Development and Performance Evaluation of Low Cost 2WT Operated Earthing Up Machine for Sugarcane Cultivation in Bangladesh

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Article

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Abstract: Like the most of crops, especially sugarcane needs to be kept upright until it is harvested. Because, lodging of sugarcane has a significant negative effect on cane yield and sugar content of sugarcane. To keep sugarcane upright earthing up is an utmost intercultural operation. In Bangladesh, most of the operations for sugarcane cultivation including earthing up are generally done in traditional method using human labor which increases production costs as well as reduces the income of sugarcane growers. So, a cost effective two-wheeled tractor (2WT) mounted earthing up machine was developed in Bang-ladesh Sugarcrop Research Institute (BSRI), Pabna to reduce drudgery and cost of sugarcane production. Field tests were conducted in experimental sugarcane field at BSRI and technical and economic performances of the developed earthing up machine were also carried out based on the field test. Average effective field capacity and field efficiency were found 0.16 ha/hr and 77.41 %, respectively for the developed earthing up machine. The earthing up machine was not found economi-cally viable when it is used only for earthing up operation. Besides, when the 2WT was being used as the main driver for other activities including earthing up operation, then the earthing up machine becomes economically beneficial with net cash flow, net present value, internal rate of return, benefit-cost ratio and payback period of BDT 148497/ha, BDT 23184, 3%, 3.81:1 and approximately 1 year, respectively. On the contrary, considering cost of only earthing up tool without 2WT, then it was found economically beneficial with net cash flow, internal rate of return, net present value, benefit-cost ratio and payback period of BDT 16428/ha, BDT 3053, 4.7%, 2.71:1 and approximately 2 years, respectively. Since 2WT is commonly used for versatile farming purposes. Therefore, versatile use of 2WT as prime mover for other machines includ-ing earthing up machine can make earthing up machine economically viable and beneficial for sugarcane growers.

Keywords: Sugarcane cultivation; development; 2WT; earthing up machine; economic performance

1. Introduction

Sugarcane is one of the most important cash-cum food crops, which plays a vital role in augmenting income and employment of farmers of the country especially in the north to south of western areas of Bangladesh. Sugarcane is also an important cash crop after jute and tea in this country and has an influential effect on country's GDP of agricultural sector (10%) [1]. Moreover, sugar and jaggery (the major raw material of which is sugarcane) are important food ingredients that are integrated into the cultural tradition of making pithas, pies and sweets in every home in Bangladesh since ages ago. As if the people of Bengal cannot do without sugar and jaggery. However, Farmers often lose their encouragement in sugarcane production because of its less profitability and long duration features compared to other short duration cash crops**.** One of the major causes to be less profitable of sugarcane cultivation is human dependent or manual operated farming system in Bangladesh in lieu of farm mechanization in sugarcane cultivation.

Due to rapid urbanization and socio-economic development of people, farm labor is being shifted to relatively less strenuous manual labor and more prestigious work. Farm workers are

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becoming scarcer day by day as a result their daily wages is too high. Consequently, the cost of sugarcane production in the conventional hand-operated sugarcane cultivation system is becoming very high. In such a delicate situation, for sustainable sugarcane production, mechanization is must in all the operations of sugarcane production systems. Not unless mechanization in one word.

In the present context of globalization, ways and means have to be further evolved to produce more sugar per unit area, time and input in order to keep pace with the population growth while preserving the soil and water resources. Today's labor force is reluctant to come forward for agricultural operations in view of the tough nature of the job and low remunerations and also considering the lack of efficiency of manual labor [2]. For this purpose, it has been experienced that use of modern machinery is inevitable necessary. Use of machinery helps in labor saving, ensures timeliness of operation, reduces drudgery, helps in improving quality of work, reduces cost of operation and ensures effective utilization of resources.

Sugarcane is a yearly deep-rooted crop. Before harvesting sugarcane, numerous intercultural activities are required and earthing up, piling up soil near the root zone area of sugarcane tillers and often referred to as "hilling-up", is one of those. Yadav and Shukla [3] described that among the all of intercultural operations, earthing up is an important and very much beneficial operation in maintaining the growth, yield and juice quality, moisture conservation, addition of organic matter to soil, enhanced availability and uptake of plant nutrients, efficient utilization of solar radiation, suppression of weeds and preventing canes from lodging. Sugarcane is a giant shaped crop plant and it is important necessary to keep it standing until before harvest. Because, lodging of sugarcane has a significant negative effect on cane yield and sugar (sucrose) content of sugarcane. In an experiment conducted in Australia that prevention of lodging resulted in 11–15% and 15–35% higher cane and sugar yields, respectively [4]. A research conducted at the Sugarcane Research Station in Punjab investigated that considerable cane yield can be achieved owing to earthing up minimizing of lodging of pre-sown sugarcane [5]. This operation converts the furrows into ridges and ridges into furrows which provide both drainage of excess water during rains and serves as irrigation channels during post-monsoon period. Along with that a moderate weeding is also done and earthen soil helps tillers for their proper growth. In many high-sugar-producing nations, the earthing-up procedure is done in two or three phases but in Bangladesh, normally earthing up is performed once for giving soil support for sugarcane.

As sugarcane is cultivated in Bangladesh in conventional method, the earthing up operation is performed using locally manufactured hand spades. Through this way, a large group workers (8-10 workers) work with hand spades morning to afternoon (8 working hrs) for about 2-3 days for 1 ha area as per effective field capacity of hand spade is 0.012–0.02 ha/hr [6]. Highest sugarcane and sugar producing countries the same operation is done in only a few hrs by using machine.

