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DEVELOPMENT OF AN ORCHARD WEEDER CUM MINI TILLER

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Abstract

Number of fruit orchards have been increased over the years and also being increasing with a reasonable pace in Bangladesh. But the orchard owners are facing problems in tilling and weeding their lands. Thus, the farmers are, now, searching for suitable power weeder cum mini tillers for both tilling and weeding operations, specifically, for a machine that can be used safely for weeding and cultivating vegetables and spices in orchard lands. Therefore, this research was undertaken to develop a power weeder suitable for both orchard and kitchen yards. On a previous BARI developed weeder, improvement was done by redesigning it during 2020-22. Then the weeder was fabricated with locally available materials and spare parts. The power weeder was operated with a 4.0 hp diesel engine and the weight of the weeder was 140 kg. The effective field capacities of the improved weeder in the orchard and in the kitchen garden as mini tiller were 0.068 and 0.075 ha/h and the field efficiencies were 73.71 and 77.84%, respectively. The operating cost of the orchard weeder cum mini tiller was 1700 Tk/ha. Net profit from the orchard weeder cum mini tiller was 150000 Tk/year. The BCR of the machine was 1.64 and the payback period was 0.33 year. The weeding index in the kitchen garden and in the orchard were 0.88 and 0.80, respectively. The orchard weeder cum mini tiller can be used in high density orchard since the designed width was less than that of the power tiller. Thus, the orchard weeder cum mini tiller could be recommended for the orchard farmers.

Keywords: Orchard, Weeder, Mini Tiller, Capacity, Efficiency, Profit.

Introduction

Weeds have always been problems in the crop cultivation process as they reduce yields and deteriorate the quality of crops. Weeds reduce yields by competing with crops for water, nutrient and sunlight. Weeds may also reduce profits directly by hindering harvest operations and producing chemicals that are harmful to crop plants (allelopathy). The weeds give shelters to insects, compete with the crops for water, light, and plant nutrients, reducing the quality and yield of crops and farmers' income (RNAM, 1993; Frayer, 1970). This competition generally occurs quite early in the life of a crop and thus, the damage causes heavy lossto the farmers (Paul *et al*., 2025; Paul *et al*., 2023; Dilipkumar *et al*., 2020). More than 3,000 weed species have been identified all over the world (Olukunle and Oguntunde,

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2006). The cost of weed management is enormous; however, the opportunity cost of weed management is higher (Kushal *et al*., 2024). Yield reduction (50-70%) is caused by poor weed control (Oni, 1990; Dilipkumar *et al*., 2020). Therefore, timely removal of weeds is essential to achieve increased agricultural production.

Four methods of weed controls such as cultural, mechanical, biological and chemical were identified (Robbins and Craft, 1962; Manuwa *et al*., 2009; Saha *et al*., 2021). The decision on which weed control method is to adopt depends on several factors such as specificity of weed problems, farm size, type of growing crops, availability of working labours and tools used (Mganilwa *et al*., 2003; Zimdahl, 2018). Mechanical weeding is an environmentally friendly method for controlling weeds (Mganilwa *et al*., 2003; Manuwa *et al*., 2009; Islam *et al*., 2024).

Mechanical weeding using improved hand tools or power operated machines appear to be the most practical and efficient method for the country. Agricultural labour is becoming scarce and their wages are also increasing day by day. On the contrary, engine is becoming popular as a source of power and engine operated machines are replacing costly and drudgery manual operations (land preparation, threshing, winnowing, etc). Therefore, Use of power weeder should get high preference to reduce the cost of weeding, maintain timeliness, and to meet-up the scarcity of agricultural labour.

