

Fabrication and performance evaluation of a solar-powered multipurpose agricultural machine

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Abstract: The improvement of seed sowing practices is necessary to meet demand and reduce import dependency in wheat production. To preserve crops from insects and to maximize production, spraying pesticides and cutting grass are crucial tasks in the agricultural sector. The purpose of this endeavor was to fabricate and invent a solar powered manually operated multipurpose agricultural machine to determine the technical performance of the machine. USD 360.87 was the total amount spent on fabrication for the solar-powered multipurpose agricultural machine. The seed sowing rate was 106.36 kg ha⁻¹. The sprayer used 450 l ha⁻¹ as its application rate. Solar-powered multipurpose agricultural machines have a theoretical and effective field capacity of 0.12 ha h⁻¹ and 0.1 ha h⁻¹ respectively. Solar-powered multipurpose agricultural machine has a field efficiency of 83%, with a mean velocity of 1.31 km h⁻¹. The cutting effectiveness of the machine was 78%. The machine's operating cost was USD 8.79 ha⁻¹. The cost of operating a solar-powered multipurpose agricultural machine for one year was USD 498.16, which included a 0.18 capital recovery factor, USD 61.84 investment Utilization, and yearly expenditures.

Keywords: Solar-powered, machine performance, multipurpose agricultural machine, economic performance.

Citation: Milufarzana, S. Banu, Md. H. Or-Rashid, Md. R. Hasan. 2025. Fabrication and performance evaluation of a solar-powered multipurpose agricultural machine. *Agricultural Engineering International: CIGR Journal*, 27(1): 85-94.

1 Introduction

In Bangladesh, around 75% of people live in the countryside and agriculture is their main income source. The total area of Bangladesh is 147570 square kilometers, and 8.5 million hectares is the total arable land. Currently, 7.90 million hectares is the net cropped area, and 15.03 million hectares is the total cropped area (BBS, 2018). For this scenario, crop protection and management have become more

rigorous due to pests, including diseases, insects, rodents, and nematodes. Among various pest control methods, globally the application of pesticides is the oldest and most extensive method.

The sprayer is the equipment used for applying liquid substances such as herbicides, pesticides, and fungicides to plants to remove any pests and control undesirable crop species. Sprayer gives optimum utilization of herbicides, pesticides, or any liquid with the lowest effort (Mishra et al., 2019). Growers typically use fuel-operated or manually operated spray nozzles to execute this piece of work. Because of the excessively bulky and heavy construction of the traditional sprayer, it causes fatigue to the operator and cannot be operated for a longer time

Received date: 2024-07-31 **Accepted date:** 2024-10-28

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(Milufarzana et al., 2021). Also, it is harmful to their health.

Nowadays, grass cutters are becoming very popular to control the wanted grass. But fuel-operated sprayers and grass-cutters are operated by using fossil fuel, which is in high cost and pollutes the environment by emitting pollutants to the environment (Tambolkar et al., 2019). Electric spray bottles and grass-cutters rely on electric power to power their batteries, but they are not suitable for rural areas that do not have enough electricity. So, nonconventional energy sources like solar energy can overcome these drawbacks (Chandrashekar and Raghavendra, 2018).

Agriculture in Bangladesh contributes about 13.47% of the country's GDP with a growth rate of 3.45% (BBS, 2020). Major food crops in Bangladesh are rice, wheat, maize, potato, pulses, and oil seeds. Wheat has been an essential and indispensable cereal as an alternative to rice for the people of Bangladesh. The annual demand for wheat in the country is less than 6 million tons but production is limited to 10 to 12 lakh tons. Therefore, imports have become the main source of meeting the demand for wheat in the

country. The reason for this, agricultural land has opposed population growth, an expert labor crisis, and farmers are doing different agricultural practices such as digging, seed sowing, spraying and grass cutting traditionally. As a result, cereals crops are not producing as much as expected. To get rid of this condition agricultural mechanization is essential in modern and commercial agriculture. Considering the above-mentioned problems, this study has been undertaken to solve the problems associated with sowing wheat seeds, spraying, and grass cutting by using solar power. To design, development, and determination of the technical and economic performance of a solar-powered multipurpose agricultural machine were the specific objectives of the study.

2 Materials and methods

2.1 Major components

The proposed solar-powered multipurpose agricultural machine consists of a frame, DC motor, solar panel, battery, cutting blade, sprayer tank, hopper, seed plow, handle, and wheel as shown in Figure 1 and with dimensions shown in Figure 2.