Although, technology has been created for the sugarcane crop, adoption of these tools and machines has not been as high as expected level. As a result, there is a significant mechanization gap, particularly in the sugarcane planting, intercultural, harvesting, and ratoon management sectors. As a result, concerted efforts must be made to adopt, develop, and popularize sugarcane machinery for a variety of operations. They also claimed that performing earthing-up operation for sugarcane is necessary till cane formation height is not more than 40 cm and this can be done in mechanical means by small size tractor or power-tiller with earthing-up equipment where row to row spacing is not more than 90cm. Above this distance the earthen soil cannot be piled up at the sugarcane tillers stems [7].

Analysis of the cost components of sugarcane cultivation shows that weeding and earthing up operation of sugarcane field comprise 10% of the total costs of sugar cane production [8]. Nawal *et al.* (2009) showed that low hp tractor drawn earthing up machine had a satisfactory field efficiency above 70 percent where average depth of operation is 10.20 cm with average ridge height of 22.35 cm along with very low average plant damage which is only 1.11% [9]. Jadhav *et al.* (2013) claimed that his newly developed indigenous plough for ridging and earthing up had power requirement for ridging and earthing up operations 0.91 hp and 1.26 hp respectively [10]. The effective field capacity was found 0.18 ha/hr. and 0.21 ha/ hr. for ridging and earthing-up operations, respectively along with the

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field efficiency of implement was found 51.55% and 56.58% for ridging, and earthing up operations, respectively.

By mechanizing this earthing up operation, the cost of sugarcane cultivation can be reduced which will help the farmer to increase income as well as profit. For this purpose low hp small scale earthing up machine (small tractor or 2WT operated earthing up machine) is necessary and is needed to develop which is suitable for sugarcane farmers of our country. Therefore, the study was carried out to develop and evaluate the performances (technical and economic) of low cost 2WT powered earthing up machine for sugarcane cultivation in the context of Bangladesh to meet the above mentioned challenges.

2. Materials and Methods

2.1. Study Location

In this study, 2WT (power tiller) operated earthing up machine was designed and developed based on the concept of anti-bed-former machine to perform the earthing up operation of sugarcane and finally transformed as a rotary tiller type earthing up machine. The fabrication as well as the transformation of rotary tiller type earthing up machine was done in the Workshop of Bangladesh Sugarcrop Research Institute (BSRI), Ishwardi, Pabna under the support of the Agricultural Engineering Division of BSRI. The field performance tests were conducted at BSRI experimental sugarcane cultivation field, Pabna.

2.2. Design Considerations

To eliminate the interference of other factors, developed earthing up machine was deliberated following variable considerations such as line to line distance of sugarcane in the field, tyne selection and adjustment for soil pulverization, depth of expected furrow after soil removal and compaction of piled up soil at sugarcane root.

i) Line to Line Distance of Sugarcane

In sugarcane field, various line to line distances are generally practiced in Bangladesh. So, the maximum width of earthing up machine should be smaller than the minimum practiced distance between lines of sugarcane in the field. The minimum line to line distance being practiced most in Bangladesh is approximately 0.75 m. So, the maximum width of earthing up machine was kept 0.61m.

ii) Tyne Selection and Adjustment for Soil Pulverization

In earthing up operation, soil between two adjacent lines was pulverized and then the soil was needed to move away to form a furrow and that soil was piled up at the root zone of sugarcane. Hence R-type or J-shaped Tyne blades helped to displace the loose soil, this type of Tyne blades was selected for this machine. The blades adjustment should be in such a way that the half of the shaft of the earthing up machine was fitted with these sorts of blades facing one direction, while the other half with blades facing the opposite direction. The half of pulverized soil moved towards one side and other half of it towards other side and a furrow was formed.

iii) Diameter of Soil Compactor of Earthing up Machine

The diameter of soil compactor was kept higher than the depth of furrow created by earthing up machine. The furrow depth was kept 0.15 m. So with some clearance for bearing, the diameter of soil compactor was kept 0.38 m. In addition to some other points were also considered before design and development. Such as- motion of the parts, materials selection, workshop facilities, cost of construction, assembling and safety of operation.

2.3. Raw Materials

2.3.1. Materials Required

Various types of materials were selected according to their strength, availability in local market and the mechanical suitability. Types of material used for earthing up machine and the criterion of

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the usage were given below and the list of materials for the earthing up machine is shown in Table-1 as follows:

i) Carbon Steel Plain Sheet (ASTM 1020)

This type material is one of the most commonly used plain sheets. It has a good strength-to-ductility ratio and can be hardened or carburized. For these reasons, this material was selected for furrower drum and covering of tiller shaft.

ii) Mild Steel Bar and Rod (ASTM A36**)**

This type material is the most commonly used steel due to its excellent welding properties and its suitable processing. It is a low cost material with good ductility, weld-ability and high impact strength. For these, this material was selected for structural and heavy duty part like frame, shaft, etc. of the earthing up machine development.

Table 1. List of materials used for earthing up machine.