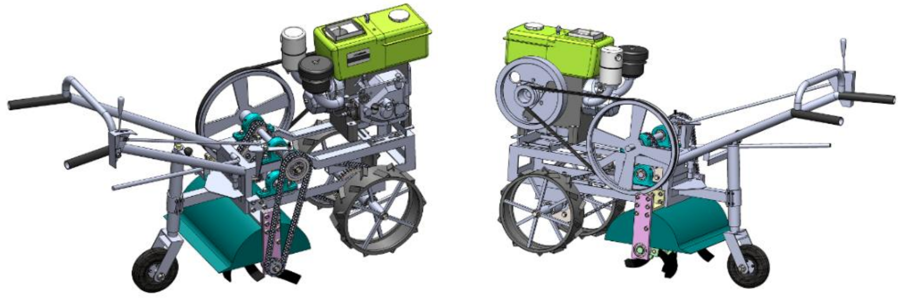
Mechanical weeders range from basic hand tools to sophisticated tractor driven or self-propelled machines. Such weeders include cultivation tools such as hoes, harrows, tined implements, brush weeders, cutting tools like mowers and trimmers, as well as implements like thistle-bars that may do both (Bond and Turner, 2005; Manuwa *et al*., 2009). The term mechanical weed control is restricted to methods implying shallow (0-50 mm) soil tillage (Kurstiens, 2002). If the working depth of cutting tools is adequately shallow and precisely controlled, they may be operated as close as 20-30 mm from plants (Ascard and Mattsson, 1991; Melander and Hartvig, 1997; Northway and Tullberg, 2000; Home *et al*., 2001). So, inter-row weed control is generally not a problem if this strip can be tilled (Kurstiens, 2002). Mechanical weed control not only uproots the weeds between the crop rows but also keeps the soil surface loose, ensuring better soil aeration and water intake capacity (Prasad *et al*., 2019). Manual weeding can give a clean weeding, but it is a slow process (Biswas 1990).

In Bangladesh, though many researchers of BARI and BRRI worked on manual weeder, a good initiation was done on development of power weeder by Hoque *et al.* (2010). The weeder was mainly developed for row crops and tested for weeding in mango orchard. Gulandaz *et al*. (2019) developed a battery-operated weeder for row crops during 2016-19. Recently, a good number of fruit orchards have been grown up and farmers are searching for suitable power weeders to use in those orchards not only to till inter row spaces for weeding but also cultivating vegetables on those spaces. Battery operated weeder was not capable to operate in the orchard.

Hoque *et al.* (2010) also suggested for further detailed study to adopt the power weeder in the orchard. However, this research was undertaken as continuation of the previous study to improve the power weeder suitable for both orchard and kitchen yards.

Materials and Methods

An orchard weeder cum mini tiller was designed and fabricated in Farm Machinery and Postharvest Process Engineering Division of BARI, Gazipur during 2021-22. The design (Fig. 1) was performed with the aid of the software, Solidworks 2022. Orthographic views of the machine with dimensions are shown in Fig. 2.



Left view Right view

Fig. 1. Isometric views of the orchard weeder cum mini tiller.

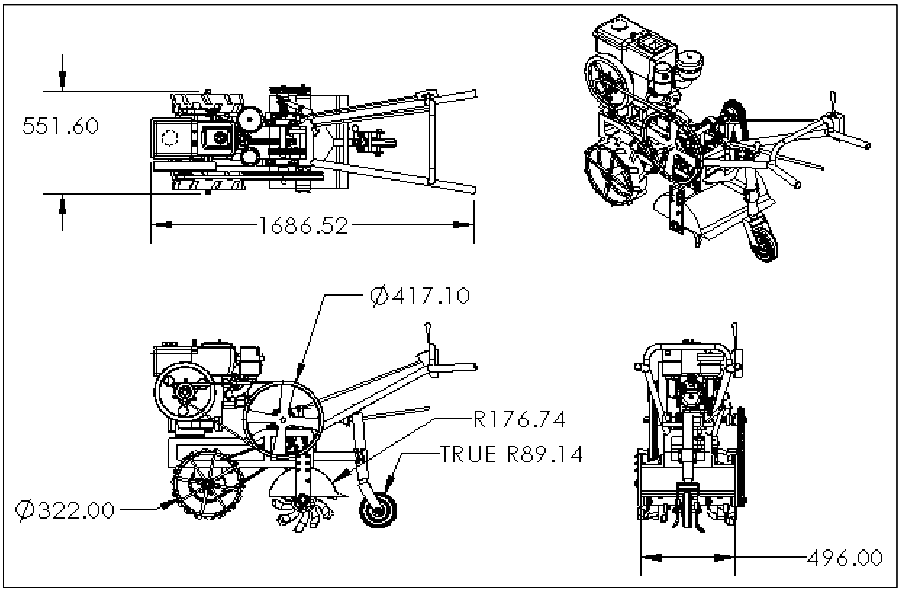


Fig. 2. Orthographic views of the orchard weeder cum mini tiller.