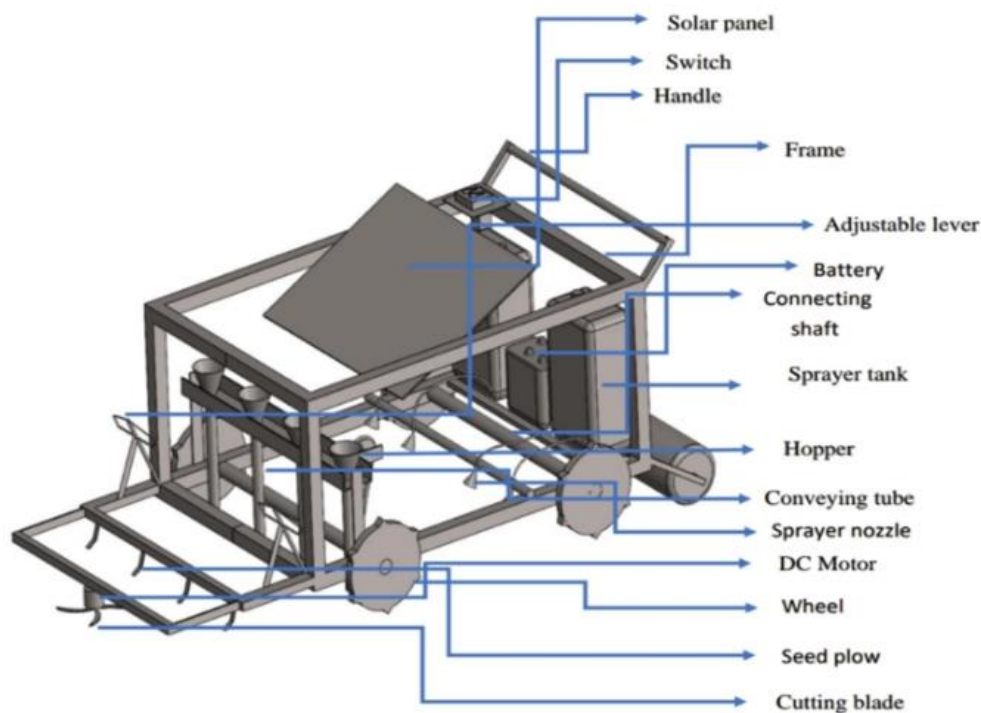


Figure 1 Graphical representation of the multipurpose agricultural machine

2.1.4 Solar charge controller

To control the solar panel charge, a solar charge controller (PE12VA) was used with a maximum output of 12 V and 30 A. This controller has 3 points: one is set up with the solar panel device, and other 2 points are attached to the battery and the load.

2.1.5 Blades

Blades are the cutting components of solar grass cutters. The blades were made of steel metals and the size of the blade was 77 mm. Three blades were attached to the motor shaft by a hub. Grasses of different heights can be cut down by adjusting the grasscutter.

2.1.6 Sprayer tank or jar

Two jars were intended for keeping liquids and spraying the liquid automatically with the help of

their inside micro pump and battery. Both were set up on the lower portion of the frame near the rear wheels. The specifications of the jar are shown in Table 3.

Table 3 Specifications of the jar

Items	Specification
Dimension	370 mm × 210 mm × 480 mm
Net weight	5.4 kg
Tank capacity	16 L
Battery	12 V 8 amp
Working pressure	0.15-0.40 Mpa
Output	DC 12V 1.2 A

2.1.7 Seed plow

It was used to sow seeds for crops by placing and burying them into the soil to a specific depth by dragging the machine. In this way, seeds were distributed evenly. There were four plows (Figure 3) attached to the iron shaft and plow to plow distance was 20 cm.



Figure 3 Seed plow

2.1.8 Seed metering device

This device was used to accumulate seed in a singular or group style, at the same time it deposited the same at specified and precise distances in a seed trench. A seed disk was included that contained a plurality of seed containment pockets. By imparting a partial vacuum these pockets can be depressurized.

2.1.9 Nozzle and switch

Four nozzles were attached to the pipe, and this pipe was supplying the liquid from the jar. There were two switches to control the spray water and cut grass by turning it on and off.

2.1.10 Wheels

To carry the frame, four wheels were attached to the chassis bearing. Wheels were made by MS flat bar. The thickness, diameter and width of the wheels were 0.8 mm, 460 mm and 50 mm respectively.