Parts	Description	Quantity
Shaft	Furrower shaft	1
Furrower drum	Conical soil compactor half drum	2
Bearing	Ball bearing with block	2
Connecting 1	Horizontal connecting bar	2
Connecting 2	Inclined connecting bar	2
Lever	Depth control bar	2
Shaft	Rotary tiller shaft	1
Radial bearing	Tiller shaft bearing	2
Tyne blade	R- type or J-shaped rotary tiller tyne blade	22
Cover	Rotary tiller cover	1
Nuts & bolts	1cm dia. nuts and bolts	68
Attachment		1

2.4.3. D Design of Earthing up Machine

CAD software was used to create a graphical representation of an earthing up machine that was identical to the original created machine. The earthing up machine's 2D and 3D model designs (Figures 1 and 2 respectively) were made using "Blender (version 2.8.1a)" software.

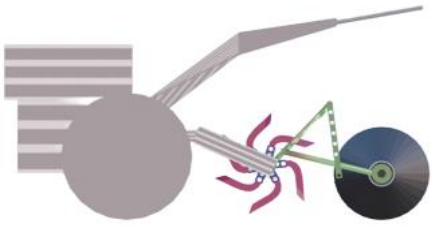

Figure 1. 2D model of earthing up machine with power tiller engine.

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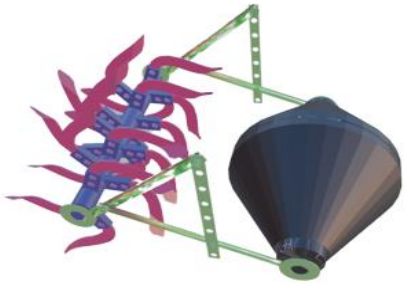

Figure 2. 3D model of earthing up machine.

2.5. Different Parts of Earthing up Machine

The earthing up tool did not have its own power supply. As a result, the earthing up machine (Figure 3) was powered by a small to medium-sized 2WT (two-wheeled tractor), locally named power-tiller. The earthing up machine was mounted behind the power tiller, which wrenched it through the gap between two lines of sugarcane tillers.

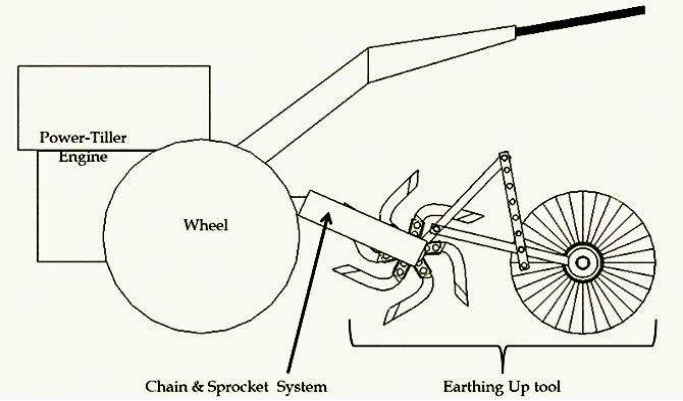

Figure 3. A net sketch of earthing up machine.

Earthing up machine consisted of some stationary and moving parts excluding the power source (power tiller engine or tractor) as shown in Figure 4. Design and development of different parts of the earthing up machine are shown in Figures 4–6.

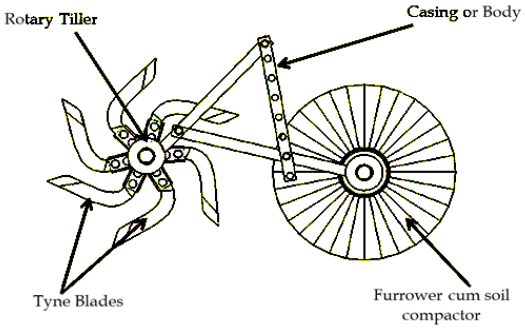

Figure 4. Different parts of earthing up machine.

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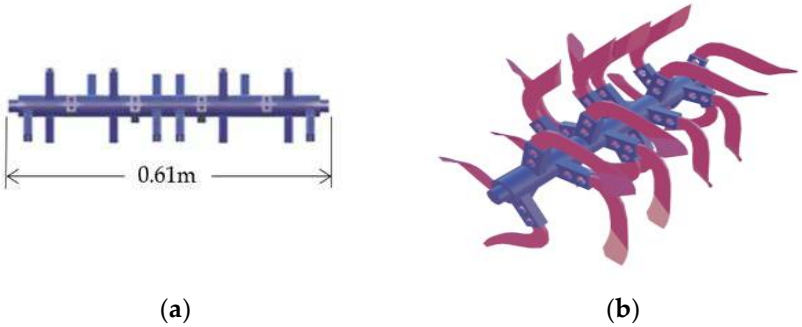

(**a**) (**b**)

Figure 5. Rotary tiller (**a**) shaft without tyne blades (**b**) shaft with tyne blades arrangement.

