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Development and evaluation of solar powered manually operated sprayer cum grasscutter

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ABSTRACT

Spraying of pesticides and cutting grasses is an essential task in the agricultural sector to protect the crops from insects for obtaining high yield. In this study, a solar-powered sprayer cum grasscutter was developed and used solar energy as a power source for spraying and cutting grasses. The total fabrication cost of the solar-powered sprayer cum grasscutter was Tk 12550. The application rate of the sprayer was 281.25 L ha^{-1}, with spray coverage of 46.7%. The theoretical and effective field capacity of sprayer cum grasscutter was found of 0.08 ha hr^{-1} and 0.06 ha hr^{-1}, respectively. The field efficiency of solar-powered sprayer cum grasscutter was found of 75%, for an average of 2.1 km hr^{-1} operating speed. This research observed that cutting efficiency was 79%. The operating cost of the machine was 903.17 Tk ha^{-1}. The capital recovery factor, capital consumption and annual cost of solar-powered sprayer cum grasscutter were 0.26, Tk 3062, and Tk 43352, respectively. The solar-powered sprayer cum grasscutter is free from pollution because no fuel is needed. The price of the machine is low as compared to others, which are available in the market.

Keywords: Sprayer, grasscutter, lolar-powered, machine performance, sprayer cum grasscutter

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1 Introduction

Bangladesh is an agricultural land with a total area of 147570 km^2 and the total cultivable land is 8.50 million hectares. This cultivable area includes 2.44 million hectares for a single crop, 3.82 million hectares for the double-cropped and triple-cropped area is about 1.63 million hectares. The net cropped area is 7.90 million hectares, and the total cropped area is 15.03 million hectares (BBS, 2018). Nevertheless, with the increasing cropped areas, crop protection and management have become more challenging because of insects and weeds. There are various pests and weeds control methods like biological control, cultural control, trap cropping, pesticides, herbicides, fumigation, and sterilization. Among them, pesticide and herbicides application is the most widespread and oldest method worldwide.

A sprayer is a mechanical device used to spray the liquid-like herbicides, pesticides, fungicides, and fertilizers to the crops to avoid any pests and control the unwanted plant species. Sprayer provides optimum utilization of pesticides and herbicides or any liquid with minimum effort (Mishra et al., 2019). Farmers usually use hand or fuel-operated sprayers to perform this task. This traditional spraying method causes user fatigue due to excessive bulky and heavy construction. The person operates manually operated sprayers, but the drawback is that it causes fatigue to the operating personnel and cannot be used for a longer time.

Moreover, the fuel-operated sprayers and grasscutters are operated using fossil fuels, and the drawback is its cost of operation is high and emits pollutant gases, leading to environmental issues (Tambolkar et al., 2019). Electrical sprayers and grasscutters are run on electricity for charging the battery; the main drawback is that they cannot be used in some rural areas due to insufficient electricity supply. On the other hand, nonconventional energy sources like solar energy can operate the sprayer and grasscutter and overcome these drawbacks (Chandrashekar and Raghavendra, 2018). Therefore, an effort was made to develop a solar operated sprayer cum grasscutter to control the insects and weeds simultaneously considering the cost of operation and environmental pollution. The study's specific objectives were to design and develop push-type solar-operated sprayer cum grasscutter and finally determine the technical and economic performance of solar-operated sprayer cum grasscutter over the manual operation.

2 Materials and Methods

2.1 MaterialsrRequired

The solar-operated sprayer cum grasscutter machine was made by locally available low-cost materials procured from the local market. Most of the solar-powered sprayer cum grasscutter parts were designed and fabricated in Halim workshop, Ansar-club Bottoly, Dinajpur.

2.2 Major components

The proposed solar-operated sprayer cum grasscutter machine consists of a mainframe shaft, solar panel, DC motor, battery, solar charge controller, cutting blade, jar, handle, and wheel as shown in Fig. 1 and with dimensions shown in Fig. 2.