2.2 Machine fabrication

The designed machine comes with a seed plow,

seed metering device, solar panel, battery, solar charge controller, DC motor, cutting blades and sprayer tank. To get intensity of solar radiation, a 60° slope was made to mount the panel on the top of the model. By the photovoltaic effect, solar cell transforms sunlight into electrical energy. Then the battery stored energy by using solar charge controller. Connecting wires were used to connect the DC motor with battery. To start and stop the working of the motor, a switch was provided between the circuit breaker. With the help of an iron plate, cutting blades were connected to the motor and motor transmit power to the mechanism. As a result, blades rotated on the shaft and making the grass cut. Four adjustable seed plows were placed in front of the machine.

When machine moved forward, this seed plow simultaneously made four rows of holes in the ground for sowing the seeds. The connecting shaft of this seed metering device and the connecting shaft of the

front wheel of the machine were connected by a chain and two peniums. When the machine drove, the seed metering device was rotated with the rotation of the front wheels and the seed fell on the perforated row through four seed conveying tube. To hold the liquid, two jars were used. With the help of an adjustable nozzle, each jar was connected to the sprayer pipe. To

eliminate the sprayed water from the container, a pump was used and then, nozzles sprayed the liquid. To turn on and off the pump, a switch was used. The pump operation and spraying liquids both the work was done by using the power of the battery. The backside of the machine was fitted with a connectable roller which covered seeds with soil at the end.



Figure 4 Photographic views of the fabricated machine

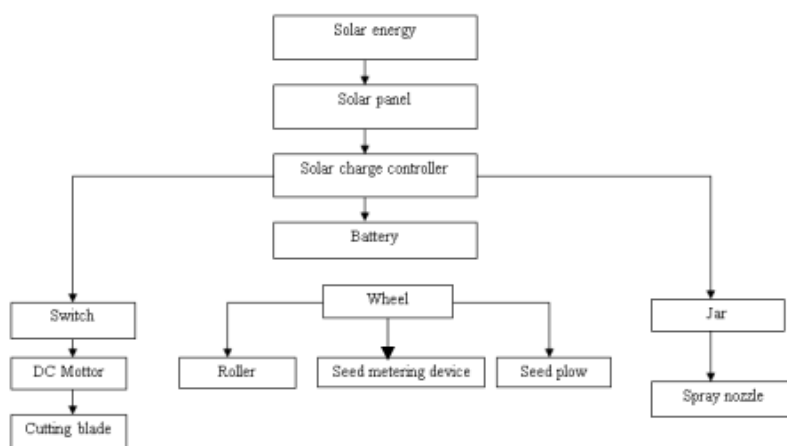


Figure 5 Fabricated machine working steps

The given flow chart (Figure 5) shows the steps of how the grass cutting, seed sowing, spraying and soil covering work begins and ends.

2.3 Technical evaluations

2.3.1 Seed rate application of the machine

The following equation was used to get the seed rate: n is the number of furrows, l is the row-to-row space (m), D is the diameter of drive wheel (m), s is the speed (rev min⁻¹), m is the seed collected mass (kg) (Karim et al., 2015).

$$\text{The effective width of the seed drill: } W = n \times l \text{ (m)} \quad (1)$$

$$\text{Circumference of drive wheel: } C = \pi \times D \text{ (m)} \quad (2)$$

$$\text{The total area covered: } A_t = \pi \times D \times W \times s \text{ (m}^2\text{)} \quad (3)$$

$$\text{Seed dropped / hectare} = \frac{m \times 10000}{A_t} \text{ kg ha}^{-1} \quad (4)$$

2.3.2 Discharge rate of the machine

The following Equation 5 was used to determine the discharge rate of the machine (Kepner et al., 1978).

$$DR = v/t \quad (5)$$

Where, DR is measured in terms of L min⁻¹ discharge rate, v is the liquid volume collected in the cylinder (L), and t is measured in minutes.

2.3.3 Traveling speed

Equation 6 was used to identify the traveling speed of the machine (Rabbani et al., 2020).

$$S = \frac{d}{t} \quad (6)$$

Where, S is the speed, m s⁻¹; d is the distance travelled, m; t is the time, s.