The major functions parts are described briefly as follows.

Engine: A diesel engine (4 hp) was used as the source of power. This engine is China made and available in the market.

Mainframe: The mainframe (Fig. 3) was supported on a wheel shaft by bearings. It was made of 40×40×5 mm MS angle. The engine was hinged on the mainframe with nuts and bolts. The mainframe also supported power transmission shafts, rotary shaft assembly, clutch mechanism, depth control wheel, and handle.

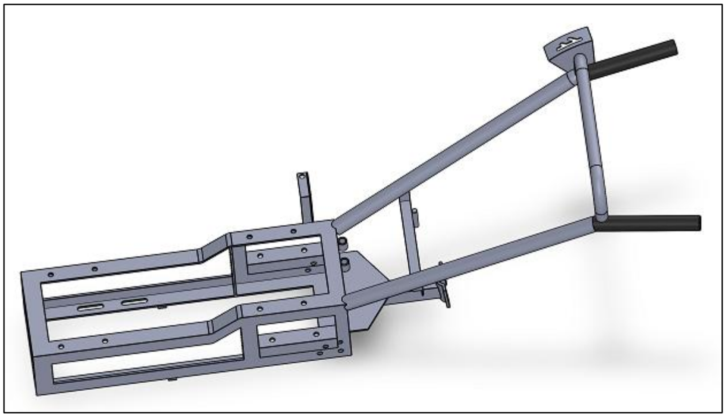


Fig. 3. Mainframe of the weeder.

Drive wheel: The weeder was supported on two drive wheels (Fig. 4) made of 50 mm flat bar. The wheel diameter was 360 mm. Lugs, made of 40x40x5 mm MS angle bar of 16 mm height, were 55 mm apart to provide grip on soil. The wheel to wheel outer distance was 500 mm and space between the wheels was 300 mm which allowed operating between 30 and 60 cm row spacing.

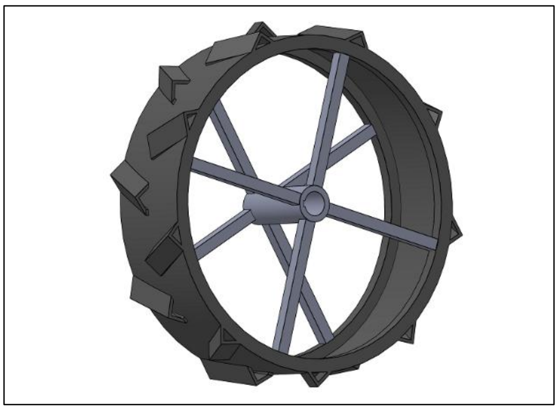


Fig. 4. Drive wheel of the machine.

Depth wheel: Depth wheel of 210 mm diameter and 65 mm width supported rear of the rotary blades by a depth control assembly. The depth of the rotary blade be adjusted by the depth control attachment. The depth wheel also bears some load of the weeder giving the operator comfort and helps maintaining the direction of travel.

Handle: The handle was made of MS pipe and attached to the mainframe (Fig. 3). This part enabled the operator to keep the weeder straight during operation and to make a turn in the headlands by hanging the handle to raise the rotary. The handle was fixed at ergonomic working height (0.90 m) of the operator. Two clutch levers were attached to the handle - one for the rotary shaft (right) and one for the wheel axle (left). An accelerator lever was also attached to the right handle. A main gear lever was provided with the load transmission system set to the wheel axle.

Rotary shaft with blade: The rotary shaft (Fig. 5) was made of MS pipe and MS shaft. Total 14 blades pockets were welded on the rotary shaft with a screw thread pattern. Tip to tip blade tilling width was 468 mm. Individual blade width was 46.95.mm. The blade pocket to blade pocket horizontal space was 8 mm.