2.2.1 Mainframe shaft

The frame was made of cast iron with dimensions of 750 mm × 600 mm × 900 mm. All parts of the machine were attached to the frame. There were four shafts to carry the total weight of the frame. Three wheels were set on the shafts so that the frame could easily be moved. A handle and a solar panel adjustable slope were made with the iron shaft. A 600 mm iron shaft was made to attach two back wheels; for easy rotation, two bearings were attached to the wheel at the end of each shaft, and then the shaft was fixed with the frame at the proper position. Four nuts joined the front-wheel with shafts.

2.2.2 Solar panel

The solar panel was fixed at the rear, near the handle, by four nuts and bolts. A slope was made of 60° to attach the solar panel to clasp the sunshine's maximum solar energy. The solar panel was connected with the solar charge controller, and the solar charge controller was connected with the battery and the DC motor. The specifications of the solar panel are shown in Table 1.

Table 1. Specifications of solar panel

Items	Specifications
Model	RD30P-36P2M
Manufacturer	RENEPV, China
Dimensions (mm)	710 × 360 × 30
Weight of the panel	3.1 kg
Peak power	30 watt
Maximum Power Current	1.63A
Maximum Power Voltage	18.34 V

2.2.3 DC motor

A DC motor (specifications are shown in Table 2) was fixed in the middle of a wooden frame. The wooden frame was 600 mm square in size. The wooden frame was attached at the centre of the machine with four nuts (10 mm) on the frame.

2.2.4 Battery

The battery was placed beside the back wheel and fixed with two nuts, mainly used to store solar energy. One side of the battery was connected to the solar charge controller. The specifications of the battery are shown in Table 2.

Table 2. Specifications of DC Motor and Battery

Items	Specifications	
	DC motor	Battery
Model	RS-775	YB9-B
Manufacturer		Lucas, Bangladesh
Weight		3.5 kg
Motor speed	1200 rpm	
Op. condition	12v 7.5 amp	12v 15 amp
Maximum Power	90 Watt	180 watt

2.2.5 Solar charge controller

A solar charge controller (P.G-206, IQRA, China) was used to control the solar panel charge with the maximum output of 12V and 30A. A solar charge controller has three points. One point is connected to the solar panel, and another two points are connected to the battery and DC motor.

