Design, fabrication and performance evaluation of a rotary power weeder for maize cultivation

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Abstract: This research work focused on the design, fabrication and performance evaluation of a rotary weeding machine for maize cultivation which is powered by a 1.25 hp petrol engine. The research work was aimed at reducing cost, labour, stress and time wastage involved in the weeding operation on the maize farm. The unit comprises of an engine, rotary blade, gearbox, fender, depth controller, walking wheel, handle and shutdown switch. The machine was fabricated from locally sourced materials, which makes it cheap and easily affordable and also easy and cheaper to maintain. The performance test of the machine was done in a maize field. The result of the field test revealed that the effective field capacity, field efficiency, weeding efficiency and the percentage of plant damage was 0.038 ha h^{-1}, 78.75%, 74.0% and 1.40% respectively. The total cost of construction the machine was US$ 191.1. The cost of weeding was US$ 1.45 h^{-1} or US$ 38.16 ha^{-1}. In compare with manual weeding the designed weeder can save 67.04% operational costs.

Keywords: maize, rotary weeder, power Operated, field Efficiency, weeding efficiency, plant damage.

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1 Introduction

Maize (*Zea mays* L.) or corn is the globe's one of the most common cereal grains surmised to have originated from Mexico and Central America about 8700 years ago (Schnable et al., 2009). Belonging to the family Poaceae, it is the principal food crop in several of the countries all over the globe, surpassing rice and wheat in terms of area, productivity, and yield (Foley, 2013). Having the highest genetic yield potential and nutritive value, it is quite commonly referred to as the "Queen of Cereals" (Singh, 2002). The maize crop is mainly cultivated during the rainy season and is used primarily for food, fuel, fodder, and industrial raw material.

In Bangladesh, maize cultivation started in the early 19th century (1809) in the districts of Rangpur and Dinajpur (Begum and Khatun, 2006). Maize cultivation has expanded massively in recent years because of huge demand for the cereal grain, making it a significant cash crop for famers in the country. During the current financial year 2022-23, farmers have grown the maize on more than 14 lakh acres, showed estimates by the Department of Agricultural Extension (DAE, 2023). A decade ago, in fiscal year 2011-12, farmers cultivated maize on 487,000 acres (BBS, 2012). They bagged nearly 13 lakh tonnes of

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maize in that year, said Bangladesh Bureau of Statistics data (BBS, 2012). During the fiscal year 2020-21, Bangladesh produced 40 lakh tonnes of maize in the fiscal year, up from 35.69 lakh tonnes the previous year (BBS, 2021).

At present, around 5 lakh farmers grow maize on about 5.50 lakh hectares of land across the country with each hectare yielding up to 11 tonnes of the grain (Dilip, 2023).

Among various biotic (insect, pest, predators, weed, etc.) and abiotic factors (drought, salinity, heat, etc.) that hinder maize production, weed is considered among the foremost factors restricting the maize crop yield. In general, weed may vastly diminish maize yield and sometimes cause complete failure of the maize plant. Weed has devastating effects on quality reduction through the mixing of weed seeds, ultimately decreasing the valuation of the crop. It also affects crop yield by competing with the main crop plant for light, water, nutrient, and sometimes producing chemicals that are considered harmful to the associated crop. Under water-stress condition, weeds can reduce crop yields more than 50% through moisture competition alone (Suvain et al., 2023). Hence, weed is still considered a formidable economic problem in maize. Poor weed control can result in over 50%-70% reduction in crop yield and one third of the cultivation costs is weed cost (Oni, 1990). In Bangladesh, improper weeding causes yield loss that range in between 40%-50% in rice, 24%-58% in wheat, almost 49% in maize, 43% in potato, 20% in sugarcane, 75%-80% in jute, 9% in tea and 25%-60% in other crops (Weed Science Society of Bangladesh, 2019). Total maize yield reduction of 58%–62% in winter and 67%–79% in summer was documented from unrestricted weed growth, including an average of 65% plant height reduction under the same weedy conditions (Mukhtar et al., 2007). It is therefore essential to control weed in order to reduce losses in production cost and improve crop yield.