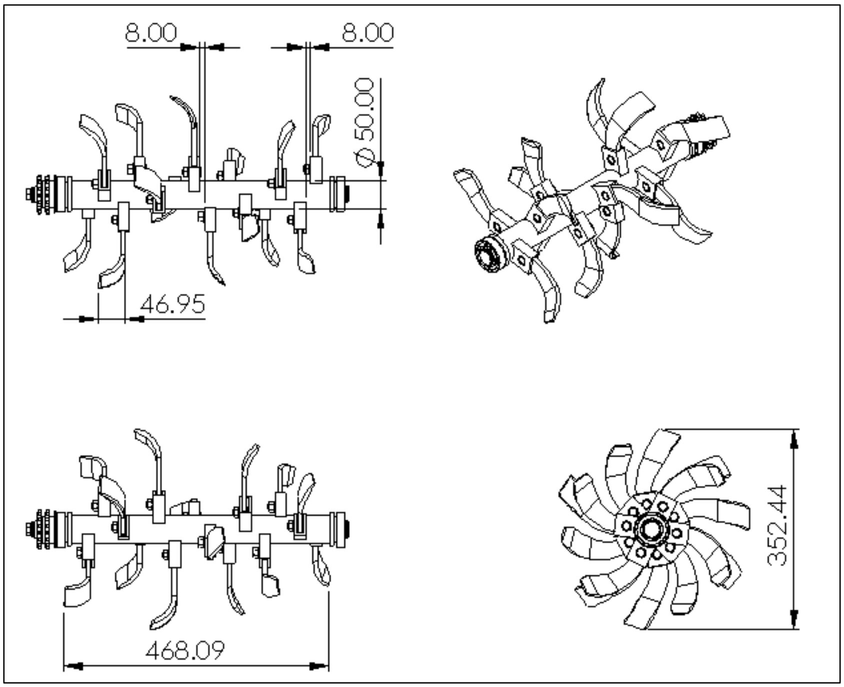


Fig. 5. The blade shaft with tilling blades.

Power transmission: The power transmission system is shown in Fig. 6. The engine speed was stepped down from 2000 to 370 rpm through belt pulley. The main pulley, where power was reduced, was directly coupled with main shaft. From the main shaft, power was divided into two ways. The rotary blade was powered from the main shaft through double gut chain and sprocket (Fig. 8). The rotational speed of the blades on the rotary shaft was maintained at 450-540 rpm. Power transmission to the blade was controlled by a dog-clutch to turn the power on and off. Power to the wheel shaft was transferred though an auxiliary shaft. There was a dog clutch in the auxiliary shaft to engage/disengage power from the wheel. The wheel speed was 35-42 rpm to obtain a laboratory speed of 2.0-2.3 km/h. The depth was adjustable by depth control wheel.