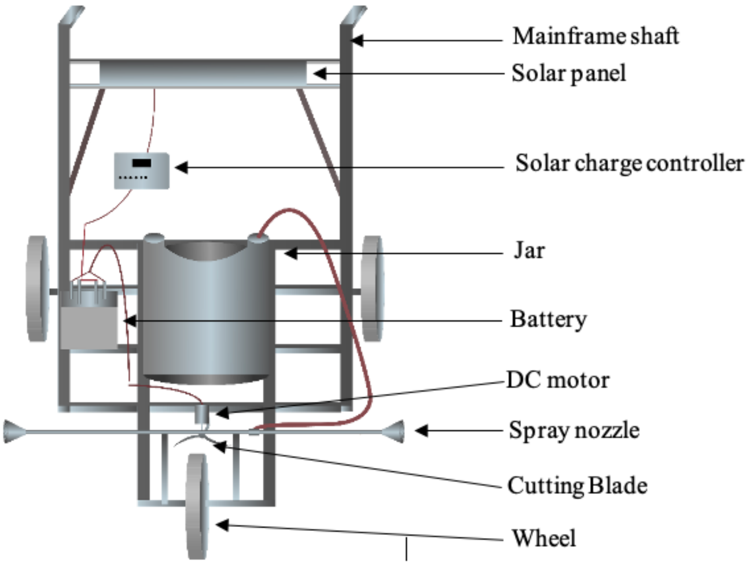

Figure 1. Schematic diagram of the solar-powered sprayer cum grasscutter

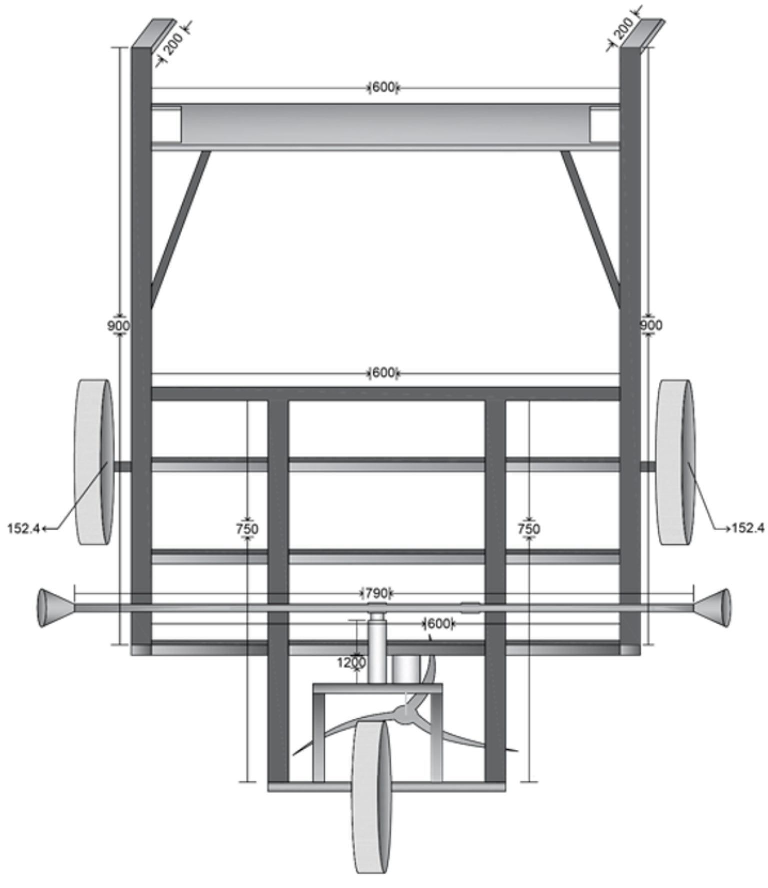

Figure 2. Schematic diagram of the solar-powered sprayer cum grasscutter with dimensions (All dimensions are in mm)

2.2.6 Blades

A total of 4 blades made of steel were used, and the blade's size was 203.2 mm (Fig. 3) with blade angle 38° for cutting the grass. The blades were attached to the iron plate by nuts and bolts. Each blade needs two nuts and bolts to attach the blade to the iron plate properly. Iron Plates was also attached with the DC motor by two nuts. The blade height can be adjusted by losing or tightening the iron plate nuts.

Figure 3. Schematic diagram of a blade

2.2.7 Jar (micro pump and battery sprayer)

The jar was used to hold liquids and placed on the bed near the front wheel. An adjustable T-shape pipe was attached with the jar to automatically spray the liquid using a micropump connected with a solar charger.

2.2.8 Nozzle

Two nozzles were attached to the pipe. Again the pipe was connected to the jar and supply liquid from the jar. An adjustable T-shape structure was made to support the pipe.

2.2.9 Switch

Two switches were used to control the spraying liquid and to cut grass by turning it on and off.

2.2.10 Wheels

Three wheels were welded to the chassis through bearings to carry the frame; the front wheel was a free rotating wheel in 360 degrees. A 600 mm iron shaft was used to attach two back wheels with bearings at the end of the shaft, fixed with the frame with proper position to rotate easily.

2.2.11 Handle

The handle was made of cast iron hollow pipe with an outside diameter of 24 mm. The length of the handle was 220 mm. It was provided for ease of driving the solar-operated sprayer cum grasscutter to push the machine.

2.3 Fabrication of the machine

The developed machine consists of a solar panel, DC motor, battery, a solar charge controller, cutting blades and a jar. It has a panel mounted on top of the model in a particular arrangement such that the slope is 60°; hence it can easily receive the intensity of solar radiation. The solar panel converts solar energy into electrical energy by the photovoltaic effect. Then this electrical energy is stored in the battery by using a solar charge controller. DC motor was connected to the battery through connecting wires. Between this circuit breaker, a switch was provided. It starts and stops the working of the motor. Cutting blades were connected to the motor with the help of an iron plate.

