.81	77.02	76.76	
CV	6.41							
LSD	T=3.13 and L × T = 8.28							
LoS	L=ns, T=*ns and L × T = *							

T_1 - One weeding by power weeder (PoW) sb one hand-weeding (HaW), T_2 - One weeding by BRRI manual weeder (BMW) sb one HaW, T_5 - Mulching sb two HaW (Local practice), NS-Not significant, *-significant at 5 %, **-significant at 1 %, LoS-Level of significance, L-Locations, T- Weeding methods, , SiLS-Silty loam soil, CLS-Clay loam soil, SCS-Sandy clay soil, SCLS-Sandy clay loam soil, LS-Loam soil, SiCLS-Silty clay loam soil and SLS-Sandy loam soil. Means followed by a common letter (s) or without a letter in the same row and column are not statistically significant whereas means with different letters differ significantly at a 5% level of probability.

3.4.4 Weeds dynamic

Weeds dynamics depended on the weeding quality, soil moisture, weeding regime, and soil conditions. Two-ways interaction of weeding methods and locations was not observed a significant effect on weeds dynamics whereas the single effect of locations and weeding methods showed a significant effect on weeds dynamics (Table 9). Weeds dynamics were observed significantly higher for BRRI manual weeder and local practices. Weeds dynamics were also observed minimum in both the locations of silt loam compared to the other locations of the country.

Table 9 Weeds dynamics after 1st weeding as affected by different weeding methods over the locations.

Treatments	SiLS	CLS	SCS	SCLS	LS	SiCLS	SLS	Mean
T_1	74.67	77.41	81.60	80.93	85.47	75.21	77.25	16.73^b
T_2	68.90	75.83	69.75	73.73	67.61	61.13	68.04	20.98^a
T_5	92.87	87.33	76.67	82.00	89.37	94.71	85.00	21.82^a
Mean	14.46^b	13.64^b	21.89^a	21.11^a	22.59^a	22.85^a	22.34^a	
CV	24.83							
LSD	L=4.69 and T=3.07							
LoS	L=*, T=** and L × T = ns							

T_1 - One weeding by power weeder (PoW) sb one hand-weeding (HaW), T_2 - One weeding by BRRI manual weeder (BMW) sb one HaW, T_5 - Mulching sb two HaW (Local practice), NS-Not significant, *-significant at 5 %, **-significant at 1 %, LoS-Level of significance, L-Locations, T- Weeding methods, SiLS-Silty loam soil, CLS-Clay loam soil, SCS-Sandy clay soil, SCLS-Sandy clay loam soil, LS-Loam soil, SiCLS-Silty clay loam soil and SLS-Sandy loam soil. Means followed by a common letter (s) or without a letter in the same row and column are not statistically significant whereas means with different letters differ significantly at a 5% level of probability.

3.4.5 Weed control efficiency

Weed control efficiency depended on the weeds density of the unweeded plots and weeding efficiency. Two ways interaction effect of the different weeding methods and locations was not significant whereas a single effect showed significant effects on weed control efficiency (Table 10). Significantly lower weed control efficiency was found for BRRI manual weeder whereas it was observed similarly in all locations except sandy clay loam where higher weed control efficiency was found.

Table 10 Weeds control efficiency after 1st weeding as affected by different weeding methods over the locations.

Treatments	SiLS	CLS	SCS	SCLS	LS	SiCLS	SLS	Mean
T_1	77.17	66.10	53.67	77.33	86.73	69.07	82.17	73.17^{ab}
T_2	75.53	75.63	60.53	67.93	61.43	71.03	59.53	67.38^{b}
T_5	92.87	73.83	48.97	74.20	88.53	94.53	84.27	79.60^{a}
Mean	81.86^{a}	71.86^{a}	54.39^{b}	73.16^{a}	78.90^{a}	78.21^{a}	75.32^{a}	-
CV	17.87							
LSD	L=12.495 and T= 8.179							
LoS	L=**, T=* and L × T = ns							

T_1 - One weeding by power weeder (PoW) succeeded by (sb) one hand-weeding (HaW), T_2 - One weeding by BRRI manual weeder (BMW) sb one HaW, T_5 - Mulching sb two HaW (Local practice), NS-Not significant, *-significant at 5 %, **-significant at 1 %, LoS-Level of significance, L-Locations, T- Weeding methods, SiLS-Silty loam soil, CLS-Clay loam soil, SCS-Sandy clay soil, SCLS-Sandy clay loam soil, LS-Loam soil, SiCLS-Silty clay loam soil and SLS-Sandy loam soil. Means followed by a common letter (s) or without a letter in the same row and column are not statistically significant whereas means with different letters differ significantly at a 5% level of probability.