Weed management is very critical for the first week after planting maize. Maize is most sensitive to weed competition during the early phase of its growth as it grows slowly during the first 3 to 4 weeks (Rajeshkumar et al. 2017). In Bangladesh, small hand tools, spades or chopping hoes, animal-drawn weeder and implements are used for traditional methods, also fewer uses of biological and chemical methods. Hand hoe weeding when done timely twice or thrice, or the use of herbicides have controlled weeds effectively in maize (Acland, 1971) Although the popularity of chemical weeding is slowly increasing day by day, but the cost of chemical weeding is very high. Also, the chemical weeding can cause an adverse effect by changing the soil quality, soil formation, damage to the environment and the human health problem while operating with chemical herbicides. According to Kumar et al. (2017), the mechanical method of weed control is the best method of weeding with little or no limitation because of its effectiveness. Many researchers have developed different types of power weeder in different countries in the world such as:

Arinola and Fagbola (2022) designed, fabricated, assembled and tested hand pushed semi-automatic mechanical weeder for use on various soil types. The highest theoretical field capacity (TFC) record was at the engine speed of 4,000 rpm which is 3.0 square meter per second. The higher soil moisture content and higher engine speed resulted in the higher field capacity.

Hossen et al. (2015) analysed the Korean multi row power weeder was modified for Bangladesh land conditions considering the line to line spacing of 18, 20 and 22 cm. All weeding Technologies were useful to remove the weeds. It is profitable over the traditional method. Single row power weeder was least profitable compare to the manual weeding.

Saravanakumar et al. (2021) confirmed the fabrication and performance evaluation of power weeder that attained less operating cost than conventional type weeder it shows c type blade give better weeding efficiency and less plant damage during the operation on field than compare to other type of blade. Weeding efficiency is reduced while the moisture is higher than 17 per cent in soil.

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 (Hossen et al., 2021). For these reasons, the present study was undertaken to design a low cost efficient rotary power weeder for maize cultivation.

2 Materials and methods

2.1 Design consideration and machine construction

The design consideration of the weeder was simple. For an effective and maximum efficiency of the machine the following criteria and factors were carefully and critically considered to arrive at a workable and cost-effective design; weight, shape, size of the machine; mechanical property of the soil e.g. hardness, toughness, strength, moisture content, ergonomic consideration such height of the machine, material availability, affordability of materials, cost of maintenance, replaceable parts. It was designed and fabricated in a way to perform a comfortable weeding operation. The weight distribution of the machine kept as minimum as possible for the operator. Figure-1 shows the 3D isometric view of the conceptual design of the weeder. The unit comprises of an engine, rotary blade, gearbox, fender, depth controller, walking wheel, handle and shutdown switch. A 2 hp, two stroke cycles, single cylinder patrol engine was used to supply power for weeding operation. The rotary blade was made of mild steel angle. Gear box was used for operating the rotary blade at different speed. The frame of the weeder was made of mild steel angle bar.