2.3.4 Application rate

The machine's application rate was determined by using Equation 7 (Chandrashekar and Raghavendra, 2018).

$$A = \frac{Q}{S \times W} \quad (7)$$

Where, the application rate A is in Lit ha⁻¹, the discharge rate Q is in Lit min⁻¹, the swath width W is in meters, and the speed of operation S is in meters per second.

2.3.5 Cutting efficiency

The cutting efficiency was computed by using

Equation 8 (Milufarzana et al., 2021).

$$\eta_{eff} = \frac{G_c}{G_c + G_u} \times 100 \quad (8)$$

Where, η_{eff} is the cutting efficiency, %; G_c is the number of grasses chopped by the machine per m²; G_u is the number of grasses un-cut grasses in the field after cutting operation per m².

2.3.6 Theoretical field capacity

The following Equation 9 was used to compute the machine's theoretical field capacity (Kepner et al., 1978).

$$C_{th} = \frac{SW}{c} \quad (9)$$

Where, C_{th} is the field capacity, ha hr⁻¹; S is the speed (forward), km hr⁻¹; W is the rated width, m; C is the constant, 10.

2.3.7 Effective field capacity

The effective field capacity of multipurpose agricultural machine was computed by the following equation.

$$C_{eff} = \frac{A}{T} \quad (10)$$

Where, C_{eff} is the field capacity (effective), ha hr⁻¹; A is the area, ha; T is the total time, hour.

2.3.8 Field efficiency

The field efficiency of the machine was computed by Equation 11.

$$\text{Field Efficiency} = \frac{\text{Effective field capacity}}{\text{Theoretical field capacity}} \times 100 \quad (11)$$

2.3.9 Turning loss

By using Equation 12, the turning loss of the machine was calculated.

$$\text{Turning loss} = \frac{N \times t}{T} \times 100 \quad (12)$$

Where, overall rotations necessary to complete the functioning are expressed in N , the time required for each turn t is in minutes and total time required to complete the operation T is in minutes.

2.3.10 Overlapping loss

Overlapping loss was determined by following Equation 13.

$$\text{Overlapping loss} = \frac{A_o}{A} \times 100 \quad (13)$$

Where, A_o is the area overlapped, ha; and A is the

total area, ha.

2.3.11 Overall operating costs

The fixed costs of depletion as well as investment interest make up the running costs of the solar-powered versatile agricultural equipment. The variable costs include labor and repair and maintenance expenses.

2.3.12 Fixed cost

The following Equation 14 was used to determine the depreciation by using the straight-line method (Barnard and Nix, 1979).

$$D = \frac{P - S}{L} \quad (14)$$

Where, D is the depreciation, \$ year⁻¹; P is the purchase price \$; S is the salvage value, \$; L is the life of machine, year.

The interest on investment was computed by Equation 15 (Barnard and Nix, 1979).

$$I = \frac{P + S}{2} \times i \quad (15)$$

Where, i is the interest rate, percentage.

2.3.13 Variable costs

Variable cost is a cost that changes when output increases and varies in total proportion to annual use but is relatively constant per hectare (Barnard and Nix, 1979). Each field operation has its own labor, repair, and maintenance costs that affect the machine's variable costs. Maintenance costs, repair and labor cost is 1 percent of the purchase cost was calculated as USD per hour (Banu et al., 2022).

2.3.14 Operating cost

The Equation 16 was used to determine the operating cost of the machine hour (Banu et al., 2022).

$$TC = FC + VC \quad (16)$$

Where, TC is the operating cost, USD; FC is the fixed cost, USD; and VC is the variable cost, USD.

2.3.15 Capital recovery factor (CRF)

The capital recovery factor and capital consumption were calculated by Equation 17 and 18 (Hunt, 1977).

$$CC = (P - S)CRF + S_i \quad (17)$$

$$CRF = \frac{i(1+i)^L}{(1+i)^L - 1} \quad (18)$$

2.3.16 Annual operating cost

The following Equation 19 was used to calculate the annual operating cost of machine hour (Banu et al., 2022).

$$AC = FC + (VC \times U) \quad (19)$$

Where, AC is the annual cost, USD; FC is the fixed cost, USD; VC is the variable cost, USD, and U is the time, hours.

2.4 Experimental site

Sowing seeds, cutting grasses, and spraying experiments were done at Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh from 15/11/2021 to 17/11/2021. It is located 343 km (25° 41' N 88° 39' E / 25.6980° N 88.6550° E) north-west of Dhaka Bangladesh. The experimental area was 152.4cm × 76.2cm for cutting grasses. The seed sowing and spraying was done to a rectangular area from. The area was 1158.24cm × 457.2cm. For the performance test of the machine, the test areas were randomly selected for three replications from the experimental site.