3.5 Grain yield

The significantly lower yield was obtained at clay loam, sandy clay loam, and loam soil compared to the potential yield of the variety. At clay loam soil, crops were damaged by severe hail storms during vegetative periods and at Sandy clay loam and loam soil, late transplanting was the main cause of less yield due to late irrigation schemes started. However, crop yield was not varied significantly with the weeding management practices at clay loam. Weeds control methods did not affect significantly crop yield at silt loam, sandy loam, silt clay loam, and sandy clay except unweeded plots which gave lower yield. However, unweeded plots gave significantly lower yields in all cases followed by BRRI manual weeder weeded plots at sandy clay loam. At loam, BRRI manual weeder weeded plots along with unweeded plots gave lower yield followed by local practices (Table 11).

Table 11 Yield performance as affected by different weeding treatments.

Treatment	Yield at 14% M.C (t/ha)						
	SiLS (BRRI dhan28)	CLS (BRRI dhan28)	SLS (BRRI dhan58)	SiCLS (BRRI dhan89)	SCLS (BRRI dhan89	LS (BRRI dhan29)	SCS (BRRI dhan28)
T_1	4.57^{a}	4.44	4.93^{a}	5.64^{a}	5.77^{a}	4.16^{ab}	4.93^{a}
T_2	4.32^{a}	3.08	4.95^{a}	5.10^{bc}	5.63^{a}	3.48^{c}	5.90^{a}
T_3	3.13^{b}	2.86	4.48^{b}	4.80^{c}	3.55^{b}	3.15^{c}	2.39^{b}
T_4	4.60^{a}	3.47	5.26^{a}	5.63^{a}	6.46^{a}	4.39^{a}	4.96^{a}
T_5	4.09^{a}	3.61	5.07^{a}	5.32^{ab}	5.97^{a}	3.90^{b}	5.30^{a}
CV, %	6.58	22.24	5.5	5.0	16.19	8.07	14.63
LSD	0.513	1.463	1.294	0.498	0.580	1.669	0.511
LoS	**	ns	**	**	**	**	**

T_1 - One weeding by power weeder (PoW) sb one hand-weeding (HaW), T_2 - One weeding by BRRI manual weeder (BMW) sb one HaW, T_3 - Unweeded, T_4 – no-weed and T_5 - Mulching sb two HaW (Local practice), NS-Not significant, LoS-Level of significant, SiLS-Silty loam soil, CLS-Clay loam soil, SCS-Sandy clay soil, SCLS-Sandy clay loam soil, LS-Loam soil, SiCLS-Silty clay loam soil and SLS-Sandy loam soil. Means followed by a common letter (s) or without a letter in the same row and column are not statistically significant whereas means with different letters differ significantly at a 5% level of probability.

3.6 Weeding cost

Developed power weeder saved more than 5000 TK (BD) compare to the manual hand weeding methods (Table 12).

Table 12 Comparative weeding cost.

Power operated weeder (PoW)					Hand-weeding (HaW)			
Purchase Price (BDTk)	TFC (BDTk/h)	TVC (BDTk/h)	OC (BDTk/h)	OC (BDTk/ha)	MWC (m^2/h)	Capacity (h/ha)	Cost (BDTk/ha)	SOTWM (BDTk/ha)
30000.0	37.12	119.78	156.91	790.93	80.0	123.5	6175.0	5384.06

TFC-Total fixed cost, TVC-Total variable cost, OC-Operation cost, MWC-Manual weeding capacity. Considered: Working life: 3 years, Average annual use: 320 h, Capacity: 0.20 ha/h and SOTWM-Save over traditional weeding methods.

4. Conclusion

Developed multi-row power weeder was found suitable in operation under different soil conditions of Bangladesh and benefited over traditional weeding practices. The Actual and theoretical capacity of area coverage of the developed weeder is varied from 0.20 to 0.25 and 0.30 to 0.26 ha/h whereas average field efficiency is varied from 75-52%. The actual capacity of area coverage varied with the soil conditions in the order of Sandy loam>sandy clay>loam>sandy clay loam>silty clay loam>silty loam>clay loam. However, the weed control efficiency of the PoW was 73.18%. Proper line spacing and skilled operator is needed to operate the machine. This machine is only suitable in a wet field. Considering the field capacity, weeding efficiency, weed control efficiency, and saving over traditional weeding practices, developed multi-row power weeder could be suggested for dissemination to the end-users.

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