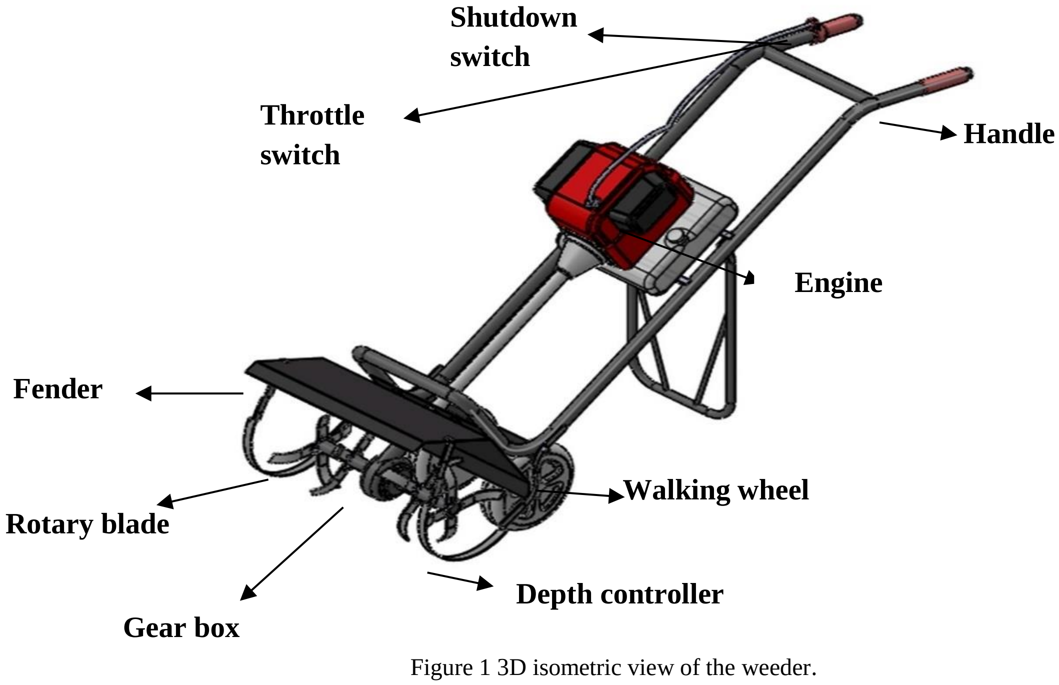

Figure 1 3D isometric view of the weeder.

2.2 Working principle

The engine power is directly connected to the power take off (PTO) shaft and the PTO shaft is connected to the worm gear box. The gear box reduced the engine speed. The rotary motion of the primary or PTO shaft is transmitted to blades through the gear box which are attached with the secondary shaft. The blades are rotated in clockwise direction and the weed is removed perfectly near to the plant. The handles are provided for turning the direction of the machine.

2.3 Performance evaluation

The performance of the weeding machine was evaluated. The study was conducted in northen part of Sadar in Dinajpur district, which is situated in 24.85º N latitude and 89.37º E longitudinal at an elevation of 35 m above mean sea level, northwest part of Bangladesh. For the performance test three plot of maize field having size 30 m^2 was used for the study. The time required for weeding each field was recorded by stop watch. Number of weeds in an area of 1m^2 was counted before and after weeding operation for determination of weeding efficiency.

2.3.1 Calculation of the operating speed

The speed of operator was calculated by ratio of distance travelled to time required (Olaoye and Adekanye, 2011).

$$S=\frac{d}{t} \quad (1)$$

Where,

S = Forward speed, ms^{-1}

d = Distance traveled, m

t = Time, s

2.3.2 Effective working depth of cut

The depth of cut of the machine with different blades was measured in the field by measuring the depth of soil layer tilled by the blade in a row. The depth of the weeding was measured by measuring scale in different rows at different places. Average of 3 observations was taken as depth of weeding and expressed in cm.

2.3.3 Effective working width of cut

The width of cut of the machine with different blades was measured in the field by measuring scale in different rows at different places.

2.3.4 Theoretical field capacity

Theoretical field capacity of the machine is the rate of field coverage of the machine that based on 100 percent of time at the rated speed and covering 100 per cent of its rated width. It is expressed as hectare per hour and determined as follows (Kepner et al., 1978)

$$TFC = \frac{SW}{C} \quad (2)$$

Where,

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

W = Cutting width, m;

S = Operating speed, km hr^{-1};

C = Constant, 10.

2.3.5 Actual or effective field capacity

Field capacity of a machine is defined as the actual rate of area covered and actual harvesting time. In other words, effective field capacity of a machine is a function of the rated width of the machine. By using the following formula effective field capacity was calculated (Hunt, 1983).

$$EFC = \frac{A}{T} \quad (3)$$

Where,

EFC = Effective field capacity, ha hr^{-1};

T = Total time for the reaping operation, hr;

A = Area of land reaped at specified time, ha.