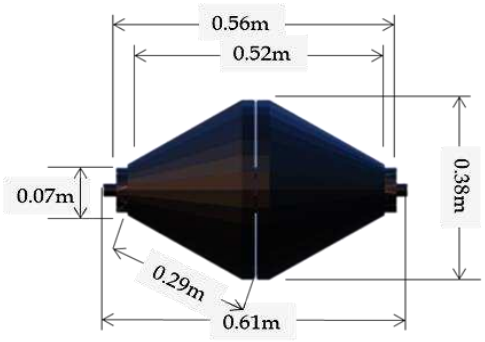

Figure 6. Furrower cum soil compactor.

a) Rotary Tiller

The rotary tiller (Figure 5) was the nearest moving element to the power source, receiving direct power from the engine via the chain and sprocket power transmission system. The rotary tiller's provided power was used to rotate the tiller-shaft (rotary-shaft) in a forward direction, allowing Tyne to pulverize the soil. To wrap Tyne around the shaft, there were 22 Tyne holders (Figure 5). The main functions of a rotary tiller were to hold and rotate Tyne for breaking soil clods, pulverizing ridge soil, and sending soil backwards to the ratoon root region for earthing up.

b) Tyne

R-type, or J-shaped Tyne blades, were employed for earthing up operations because of their functional benefits. This sort of Tyne blade sent the cut dirt both side and backward during rotating movement. To take advantage for earthing up operations, half of the shaft of the created earthing up machine was fitted with these sorts of blades facing one direction, while the other half blades facing the opposite direction (Figure-5b). The soil of the ridge between two sugarcane ratoon was swept from the center to both sides of the ridge and a furrow was produced for such facing of the blades.

c) Furrower cum Soil Compactor

The furrower cum soil compactor is just after the rotary tiller and Tyne blades. It is a drum configuration with two cone-shaped cylinders as shown in Figure-6. The drum revolved around a separate shaft. These two cone-shaped cylinders were fitted to the shaft such that the diameter in the center of the drum remains bigger than the diameter on the side. The crushed earth was rolled over this structure, which generated a V-shaped furrow. This drum structure also compacted material that had already replaced to the root area of sugarcane tillers, prevented soil from sweeping away from the cane root area and also provided wind resistance to the ratoon soil.

d) Casing or Body

Casing (Figures 1 and 2) is the frame of an earthing up machine that holds the shaft of the furrower cum soil compactor. It kept the furrower linked to the rest of the earthing up equipment. In addition, the casing acted as a dead weight for the soil compactor, allowing it to make a furrow. Because of the casing was so near to the furrower cum soil compactor, it also cleaned mud, grass, and other debris from the furrower drum.

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2.6. Fabrication of Earthing up Machine

The selected raw materials were first cut with a cutter machine into the desired form and size. Then the cut sheets were welded together with electric arc welding to produce two funnel-shaped drums. The shaft for the furrower was comprised of a hollow cylinder and thick MS rod. For simple operation of the earthing up machine and smooth shaft rotation, two MS ball bearings were employed. R-type, or J-shaped, Tyne blades were installed in Tyne holders on the Tyne shaft. The Tyne blades were adjusted to meet the needs of the operation. Over the arrangement of tiller blades, a covering was employed. After that the power tiller engine was adjusted in front of the rotary tiller. The furrower cum soil compactor was placed behind the rotary tiller after the Tyne blades were installed. The earthing up machine's casing or body was used to connect the furrower part. The body or casing was built of strong MS bars. A depth control bar was added to the casing, allowing the earthing up equipment to be utilized for different furrow depths.

2.7. Field Test of Developed Earthing up Machine

The developed earthing-up machine was tested in the experimental sugarcane cultivation field in BSRI, Ishwardi, Pabna. Before testing the machine in the field, the soil moisture was recorded with the help of digital soil moisture-meter (Figure 7a). The data were recorded from random places of the experimental field. After soil moisture recording, the developed earthing up machine was started and earthing-up and weeding operations were performed in that experimental sugarcane field. The developed machine was operated by an expert machine operator as shown in Figure 7b.

(**a**) (**b**)

Figure 7. (**a**) soil moisture measurement before earthing-up operation, (**b**) Field test of the developed earthing-up machine.

During machine operation, various measurements such as operational time and other time measurements were recorded with the help of stop-watch. Other measurements such as furrow width, depth of furrow, running distance, machine width were recorded after the earthing up operation. Using all the recorded data, the field performance of the developed machine was evaluated and the cost was also analyzed.

2.8. Performances of Earthing up Machine

i) Soil Moisture Content

In this study, a digital soil moisture meter was used to measure the soil moisture content. The probe of digital moisture meter was put to a specified depth into the soil of the trial field as shown in Figure 7a. The moisture content of the soil was promptly displayed on the digital screen after insertion of the moisture meter. The "Hold" button was pushed to prevent unnecessary change in reading.

Ii) Soil Disturbance

While testing the earthing up machine in the sugarcane field, the soil was turned over and the disturbed soil was earthen up, resulting in two ridges on both sides of the furrow. In Figure 8 W_{st} denoted the distance between the outside margins of the two ridges. The ridge to ridge distance is a

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distance between the two summits of the ridges on both sides of the furrow (RRC). The rest of the disturbed soil created the furrow's shallow groove. In Figure 8, the second line (the damaged soil surface) represents the groove's profile. The disturbed dirt was meticulously cleaned until the furrow's contour was seen clearly. The disturbed soil surface and the furrow's shape were meticulously measured. The top width of furrow (W_{sb}) on the original soil surface was determined the disturbed soil cross-sectional area. The height of the ridge was measured from the top of the ridge to the original soil surface (H_r). Figure 8 depicted the aforementioned soil disturbance characteristics.