Figure 4. A photographic view of solar-powered sprayer cum grasscutter machine

The motor power transmits to the mechanism, making the blade rotate on the shaft, making the grass cut. A jar (micro pump and battery sprayer) was used to hold liquid. The capacity of the jar was 16 L and connected to the sprayer pipe with an adjustable nozzle. Again the jar was connected to the solar charge controller. A pump was used to suck the spraying liquid from the jar and spray it through nozzles. A switch was used to turn on and off the pump. The pump operates using power in the battery, and therefore liquid from the jar is sprayed out through the sprayer.

2.4 Experimental site

The experiment of cutting grass and spraying was conducted in the central mosque HSTU, Dinajpur, from 15 June 2019 to 19 October 2019 and in front of the academic building-1 of HSTU, Dinajpur, from 25 June 2019 to 19 October 2019.

2.5 Technical evaluation

2.5.1 Discharge rate of the sprayer

The discharge rate of solar-powered sprayer cum grasscutter was measured from the volume of liquid discharged from the sprayer nozzle in the specified time. The measuring cylinder was used to collect the discharged liquid from the sprayer nozzle, and a digital timer was used for recording the time of discharge. The procedure was repeated three times, and the mean discharge rate in litre per minute was calculated using the following equation (1):

$$DR = \frac{v}{t} \tag{1}$$

where, DR = discharge rate (L min^{-1}), v = volume of liquid collected in cylinder (L), and t = time (min).

2.5.2 Travelling speed

The speed of the machine was determined by using the following equation (2):

$$S = \frac{d}{t} \tag{2}$$

where, S = traveling speed (m s^{-1}), d = distance traveled (m), and t = time (s).

2.5.3 Application rate

The sprayer application rate depends on discharge rate, swath width, and speed of operation. The following equation (3) was used to calculate the application rate sprayer (Chandrashekar and Raghavendra, 2018).

$$A = \frac{Q}{S \times W} \tag{3}$$

where, A = application rate (L ha^{-1}), Q = discharge rate (L min^{-1}), W = swath width (m), S = speed of operation (m s^{-1}).

2.5.4 Spray coverage

The percentage of spray coverage was determined from ImageJ software. At first, we sprayed colour water on white paper, then took a photo. After that, this photo was loaded in ImageJ software to analyze the spray coverage.

2.5.5 Cutting efficiency

A test area of 1 m × 1 m was randomly selected for three replication from the experimental site to determine the cutting efficiency. At first, the number of grass was counted in the marked test area. After that, the sprayer cum grasscutter was pushed in the forward direction to cut the grass from the experimental site. After completing the operation, the number of cut and un-cut grass was counted from the test area. The cutting efficiency was computed of the sprayer cum grasscutter by using the following expression (4):

$$\eta_{eff} = \frac{G_c}{G_c + G_u} \times 100 \tag{4}$$

where, η_{eff} = cutting efficiency (%), G_c = number of grasses cut by the machine (m^{-2}), and G_u = number of grasses remain uncut (m^{-2}) after cutting operation.

2.5.6 Theoretical field capacity

The theoretical field capacity is the rate of field coverage that would be obtained if the machine performs its function 100% of the time at the rated forward speed and always covers 100% of its rated width. Therefore,

$$C_{th} = \frac{SW}{c} \tag{5}$$

where, C_{th} = theoretical field capacity (ha hr^{-1}), S = forwar speed (km hr^{-1}), W = rated width (m), and c = constant (10).

2.5.7 Effective field capacity

The effective field capacity is the actual average rate of field coverage by the sprayer cum grasscutter and calculated using the following equation (6):

$$C_{eff} = \frac{A}{T} \tag{6}$$

where, C_{eff} = effective field capacity (ha hr^{-1}), A = total area covered (ha), and T = total time (hr).

2.5.8 Field efficiency

It is the ratio of the effective field capacity to theoretical field capacity. The field efficiency of the sprayer cum grasscutter was calculated using the following equation (7):

$$F_{eff} = \frac{C_{eff}}{C_{th}} \times 100 \tag{7}$$

2.5.9 Turning loss

The tuning loss of the solar-operated sprayer cum grasscutter was calculated by using the following equation (8):

$$\text{Turning loss} = \frac{N+t}{T} \times 100 \quad (8)$$

where, N = total number of turns required to complete the operation, t = time required for each turn (min), and T = total time required to complete the operation (min).