3 Results and discussion

Table 4 shows the technical performance of the machine. The average seed sowing rate and flow rate of the sprayer were 106.36 kg ha⁻¹ and 0.75 L min⁻¹ while the traveling speed of the machine was 1.31 km h⁻¹. Also, the application rate was 450 L ha⁻¹ with a swath width of 91.5 cm. This result agrees well with the study (Pachpor et al., 2019; Issa et al., 2020). The average height of the grasses was 180 mm before cutting and after cutting it was 70 mm. At 1.31 km h⁻¹ operational speed, the cutting efficiency was 78%. Also, 12.5% and 6.06% were the turning and overlapping loss of the machine. These two losses were high because of small-sized experimental field. The theoretical field capacity, effective field capacity, and field efficiency of the multipurpose agricultural machine were 0.12 ha h⁻¹, 0.1 ha h⁻¹, and 83% respectively. This result is like the findings of previous studies (Magar et al., 2010; Bhutada and Shinde, 2017).

Table 4 Technical performance of the machine

Particulars	Observations
Seed rate(kg ha ⁻¹)	106.36
Before cutting, the average height of the grass(mm)	180
After cutting, the mean height of the grass in mm	70
Loss due to turning (%)	12.5
Loss due to overlapping (%)	6.06
Cutting efficiency (%)	78
Field capacity (Theoretical)(ha h ⁻¹)	0.12
Field capacity (Effective)(ha h ⁻¹)	0.1
Field efficiency (%)	83

3.1 Fabrication costs of the machine

Table 5 shows the total manufacturing cost of a solar-powered multipurpose agricultural machine is USD 359.08. It is less expensive than other machines

on the market. Due to the use of solar power, there is no operating fuel cost. Moreover, this machine can be operated efficiently and smoothly by one person.

Table 5 Total fabrication costs of solar-powered multipurpose agricultural machine

Material / Instruments name	Cost (USD)
Iron structure	37.56
Solar panel	12.82
Solar charge controller	1.37
Battery (12V 7.5amp)	9.16
Sprayer (2 jar)	45.80
Seed metering device	43.97
Wheel (4 wheels)	14.66
Bearing (6 Nos)	9.89
Connecting shaft (2 Nos)	9.67
Penium (3 Nos)	9.62
Chain	7.97
DC Motor	4.12
Cutting Blades (3 Nos)	1.65
Seed plow (4 Nos)	3.02
Seed hopper	2.93
Funnel (4 Nos)	2.02
Seed conveying pipe	2.75
Roller	7.14
Iron pipe	8.89
Nuts bolts	3.94
Electric weir	2.84
Making charge	119.08
Total cost	360.87

Table 6 Operating costs of multipurpose agricultural machine

Item	Costs, USD
Fixed costs	Depreciation (USD yr ⁻¹)
	Interest on investment (USD yr ⁻¹)
Total fixed costs	USD yr ⁻¹
	USD hr ⁻¹
	USD ha ⁻¹
Variable costs	Labor (USD hr ⁻¹)
	Maintenance (USD hr ⁻¹)
Total variable costs	USD ha ⁻¹
	USD hr ⁻¹
Operating costs	USD hr ⁻¹
	USD ha ⁻¹
	CRF
	Capital consumption (USD)
	Cost per year (USD)

3.2 Operating costs of the machine

Table 6 depicts the operating costs of the machine where the fixed costs and variable costs of the machine were USD 1.01 ha⁻¹ and USD 12.36 ha⁻¹ respectively when the yearly use of 800 hours.

4 Conclusion

A solar powered manually operated multipurpose agricultural machine was developed and evaluated. Based on the findings, the seed sowing rate of the machine was 106.36 kg.ha⁻¹ and the application rate was 450 l ha⁻¹. With a 78% cutting efficiency, the grasscutter cut the grass 70 mm above ground level. The spraying efficiency of manually operated multipurpose agricultural machine was discovered of 83%. The operating cost of the machine was USD 8.79 ha⁻¹. Compared to the conventional machine, the construction cost was found to be lower. This machine can be autonomous through the remote-control system, and the blade can be adjusted.

Acknowledgements

This study was funded by the Institute of Research and Training (IRT), Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh.

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