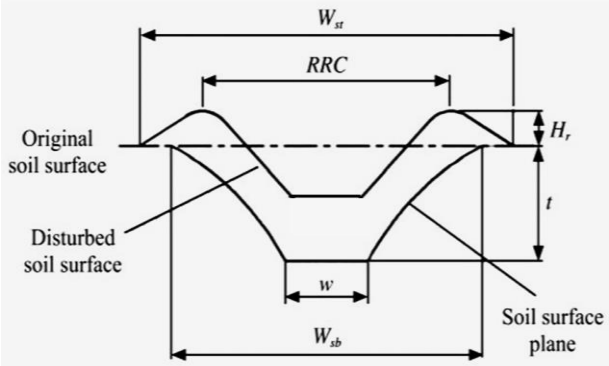

Figure 8. Parameters used to define soil earthing up [Note: Maximum width of soil throw=W_{st}; Height of the ridge=H_r; Ridge to ridge distance= *RRC*;].

Now, the area of furrow after earthing up A_f was calculated with following equation:

$$A_f = \frac{w+W_{sb}}{2} \times t \quad (1)$$

where, A_f = Area of furrow (m^2); W_{sb} = Top width of furrow (m); w = Bottom width of furrow (m);t = Depth of furrow (m)

Soil disturbance efficiency,

$$s\ (\%) = \frac{A_f}{(\frac{w_c+W_c}{2}) \times t_c} \times 100 \quad (2)$$

where, s =Soil disturbance efficiency (%); A_f = Area of furrow (m^2); w_c = Soil compactor middle width (m);W_c = Soil compactor edge to edge width (m); t_c = Soil compactor depth (m)

iii) Effective Field Capacity

Effective field capacity of the earthing up machine was calculated using the following equation:

Effective field capacity (ha/hr),

$$C_{eff} = \frac{A \times 6}{T \times 1000} \quad (3)$$

where, A= Area covered at time T (m^2); T = Operational time (min)

iv) Theoretical Field Capacity and Field Efficiency

Theoretical field capacity of the earthing up machine was calculated using the following equation:

Theoretical field capacity (ha/hr),

$$C_{th} = \frac{S \times W}{10} \quad (4)$$

where, S= Speed of machine (km/hr);W = Width of machine (m)

Field efficiency of the earthing up machine was calculated using the following equation:

Field efficiency (%),

$$e = \frac{C_{eff}}{C_{th}} \times 100 \quad (5)$$

where, C_{th} = Theoretical field capacity (ha/hr); C_{eff} = Effective field capacity (ha/hr)

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2.9. Economic Analysis of the Machine

Like other farm machinery, the costs of earthing up machine was categorized into two: annual ownership costs, which occurred regardless of machine use, and operating costs, which varied directly with the amount of machine use [11].

i) Ownership Costs of Earthing up Machine

Ownership costs (also called fixed costs) included depreciation, interest (opportunity cost), taxes, insurance, and housing, repair & maintenance cost.

a) Depreciation

The annual depreciation cost of earthing up machine was computed in the straight-line method using following equation [11]. Depreciation (BDT/yr.),

$$D = \frac{P - S}{M} \quad (6)$$

where, P = Machine price (BDT); S = Salvage value (BDT) = 5% of P; M = Economic life of earthing up machine (yr.)

b) Annual Interest

Annual interest cost of earthing up machine was computed in the straight-line method using following equation [1].

Annual interest (BDT/yr.),

$$I = \frac{P + S}{2} \times i \quad (7)$$

where, P = Machine price (BDT); S = Salvage value (BDT) = 5% of P; i = Interest rate (decimal/yr.)

c) Total Ownership or Fixed Costs

The estimated costs of depreciation and annual interest were added together to find the total ownership cost. In the cost calculation of earthing up machine, taxes, insurance, and housing cost were negligible. So,

$$FC = D+I \quad (8)$$

where, FC = Total ownership or fixed costs (BDT/yr.); D = Depreciation (BDT /yr.); I = Annual interest (BDT/yr.)

ii) Operating Costs of the Machine

Operating costs or operational costs (also called variable costs) of earthing up machine included all costs for successive machine operation such as repairs & maintenance cost, fuel cost, lubrication cost, and operator or labor cost.

a) Repairs and Maintenance Cost

Repair costs occurred because of routine maintenance, wear and tear, accidents etc. Many experts mentioned that total repairs and maintenance costs of most farm machines averaged about 1-2 percent of machine price or manufacturing cost for rotary tiller. So,

$$R\&M = 0.02\times P \quad (9)$$

where, R&M =Repairs and maintenance cost (BDT/hr); P = Machine price (BDT.)

b) Fuel Cost

Earthing up machine required a power tiller or small two-wheeled tractor for the power supply. As for the developed machine, the power source was the diesel engine of that power tiller. So, there was a fuel cost which was calculated using following equation:

Fuel cost (BDT/hr),

$$F= f\times p \quad (10)$$

where, f= Fuel consumption (liter/hr); p = Price of fuel (BDT/liter)

c) Lubrication Oil Cost

Surveys indicated that total lubrication costs on the most farms average about 15 percent of fuel costs (William et. al., 2015). The lubrication oil cost was calculated using following equation,

Lubrication cost (BDT/hr),

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$$O = 0.15 \times F \quad (11)$$

where, F = Fuel cost (BDT/hr)

d) Labor (Operator) Cost

Again at least one operator was required to operate this earthing up machine. So, for earthing up operation, the operator cost was calculated using following equation:

Operator cost (BDT/hr),

$$L = l \times \text{no. of operator} \quad (12)$$

where, l = wages of operator (BDT /hr) = $\frac{\text{wage of operator (BDT./day)}}{\text{working time (hr/day)}}$

e) Total Operating or Variable Costs

Repair and maintenance, fuel, lubrication and labor costs were added to calculate total operating cost of the developed machine. So,

$$VC = R\&M+F+O+L \quad (13)$$

where, VC = Total operating or variable costs (BDT/hr); R&M = Repairs and maintenance cost (BDT /hr); F = Fuel cost (Tk. /hr); O = Lubrication oil cost (BDT./hr); L = Labor or operator cost (BDT /hr)

iii) Total Cost of the Machine

After all costs being estimated, the total operating cost per hr was converted to cost per year and then this was added to the total ownership cost per year to calculate total cost per year to own and operate the developed earthing up machine. So, the total cost of earthing up machine was calculated as follows:

$$TC_{yr} \text{ (BDT /yr.)} = FC + (VC \times H_{ye}) \quad (14)$$

$$TC_{hr} \text{ (BDT/hr)} = \frac{TC_{yr}}{H_{ye}} \quad (15)$$

$$TC_{ha} \text{ (BDT/ha)} = \frac{TC_{hr}}{C_{eff}} \quad (16)$$

where, TC =Total cost of earthing up machine; FC = Total ownership or fixed costs (BDT/yr.); VC = Total operating or variable costs (BDT /hr); H_{ye} = Expected total operational time in a year (hr/yr.); C_{eff} = Effective field capacity (ha/hr)

Finally, total cost per year was divided by the hourly work rate in ha/hr to calculate the total cost/ha as shown in equation (xvi).

iv) Net Cash Flow (NCF)

Net cash flow (NCF) refers to either the gain or loss of funds over a period. As the earthing up machine was developed to reduce the human labor for earthing up operation, there was a difference between these two methods of earthing up operation and the difference was the revenue of using the earthing up machine. So,

Net cash flow (BDT /ha),

$$NCF = C_{manual} - TC_{ha} \quad (17)$$

where, TC_{ha} = Total cost of earthing up machine (BDT /ha);

C_{manual} = Total cost by manual method (BDT/ha) = $\frac{\text{wage of labor (BDT./day)}}{\text{working time (hr/day)}} \times H_{ym}$;

H_{ym} = Man-hr required (hr/ha)= no. of labor (nos./ha) × no. of day × working time (hr/day)

v) Net Present Value (NPV)

A technology or machine is said to be financially feasible when the net present value is positive. The bigger the net present value, the project is the more profitable. The following formula was used for calculating the net present value of developed machine (Rahman *et. al.*, 2018).

Net present value (BDT),

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$$NPV = \sum_{t=1}^{n} [\frac{NCF}{(1-i)}] - P \quad (18)$$

where, NCF =Net cash flow (BDT); i = Interest rate (decimal/yr.); P = Machine price = Initial capital investment (BDT)

vi) Internal Rate of Return (IRR)

Internal rate of return is a discount rate that makes the net present value (NPV) of all cash flows equal to zero in a discounted cash flow analysis. The net present value of the developed earthing up machine was calculated using the following equation (Rahman et. al., 2018):

Internal rate of return (decimal),

$$IRR = \sqrt{\frac{NCF}{P}} - 1 \quad (19)$$

where, NCF = Net cash flow (BDT /yr.); P = Machine price = Initial capital investment (BDT)

vii) Benefit-Cost Ratio of the Machine

The important tool of cost-benefit analysis is the benefit-to-costs ratio (BCR), which is the total cost of the benefits or outcomes divided by the total monetary costs of obtaining them. So, the benefit-to-costs ratio of earthing up machine was determined by following equation:

Benefit-cost ratio (decimal),

$$BCR = \frac{NCF}{TC_{ha}} \quad (20)$$

where, NCF =Net cash flow (BDT/ha); TC_{ha} = Total cost of earthing up machine (BDT/ha)

vii) Pay-Back Period of the Machine

Payback period means the period of time that a project requires recovering the money invested in it. Therefore, the payback period of the earthing up machine was computed using the following equation:

$$\text{Payback period (yr.)} = \frac{\text{Investment per year}}{\text{Benefit per year}} = \frac{TC_{hr} + (\frac{P}{H_{ye}})}{NCF \times C_{eff}} \quad (21)$$

where, NCF =Net cash flow (BDT); TC_{hr} = Total costs of earthing-up machine (BDT/hr); P = Machine price = Initial capital investment (BDT); H_{ye} = Expected total operational time in a year (hr/yr.); C_{eff} = Effective field capacity (ha/hr)

3. Results and Discussion

All results and decisions were deliberated after proper analyses of data obtained from field trials of the developed earthing up machines during earthing up operation. Secondary data of field and financial performances of power-tiller for tillage also used to clarify the analysis, results and discussion.

3.1. Specification of the Machine

The components of developed earthing up machine are mainly a two-wheeled tractor (power-tiller), as prime mover, and an earthing up tool showing in Figure 9a,b. The specification of developed earthing up machine and the fabrication cost of earthing up tool were shown in Table 2 and Table 3 respectively.

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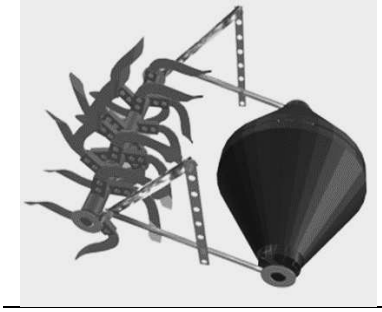
(**a**) (**b**)

Figure 9. Developed earthing up machine. (**a**) Side view of earthing up tool. (**b**) Rear view ofearthing up machine.