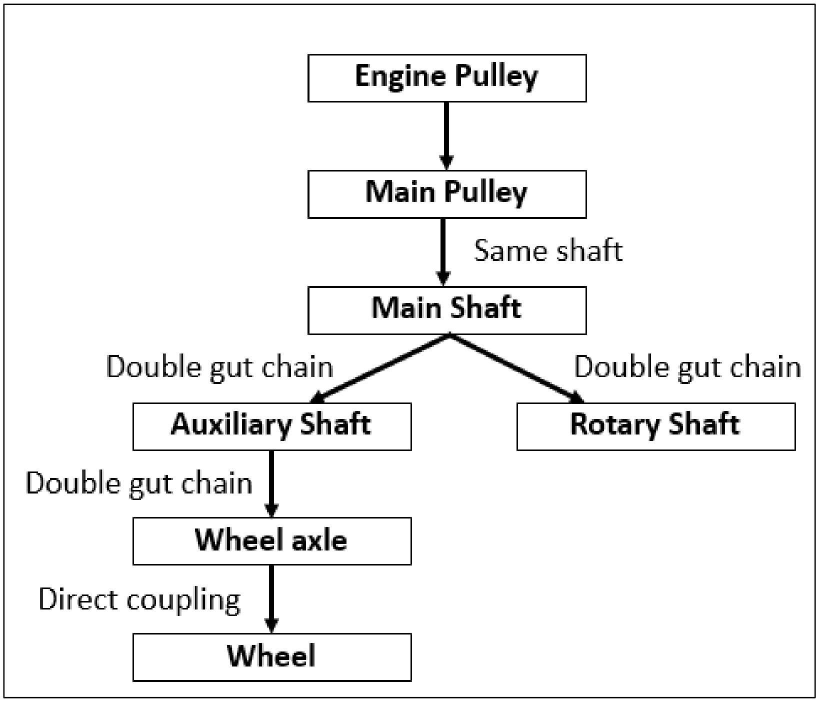


Fig. 6. Power transmission system of power weeder.

The machine was fabricated with locally available materials (Fig. 7) during 2020-21. The orchard weeder cum mini tiller was modified (Fig. 8) during 2021-22. The main components of the improved orchard weeder cum mini tiller comprised of drive wheel, depth wheel, mainframe, handle, power transmission system and engine. The materials of the machine were MS sheet, MS angle bar, steel rod, belt, pulley, chain and sprocket, nut and bolts. The fabricated machine (Fig. 9) removed the big gear box with typical power transmission system. Comparative specifications of both previous, and modified models during 2021-22 are shown in Table 1. The specifications of both the models are shown in Table 2.

Fig. 7. Previous model.

Fig. 8. Modified model.

(a) Right side view (b) Left side view

Fig. 9. Different views of the orchard weeder cum mini tiller.

Table 1. Comparative specifications and costs of both previous and improved weeder models

Sl.No.	Items	Previous in 2020-21	Modified in 2021-22
1	Power	4 hp	4 hp
2	Drive wheel type	Mild steel	Mild steel
3	Drive wheel diameter	330 mm	360 mm
4	Drive wheel lugs height	10 mm	15 mm
5	Depth wheel diameter	150 mm	210 mm
6	Power transmission	V belt; chain sprocket	V belt; double gut chainchain sprocket
7	Rotary shaft width	380 mm	380 mm
8	Weight	100 kg	140 kg

Table 2. Specification of the orchard weeder cum mini tiller

SL. No.	Parameters	Observation/value
01	Overall dimension (LxBxH), mm	1650 x 540 x 1200
02	Power, hp	04
03	Fuel type	Diesel
04	Fuel consumption, l/h	0.5
05	Power supply control	Dog Clutch
06	Main power transmission	Belt Pully
07	Other power transmission	Double chain
08	Tilling mechanism	Rotary tiller
09	Rotary blade speed, rpm	650
10	Number of blades, No.	12
11	Blade size, mm	80
12	Tilling width, mm	410
13	Soil tilling depth, mm	40-60
14	Rotary depth controller	Tail wheel with easy adjusting
15	Number of drive wheel	02
16	Drive wheel type	Metallic case wheel
17	Drive wheel size, mm (dia. x width)	360 x 100
18	Depth wheel size, mm (dia. x width)	210 x 65
19	Weight, kg	140

Performance test and evaluation

To ascertain various design parameter of the weeder, laboratory test was carried out to determine the engine speed, rotary speed and fuel consumption. Fuel consumption was determined from operating the power weeder at field speed in tilled soil and measuring the time and volume of fuel required.

The field experiment was conducted at a kitchen garden (Fig. 10) and a malta orchard (Fig. 11) at Bangladesh Agricultural Research Institute (BARI), Gazipur during 2021-22.

Fig. 10. Field performance evaluation of the weeder in a kitchen garden.

Fig. 11. Field performance evaluation of orchard weeder in a malta orchard.