2.5.10 Overlapping loss

It is the ratio of overlap area to total area. The overlapping loss was calculated by using the following equation (9):

$$\text{Overlapping loss} = \frac{A_o}{A} \times 100 \quad (9)$$

where, A_o = overlapped area (ha), and A = total area (ha).

2.6 Operating cost

The selection of machines for agricultural activities usually depends on least-cost operation criteria. The operating of solar-powered sprayer cum grasscutter consists of (a) fixed cost-depreciation and interest on investment; (b) variable cost- labour and repair and maintenance cost.

2.6.1 Fixed cost

In this study, the straight-line method is used to calculate the depreciation using the following equation (Barnard and Nix, 1979).

$$D = \frac{P-S}{L} \quad (10)$$

where, D =depreciation cost (Tk yr^{-1}), P = purchase price of the machine or implement (Tk), S =salvage value (Tk), and L = Life of the machine or implement (yr).

The interest on investment in solar-powered sprayer cum grasscutter is included in fixed cost estimation. The following equation is used for the calculation of interest on investment:

$$I = \frac{P+S}{2} \times i \quad (11)$$

where, i =interest rate (decimal).

2.6.2 Variable costs

The variable cost is one, which changes when the level of output alters and vary in total in proportion to annual use but is approximately constant per ha (Barnard and Nix, 1979). The variable cost of solar-powered sprayer cum grasscutter depends on labour and repair & maintenance cost for each field operation. The cost of labour and repair and maintenance (1% of purchase price) was calculated in Tk hr^{-1}.

2.6.3 Operating cost

All calculated fixed costs and variable costs were converted into Tk ha^{-1}, and the summation of fixed and variable costs had given the operating cost of solar-powered sprayer cum grasscutter in Tk ha^{-1}.

$$TC = FC + VC \quad (12)$$

where, TC total operating cost (Tk), FC = fixed cost (Tk), and VC = variable cost (Tk).

2.7 Capital Recovery Factor (CRF)

A capital recovery factor can be used to combine the total depreciation and interest changed into a series of equal annual payments at compound interest. These payments plus the interest on the depreciated amount can be used to estimate the capital consumption (CC) of farm equipment as:

$$CC = (P-S)\,CRF + Si \quad (13)$$

where, $CRF = {}^{i(1+i)^L}/_{(1+i)^L-1}$, and i = interest rate (decimal).

2.8 Annual operating cost

The annual operating cost of solar-powered sprayer cum grasscutter is determined by the summation of fixed and variable costs. The following equation was used to calculate the annual operating cost of solar-powered sprayer cum grasscutter.

$$AC = FC + (VC \times U) \quad (14)$$

where, AC =annual cost (Tk), FC = fixed cost (Tk), VC = variable cost (Tk), and U = hours of use.

2.9 Data analysis

After data collection, data were coded, compiled, tabulated, and analyzed by MS Excel (Microsoft Excel, Microsoft, USA) in accordance with the objectives of the study.

3 Results and Discussion

3.1 Technical performance

The average flow rate of the sprayer was found 0.9 L min^{-1} when the travelling speed was 1.2 km hr^{-1}. The application rate of the sprayer was also found of 281.25 L ha^{-1} with swath width of 1.16 m. From the Image analysis, the spray coverage of the sprayer was found 46.7%. Pachpor et al. (2019) found the sprayer's average flow rate was 0.023 L sec^{-1}, and the application rate was 112.4 L ha^{-1}. In another study by Issa et al. (2020), the sprayer's flow rate was 0.79 L min^{-1}, and the application rate was 0.04 L m^2. In the experimental field, the grass's average height was 200 mm before the cut, and it was 90 mm after the cut. The average cutting efficiency was 79% when the speed of operation was 2.1 km hr^{-1}. The turning and overlapping loss for the sprayer cum grasscutter was found at 6.38% and 9%, respectively; it seems too high due to the experiment field size is small. From the calculated data of Table 3, the theoretical field capacity was found 0.08 ha hr^{-1}, and the effective field capacity was 0.06 ha hr^{-1}. The field efficiency of the sprayer cum grasscutter was found 75%. According to Magar et al. (2010), the machine's effective field capacity was 0.07 ha hr^{-1}, and efficiency was 70% when the operation speed was 2 km hr^{-1}. In another study by Bhutada and Shinde (2017), the machine's effective field capacity was 0.0440 ha hr^{-1}, and efficiency was 83.17% when the operation speed was 1.89 km hr^{-1}.