Table 2. Specification of the earthing up machine.

Items	Specification
Type of machine	Walking type earthing up machine
Two-wheeled tractor (power-tiller)	
Length	2.9m
Width	1.0m
Height	1.2 m
Weight	370 kg (with drawbar)
Engine	Model- S 195 (4-stoke diesel engine)
Power	Maximum output: 13.2 HP (2000 rpm)
Power transmission system	Belt and pulley, gearbox, chain and sprocket

Table 3. Fabrication cost of earthing up tool.

	**Assembly name**	**Earthing up tool**
	Date of report	**24 February, 2022**
	Stock weight	**20 kg**
	Lot size	**1**
	No. of assembly unit	**1**
	Cost per unit	**BDT 15000**

3.2. Field Performance the Machine

Field performance of the developed earthing up machine depends upon its machine width, forward speed and soil condition. The field performance test of the developed earthing up machine is shown in Figure 10 and also the experimental and analyzed details data of field performance of the developed earthing up machine are given in Table 4. The average effective field capacity, theoretical field capacity and field efficiency of developed earthing up machine were found 0.12 ha/hr, 0.16 ha/hr and 77.41 %, respectively as shown in Table 4. According to ASABE (American Society of Agricultural and Biological Engineers) standard-2011, the developed earthing up machine can be beneficial for the mechanization of sugarcane cultivation in Bangladesh as its field efficiency was found 85.60% where the standard range is 70-90%.

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(**a**) (**b**)

Figure 10. Field performance test of the developed earthing up machine. (**a**) Sugarcane field before earthing up. (**b**) Earthing up with developed machine.

Table 4. Field performance analysis of earthing up machine.

Parameters	Symbol	Unit	Trial 1	Trial 2	Trial 3
Area covered	A	m^2		1120	
Required time	T	min	85	88	90
Effective field capacity	$C_{eff\,(1,2,\ldots,n)}$	ha/hr	0.0791	0.0764	0.0747
Avg. effective field capacity	C_{eff}	ha/hr		0.0767 ± 0.0025	
Distance travelled	d	m		112	
Travelling time	t	sec	450	450	450
Machine forward speed	S	km/hr	0.9	0.9	0.9
Machine working width	w	m		1	
Theoretical field capacity	$C_{th\,(1,2,\ldots,n)}$	ha/hr	0.0896	0.0896	0.0896
Avg. theoretical field capacity	C_{th}	ha/hr		0.0896 ± 0.00001	
Field efficiency	e	%		85.60 ± 2.68	

3.3. Soil Moisture and Soil Disturbance

Soil moisture content affects the soil disturbance quantity of earthing up machine. The experimental and analyzed details data demonstrating the effect of soil moisture content on the soil disturbance during earthing up operation by the developed machine has been shown in Table 5.

Table 5. Effect of soil moisture on soil disturbance during earthing up machine operation.

Parameters	Symbol	Unit	Trial 1	Trial 2	Trial 3	Trial 4
Soil moisture content	$SMC_{(1,2,\ldots,n)}$	%	22.9	23.6	25.6	21.7
Top furrow width	W_{sb}	m	0.47	0.46	0.47	0.48
Bottom furrow width	w	m	0.071	0.078	0.069	0.061
Depth of furrow	t	m		0.143		
Area of furrow cross-section	$A_{f(1,2,\ldots,n)}$	m^2	0.0723	0.0714	0.0721	0.073
Soil compactor edge to edge width	W_c	m		0.48		
Soil compactor middle width	w_c	m		0.008		
Soil compactor depth	t_c	m		0.16		
Soil disturbance efficiency	s	%	93.35	92.14	93.16	94.27

Table 5 showed as the soil moisture decreases, the soil disturbance efficiency rises, in the other words the pulverized soil can be more displaced and piled up to the root area of the sugarcane ratoon. The field trials showed that the soil disturbance efficiency was found 93.35% at 22.9% soil moisture. When soil moisture rose to 23.6%, soil disturbance efficiency decreased to 92.14%. Again when soil moisture decreased to 21.7%, the soil disturbance efficiency rose to 94.27%.

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3.4. Financial Performance Analysis the Machine

Financial performances of earthing up machine including its power source and earthing tool have been analyzed from the data obtained during earthing up operation. The financial performance of power-tiller of earthing up machine for other field operation like tillage has also been analyzed for clear the comparison.

I) Earthing up Machine When No Other Operation by Its Power-Tiller

After financial analysis from obtained data, the ownership or fixed cost and operating or variable cost for earthing up operation with the developed machine (when no other operation by power-tiller) were found BDT 14686/yr. and BDT 3263/hr, respectively as shown in Table 6. Total cost for earthing up operation in this case was found BDT 2364550/yr. i.e. BDT 42819/ha. On the other hand, the total cost of earthing up operation in manual method using labor was found BDT 22500/ha. Net cash flow for earthing up operation of the developed machine for this circumstance were found negative which is BDT 20319/ha. The negative net cash flow indicates the incompatibility of the developed earthing up machine only for the use of earthing up operation and no other operations by its power-tiller. This also encourages to ensure multipurpose use of power-tiller such as using power-tiller for tillage.

Table 6. Financial performance analysis of earthing up machine.