2.3.6 Field efficiency

Field efficiency is defined as the ratio of the actual field capacity and theoretical field capacity expressed in percent (Kepner et. al., 1978).

$$E_f = \frac{EFC}{TFC} \times 100 \quad (4)$$

Where,

E_f = Field capacity, %;

EFC = Effective field capacity, ha hr^{-1};

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

2.3.7 Fuel consumption

Before starting the weeding operation by the rotary weeder in the test plot, the fuel tank was completely filled. After weeding the test plot, fuel tank of the rotary weeder was again filled up to its full measure the required quantity of fuel and recorded. Fuel consumption was determined in litres per hour (Lit hr^{-1}), is the amount of refueling for the weeding, in every step of test trial the fuel using measuring cylinder. Fuel consumption was calculated by using standard method as follows

$$FC = \frac{q}{t} \quad (5)$$

Where,

FC = Fuel Consumption, Lit hr^{-1};

q = Quantity of fuel consumed, Lit;

t = Consumption time, hr.

2.3.8 Weeding efficiency

Weeding efficiency is the ratio between the numbers of weeds removed by power weeder to the number of weeds present in a unit area and is expressed as a percentage. The samplings were done by quadrant method, by randomly selection of spots by a square quadrant of 1 square meter (Tajuddin, 2006). Higher the value of weeding efficiency better is the weeder performance.

$$weeding\ efficiency, W_e = \frac{W_1 - W_2}{W_2} \quad (6)$$

Where,

W_1 = Number of weeds counted in a unit area before weeding operation;

W_2 = Number of weeds counted in same unit area after weeding operation.

2.3.9 Plant damage

The percentage of plant damage that were caused due to operation of different weeders was determined by counting the number of uprooted or damaged plants in a row and by using the relation,

$$d = \frac{Q_1 - Q_2}{Q_2} \quad (7)$$

Where,

Q_1= number of plant in 10 m row length before weeding;

Q_2= number of plant in 10 m row length after weeding.

2.3.10 Performance index

The performance index of the weeder can be calculated by multiplying field capacity, weeding efficiency, plant damage percentage and dividing the result with the power input of the weeder.

$$PI = \frac{FC \times W_e \times d}{P} \quad (8)$$

Where,

PI = Performance index;

FC= Field Capacity of weeder, ha hr^{-1};

W_e= Weeding efficiency, %;

d = Plant damage factor = (100-% plant damage);

P = Power input, hp.

2.4 Cost Analysis of the Weeder

A Simple cost analysis was done for the weeder. The analysis included the actual cost of the device, annual fixed cost and variable cost. The annual fixed cost included depreciation, interest and shelter cost. Variable cost included repair and maintenance cost, labor cost and fuel cost. Assumption was made as interest 9%, shelter 0.01% per year; repair and maintenance cost 0.01% per hr, operation per day 8 hrs, annual use 300 hrs and estimated life span 10 yrs of the machine. The cost was calculated using following formulas: The annual depreciation was calculated as

$$D = \frac{P - S}{L} \quad (9)$$

Where,

D = depreciation;

P = purchase price of the machine, US$

S = salvage or selling price, US$

L = Life of the machine, yr

Interest on investment was calculated as,

$$I = \left[\frac{P + S}{2}\right] \times i \quad (10)$$

Where,

I = interest on investment,

P = purchase price of the machine, US$

S = salvage or selling price, US$

i = current interest rate.

Total cost per year calculated as,

Total cost = Annual fixed cost + Variable cost (11)

3 Results and discussion

3.1 Specification of the weeder

The specifications of the weeder such as dimensions of the different parts of the weeder, the type and power of the engine shown in the Table 1.

3.2 Field performance of the weeder

The field performance of the weeder was shown in Table 2. From Table 2 it was seen that the theoretical field capacity and the effective field capacity of the weeder was 0.048 ha h^{-1} and 0.038 ha h^{-1} respectively. The field efficiency of the weeder was 78.75% found from the field test result which is almost similar to a multi-rows power operated weeder designed by Hossen et al. (2021) in Bangladesh Rice Research Institute (BRRI), Gazipur.

3.3 Performance parameter of the weeder

The performance parameter of the weeder after the field test was shown in the Table 3. The weeding efficiency of the weeder was 74.0% found from the field test. The weeding efficiency of the multi row power weeder designed by Anwar et al. 2021 was found 78.93% which is slightly higher from us and for manual weeding efficiency was 69.28% which lower than us. The plant damage percentage was 1.4%. Fuel consumption of the weeder was found 0.75 liter hr^{-1}. The performance index was calculated and it was 179.97.