The engine was started and clutch of rotary shaft was engaged. The depth was measured with a steel rule and set at 35-60 mm by adjusting rear wheel, depending on soil moisture, weed rooting, and soil condition (hard or soft). The wheel clutch was engaged and the machine traveled forward cutting the weeds and soil. Time to cover the length of the field was recorded. Seven-to-ten-centimeter margins on both sides of plants were left to protect the plant from injury. The effective width and depth of weeding were randomly measured by a steel tape. Lost time due to adjustments and interruptions were recorded. The weed count before weeding (WI) was done for the strip between crop rows and then tilled it by the power weeder. The weeder was also tested in the kitchen garden to till the soil in small plot at BARI campus. Three quadrants of 50×75 cm were previously marked on the soil and the weed species and number were recorded. Weed counts (uncut) were done in these three quadrates after one pass of the weeder. Weeds not uprooted or cut partially were counted as uncut, as it could survive. Effective field capacity (EFC) was calculated from the record of the total time required to cover unit plot. It included turning time and time required for break downs or adjustments. Theoretical field capacity (TFC) was calculated from the mean values of working width and speed. Field efficiency was calculated from the ratio of EFC and TFC. Average forward speed was calculated for each plot from the record of time required to travel one line (6 m).

Theoretical field capacity (TFC), effective field capacity (EFC), field efficiency (η), weeding index (e) were calculated using the following equations 1-4 (Dauda et al., 2013; Hoque *et al*., 2010).

$$TFC = \frac{W \times S}{10} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

$$EFC = \frac{A}{t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

$$\eta = \frac{EFC}{TFC} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

$$e = \frac{W_1\text{-}W_2}{W_1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4)}$$

Here, TFC= theoretical field capacity (ha h^{-1}), W = machine cutting width (m), S = speed of operation (km h^{-1}), EFC= effective field capacity (ha h^{-1}), A = working area (ha), t = working time (h), and η = field efficiency (%), W_1= weed count before weeding, W_2= weed count after weeding by mini tiller and e = weeding index (%).

Financial analysis

An economic analysis of the orchard weeder cum mini tiller was performed. The cost analysis included the operating costs of the machine. The operating costs of the machine included fixed costs and variable costs. The fixed costs of the machine included capital consumption and housing. Variable costs included labour, diesel, repair, and maintenance, lubrication cost. Labour was required to operate the machine.

Fixed cost

Fixed cost of the machine included annual depreciation, interest on investment, and shelter. Capital consumption included depreciation and interest as shown in equation (5-9) (Hunt, 2008).

i) Capital consumption (CC)

$$CC = (P\text{-}S)\ CRF + S \times I \qquad \text{(5)}$$

Where, P = purchase price, Tk; S = salvage value (10%P), Tk; CRF= capital recovery factor

$$CRF = \frac{i(1+i)^L}{(1+i)^L - 1} \qquad \text{(6)}$$

Where, i = rate of interest, L = life of machine, yr

ii) Shelter, T = 3.0% of purchase price of the machine, Tk (Hunt, 2008).

$$\text{Total fixed cost per year, } FC = CC + T \qquad \text{(7)}$$

Variable Cost

In calculation of variable cost, the following relations were assumed (Hunt, 2008).

i) Labour cost per hour, L_b=Tk man-h^{-1}

ii) Diesel cost per hour, D=Lh^{-1}

iii) Repair and maintenance (R&M) cost per year =3.5% of purchase price of the machine

iv) Lubrication cost per year, L= 3% of the diesel cost

Total variable cost, VC=L_b+D+R&M+L (8)