	Parameters	Symbol	Unit	Earthing up machine (when no other operation by its power-tiller)	Earthing up tool (without investment for power-tiller)	Earthing up machine (when its power-tiller also used for other activities)
Fixed costs						140000
	Machine life	M	yr.	20	20	20
	Salvage value	S	BDT	7750	750	7000
	Depreciation	D	BDT /yr.	7362.50	712.50	6650.00
	Interest rate	i	decimal	0.09	0.09	0.09
	Annual interest	I	BDT /yr.	7323	708	6615
	Total ownership or fixed costs	FC	BDT/yr.	14686	1421	13265
Operating or variable costs	Repair & maintenance costs	R&M	BDT/hr	3100	300	2800
	Fuel consumption	f	litre/hr	1.10	1.10	1.10
	Fuel price	p	BDT/litre	80	80	80
	Fuel cost	F	BDT /hr	88	88	88
	Lubrication oil cost	O	BDT /hr	13	13	13
	Operator wage	*l*	BDT/hr	62.50	62.50	62.50
	No. of operator	n	nos.	1	1	1
	Operator cost	L	BDT /hr	62.50	62.50	62.50
	Total operating or variable costs	VC	BDT /hr	3263	463	2963
Total cost of earthing up machine	Expected total operational time	H_{ye}	hr/yr.	720	720	480
	Total cost/yr	TC_{yr}	BDT /yr.	2364550	335285	1435841
	Total cost/hr	TC_{hr}	BDT/hr	3284	465	2991

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	Avg. effective field capacity	C_{eff}	%	0.0767	0.0767	0.0767
	Total cost/ha	TC_{ha}	BDT /ha	42819	6071	39002
Net cash flow	Operational man-hr in manual method	H_{ym}	hr/ha	360	360	3000
	Total manual cost	C_{manual}	BDT/ha	22500	22500	187500
	Net cash flow	NCF	BDT/ha	-20319	16428	148497
Net present value		NPV	BDT	-177329	3053	23184
Internal rate of return		IRR	%		4.7	3.0
Benefit-cost ratio		BCR	decimal		2.71	3.81
Payback period		P_P	yr.		1.57	0.58

Ii) Earthing up Tool without Considering Power-Tiller

The ownership or fixed cost and operating or variable cost for earthing up tool (without investment for power-tiller) were found BDT 1421/yr. and BDT 463/hr respectively. Total cost for earthing operation in this case was found BDT 335285/yr. which is BDT 6071/ha. On the other hand, the total cost of earthing up operation in manual method using labor was found BDT 22500/ha. The net cash flow, net present value (NPV) and internal rate of return (IRR) were found BDT 16428/ha, BDT 3053-and 4.7% respectively as shown in Table-6. In this case, the value of NPV and IRR both are positive. These values indicate the viability of using the developed earthing up tool only for the use of earthing up operation. The benefit-cost ratio and payback period for this case were found 2.71**:**1 and 1.57 years i.e. approximately 2 years respectively.

iii) Earthing up Machine When its Power-Tiller Used for Other Activities

The ownership or fixed cost and operating or variable cost for earthing up machine (when its power-tiller also used for tillage) were found BDT 13265/yr. and BDT 2963/hr, respectively. Total cost for this case was found BDT 1435841/yr. which is BDT 39002/ha. On the other hand, the total cost of earthing up and tillage operation in manual method using labor was found BDT 187500/ha. Net cash flow, net present value (NPV) and internal rate of return (IRR) were found BDT 148497/ha, BDT 23184 and 3%, respectively as shown in Table-6. In this case, the value of NPV and IRR both are also positive. These values indicate the suitability of the earthing up machine (when its power-tiller also used for other activities). The benefit-cost ratio and payback period for this case were found 3.81**:**1 and 0.58 years i.e. approximately 1 year respectively. Therefore, the versatile use of two wheeled tractors (power-tillers) as the main driver of other machines including earthing up machines can make earthing up machines financially viable for sugarcane growers.

4. Discussions

This is the first mechanical earthing up operation of sugarcane in Bangladesh. The major sugarcane growers of Bangladesh are landless or marginal farmers. So for them the low cost of the machine is an important factor. The machine is designed with readily available 2WT driving power to keep it within the farmer's affordability and reach.

In some developed countries tractor operated weeder cum earthing up machine for sugarcane is used [12–14]. Moreover, 2WT powered rotary tillers or low power (2.5-5.5 HP) self-propelled machines are being used for weeding cum earthing up purposes in most of the cases [15–17]. Effective

field capacity and efficiency of earthing up machine developed by Nawale et al. (2011) were 0.11 ha/hr and 65.57% respectively which was lower than that (0.16 ha/hr and 77.41 %) of the earthing up machine developed by the present study. The efficiency of earthing up equipment developed by Manian and Arvinda (2004) was 60.24%. These revealed that the field performances of the present study were better and justified.

5. Conclusions:

Technical and financial performances of the developed earthing up machine were estimated based on field data. Average effective field capacity and field efficiency were found satisfactory for the developed earthing up machine. Earthing up machine found is not financially beneficial only for earthing up operation. Besides, when the two-wheeled tractor (power-tiller) was being used as the main driver for other activities including earthing up operation, then the earthing up machine becomes financially beneficial. Besides, the earthing up tool is also financially viable for sugarcane growers. Thus, it can be concluded that the versatile and adaptive use of two-wheel tractors (power-tillers) as prime movers for earthing up machines can be beneficial to sugarcane growers.

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