Table 1 Specification of the weeder

Items	Specification
Type of machine	Engine operated wheel moving weeder
Dimension of the weeder	
Length (mm)	1400
Width (mm)	300
Height (mm)	210
Engine model	1E40F
Engine type	Air-cooled, 2 Stroke, single cylinder petrol
Engine power	1.25 kw, 7000 rpm (1.5hp)
Carburetor	Diaphragm Type
Starting method	Manually drawing wound type
Power source	Petrol
Number of row	single
Wheels	Two ground wheel
Wheel diameter(mm)	200
Blade diameter (mm)	240
Shaft length (mm)	356
Shaft diameter (mm)	28
Shaft thickness (mm)	2

Table 2 Field performance of the weeder

Sl. No	Distance travelled (m)	Time taken to travel this distance (sec)	Speed of travel (km h^{-1})	Average Speed of travel (km h^{-1})	Theoretical field capacity (ha h^{-1})	Effective field capacity (ha h^{-1})	Field Efficiency (%)
1	10	20	1.8	1.71	0.048	0.038	78.75
2	10	22	1.63				
3	10	21	1.71				

Table 3 Performance parameter of the weeder

Plot no.	Weeding efficiency (%)	Plant damage (%)	Fuel consumption (lit hr^{-1})	Performance index
1	72.47	1.7	0.75	179.97
2	74.26	0.8	0.83	
3	75.26	1.7	0.67	
Average	74	1.4	0.75	

3.4 Economics of the weeder

The present weeder was designed and fabricated in such a way as to keep its cost low. Table 4 shows the cost factors and items of the weeder. From the table, it can be seen that the cost of weeding with the present weeder was only US$ 38.16 per hectare.

In comparison with manual weeding, in manual weeding the average capacity of a man was 0.1012 ha day^{-1} but the effective field capacity of the weeder was 0.3024 ha day^{-1}. It revealed that the weeding by the rotary weeder was almost 3 times faster than manual weeding. In case of manual weeding the total weeding cost US 116.48 $ per hectare whereas weeding by the rotary weeder costs US$ 38.16 per hectare. It was estimated that weeding costs could be saved 67.04%.

Table 4 Cost factors and items of the weeder

Cost factors/items	Unit	Amount
Cost of the weeder	US$/Unit	
Materials	US$	63.7
Gear box	US$	9.1
Engine	US$	77.35
Construction cost	US$	40.95
Total Cost	US$	191.1
Life of the weeder	Year	10
Annual use	Hrs	300
Annual fixed cost		
Depreciation	US$ yr^{-1}	17.20
Interest (13%)	US$ yr^{-1}	9.46
Shelter(0.01% of P)	US$ yr^{-1}	0.019
Total	US$ yr^{-1}	26.67
Total	US$ hr^{-1}	0.089
Variable Cost		
Repair and maintenance (0.01% of P)	US$ hr^{-1}	0.019
Labour (single labours, 400tk/day)	US$ hr^{-1}	0.46
Fuel cost	US$ hr^{-1}	0.89
Total	US$ hr^{-1}	1.36
Total cost	US$ hr^{-1}	1.45
Cost of weeding (assuming 0.038 ha/hr)	US$ ha^{-1}	38.16

4 Conclusions

A manually operated rotary power weeder for maize cultivation operated by a 1.25 kW petrol engine was designed and developed for weeding with minimum plant damage and power requirement. The effective field capacity and field efficiency of the weeder was 0.038 ha h^{-1} and 78.75% respectively found from the performance test in the field. The weeding efficiency of the weeder was 74.0% and the plant damage was 1.40%. The fuel consumption of the engine for weeding operation was 0.75 liter h^{-1}. The cost of operation of the developed weeder was found to be US$ 1.45 h^{-1} and US$ 38.16 ha^{-1}. The developed rotary weeder was saved 67.04% operational costs in compare with manual weeding.

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