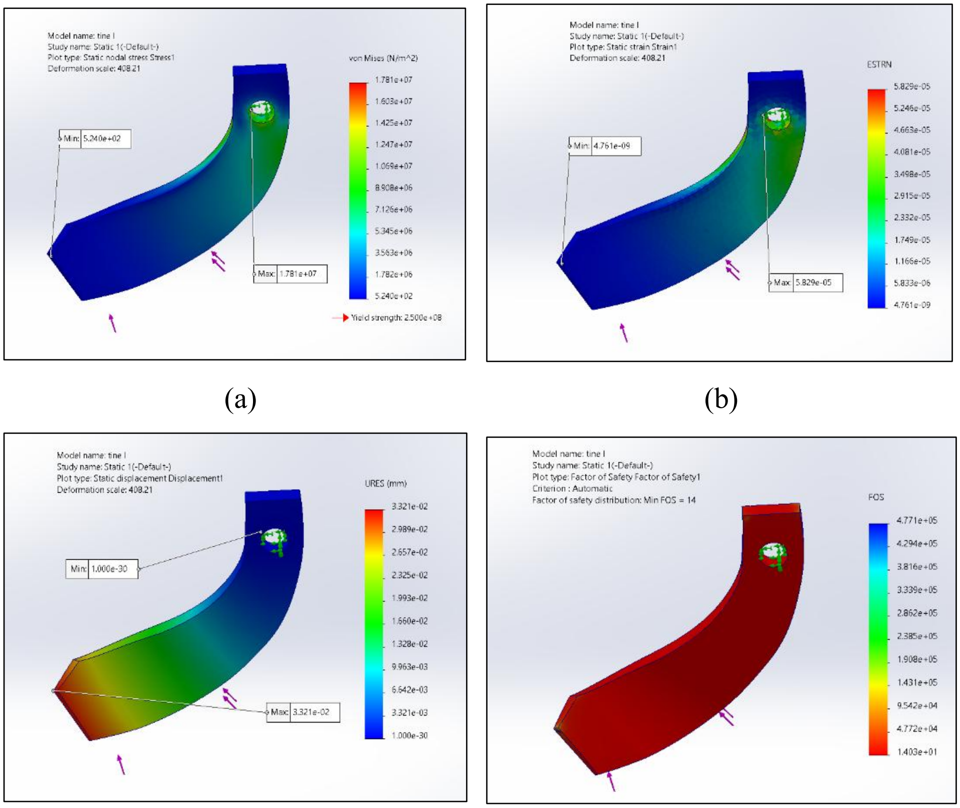
Annual cost/operating cost, AC= FC+VC (9)

Results and Discussion

The design analysis of tilling blade of orchard weeder cum mini tiller was done. The results of the analysis are shown in Fig. 13. The highest, medium, and lowest scales are represented by the colors- red, green, and blue in the figures, respectively. The design analyses were studied based on the load enforced on the tilling blade. To perform this, 100 N force was considered for the blade. The minimum factor of safety value of tilling blades was 14. This illustrated that the material would start to yield if much higher force is applied. The results also presented that the tine yield strength was 2.5×10^8 Nm^2, proposing that the tine or tilling blade of the orchard weeder cum mini tiller will start to bend in the other direction when the magnitude of the strength is greater than this amount (Fig. 12). It was noticed that the maximum and minimum von Mises stress 1.78×10^7 Nm^2 and 5.24×10^2 Nm^2. The highest displacement and strain of the head thrower were 3.32×10^{-2} mm and 5.83×10^{-5}, respectively. It revealed that maximum stress and strain of the tine were found in the connection point of the tine and the pocket. The maximum displacement of the tine may occur at the tip.

Laboratory Test

The laboratory test result is summarized in Table 3. The rotary blade speed was 450 rpm in the laboratory trial without load but the speed was reduced to 525 rpm when the weeder was used in the field. The theoretical field capacity of the improved power weeder was 0.09 ha/h. The fuel consumption was low (0.55 l/h) because the engine was only 4.0 hp.



(a) (b)

(c) (d)

Fig. 12. Tine analyses with application of 100 N force for: (a) stress; (b) strain; (c) displacement; and (d) factor of safety.

Table 3. Laboratory test of power weeder

Parameter	Values
Rated engine speed, rpm	2000
Rotary blade speed, rpm	400-500*
Fuel consumption, l/h	0.55
Theoretical field capacity, ha/h	0.09

* Field speed was 450 rpm

Field Test

The forward speed, depth of weeding, and field capacity were found good for the machine (Table 4). The soil was in friable condition and weeder was operated to the desired depth (3-4 cm). A chain-cover was also used to protect the chain-sprockets from dust. The dust protector also gave the advantage to reduce dust through to the operator in back. The field test results showed that the weeds in the malta orchard were effectively killed or uprooted in mechanical method. The effective field capacity of the improved weeder in the malta orchard was 0.068 ha/h and the field efficiency was 73.71%. The effective field capacity and field efficiency of the improved weeder in the kitchen garden as mini tiller was 0.075 ha/h and 87.22%, respectively. When the machine was used as weeder in the kitchen garden and orchard, the weeding index was 0.88 and 0.80, respectively (Fig. 13).