3.2 Fabrication cost of the machine

From Table 4, the total fabrication cost of the sprayer cum grasscutter is Tk 12550. It is inexpensive as compared to other machines that are available in the market. The operating fuel cost is zero due to operation by solar power. Also, one person, even a woman, can operate this machine efficiently and smoothly.

3.3 Operating cost of the machine

From Table 5, The fixed cost of a solar-powered sprayer cum grasscutter was 61.5 Tk ha^{-1} when the annual use of 800 hours. The variable cost was 841.5 Tk ha^{-1}. The solar-powered sprayer cum grasscutter's operating cost is 903.17 Tk ha^{-1} which is lower than the manual operation. The capital recovery factor, capital consumption and annual cost of solar-powered sprayer cum grasscutter were 0.26, Tk 3062, and Tk 43352, respectively.

3.4 Advantages of the machine

The solar-powered sprayer cum grasscutter machine is simple in design, and less human effort is required; not required skilled person to handle the machine. It is also mentionable that the machine was operated using solar energy, a clean form of energy, and hence does not create any pollution. It also produced less noise than the conventional grasscutter, which uses gasoline/diesel as its fuel. Overall, it is a low cost, and less maintenance required during the operation machine.

Table 3. Operating cost of solar-operated sprayer cum grasscutter

Particulars	Observations
Avg. height of grass before cut (mm)	200
Avg. height of grass after cut (mm)	90
Turning loss (%)	6.38
Overlapping loss (%)	9
Cutting efficiency (%)	79
Theoretical field capacity (ha h^{-1})	0.08
Effective field capacity (ha h^{-1})	0.06
Field efficiency (%)	75

Table 4. Fabrication cost of solar-powered sprayer cum grasscutter machine

Cost items	Cost (Tk)
Main Frame	1800
Cutting Blades (4)	400
Solar panel (30 Watts)	1400
Battery (12 Volt, 15 amp)	1200
Spray Nozzle (2 spray nozzle)	100
DC motor (1 DC motor)	650
Solar charge controller	350
Wheel (3 wheels)	1000
Jar	2500
Making charge	2500
Others	650
Total =	12550

Table 5. Operating cost of solar-operated sprayer cum grasscutter

Item	Amount
Fixed cost	
Depreciation (Tk yr^{-1})	2259
Interest on investment (Tk yr^{-1})	690
Total fixed cost	
Tk yr^{-1}	2959
Tk hr^{-1}	3.69
Tk ha^{-1}	61.5
Variable cost	
Labor (Tk hr^{-1})	50
Repair and maintenance (Tk hr^{-1})	0.5
Total variable cost	
Tk ha^{-1}	841.67
Tk hr^{-1}	50.5
Tk ha^{-1}	841.67
Operating cost	
Tk hr^{-1}	54.19
Tk ha^{-1}	903.17
Capital Recovery Factor	0.26
Capital consumption (Tk)	3062.2
Annual cost (Tk yr^{-1})	43352

4 Conclusion

A solar-powered sprayer cum grasscutter was developed and evaluated. The sprayer's application rate was 281.25 L ha^{-1}, with spray coverage at 46.7% based on the findings. The grasscutter had cut the grass of height 90 mm above ground level with the cutting efficiency of 79%. The spraying efficiency of solar-powered sprayer cum grasscutter was found of 75%. The operating cost of the machine was 903.17 Tk ha^{-1}. The fabrication cost was also found low compared to the conventional machine. In the future, this machine can be autonomous by using the remote control system, and the shape of the blade can be changed.

Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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