Table 4. Field performance of improved weeder during 2021-22

Crop	Forward speed (km/h)	Weeding width (mm)	Weeding depth (mm)	Effective field capacity (ha/h)	Field efficiency (%)
Orchard	2.25	410	45	0.068	73.71
Kitchen garden	2.35	410	50	0.075	77.84

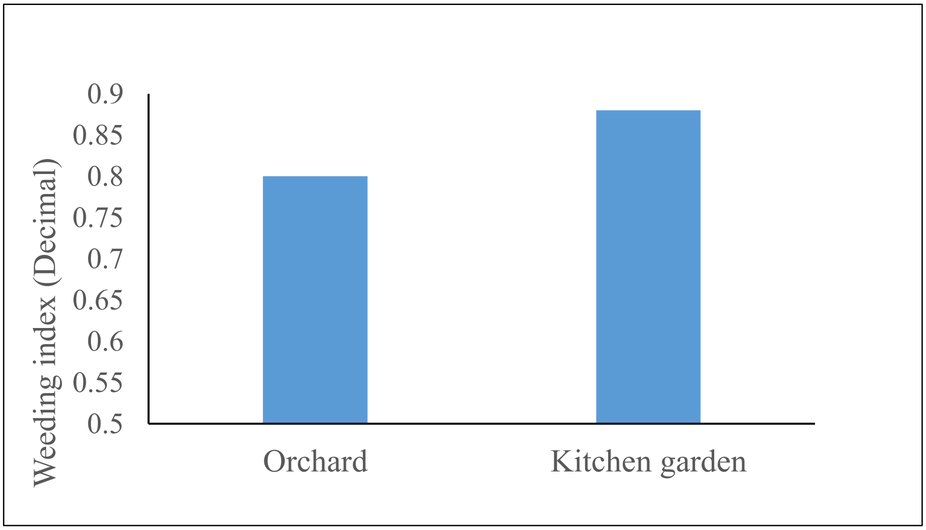


Fig. 13. Weeding index in orchard weeder and kitchen garden.

Financial analysis of the orchard weeder cum mini tiller is shown in Table 5. The operating cost of the orchard weeder cum mini tiller was 1700 Tk/ha. Net profit of the orchard weeder cum mini tiller was 15000 Tk/year. The BCR of the machine was 1.64. The payback period of orchard weeder cum mini tiller was 0.33 year.

Table 5. Financial analysis of the orchard weeder cum mini tiller

Cost Item	Orchard weeder cum mini tiller
Price, Tk	50000.00
Working days per year	100.00
Machine life, year	5.00
Salvage value, Tk	5000.00
Capital consumption cost (CC), Tk	9743.25
Shelter, Tk	250.00
Total fixed cost, Tk/year	9993.25
Total fixed cost, Tk/h	12.49
Labour cost per hour, Tk/h	62.50
Diesel cost, Tk/h	35.75
Repairing cost, Tk/h	2.19
Lubricating cost, Tk/h	1.0725
Total variable cost, Tk/h	101.51
Total operating cost, Tk/h	114.00
Capacity of the machine, ha/h	0.07
Operating cost, Tk/ha	1701.52
Operating cost, Tk/yr	91201.25
Custom hire-based income (@4500 Tk/ha), Tk/yr	241200.00
Net profit, Tk/yr	149998.75
BCR	1.64
Payback period (year)	0.33

Conclusion

An improved power weeder was designed and fabricated to operate with 4.0 hp diesel engine to operate in orchard and kitchen garden. The weight of the weeder was 140 kg. The width of weeding/tilling was 410 mm. The power weeder could be an effective means for fast and low-cost weeding of fruit orchard. This machine could be used year-round. The effective field capacity of the improved weeder in the orchard and kitchen garden as mini tiller were 0.068 and 0.075 ha/h and field efficiency were 73.71 and 77.84%, respectively. The BCR of the machine was 1.64. The payback period of orchard weeder cum mini tiller was 0.33 year. The orchard weeder cum mini tiller can be used in high density orchard since the width is less than the power tiller. Thus, this orchard weeder cum mini tiller could be recommended for the orchard farmers.

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