Development and performance study of a solar-operated lawn mower

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Abstract:- The solar-powered lawn mower consisted of direct current (DC) motor (12V-21000 rpm), rechargeable battery (12V-9A), solar panel (30W), solar charge controller (10A), stainless-steel blade, and control switch. The machine's field efficiency was found to be as high as 88.13% when four blades with 0.5 mm blade thickness and 45 mm cut height were used, and as low as 72.75% when two blades with 1 mm blade thickness and 15 mm cut height were used. With 0.5 mm blade thickness and 45 mm cut height, the mower's highest effective field capacity was 0.02769 $hahr^{-1}$; with 1 mm blade thickness and 15 mm cut height, its minimum effective field capacity was 0.02286 hah^{-1}. The fabrication cost of the mower was $71.89. The average effective field capacity of the machine was found 247.64 m^2h^{-1}, field efficiency 78.82% and cutting efficiency was 98%. The cost of the cutting operation was 0.0019 $\$m^{-2}$. It revealed that mowing by the solar lawn mower was almost 3 times faster and more cost-saving than manual mowing.

Keywords: Lawn mower, solar-operated lawn mower, solar power, mower performance, development cost of mower.

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1 Introduction

The aesthetic value of the environment is as important as food and shelter to modern life. Grasses generally find a way to survive in a range of environments, and need to curtail their growth to enhance the beauty of our habitat environment. The grass cutting may be particular action to an advanced lawn, as well as ground settling strategies (Rao et. al. 2014). In the past and even until now, cutting grass in schools, sports tracks, fields, industries area, hotels, public centers, etc. was done with a cutlass. As man evolved intellectually, grass-cutting inevitably developed into an art. With the advancement of technology, grass cutting evolved from using machetes, hoes, and cutlasses to using power grass cutters. Technology has continued to advance and better techniques of grass-cutting have been invented and constantly improved upon. This gave birth to the invention of the mower. A mower is a machine used for cutting grass or weeds as herbs and shrubs (Cameron, 2017). Any area of grass; mostly tough grass is neatly cut like in a private garden or a public park (Okafor, 2013). A lawn mower is a machine that uses single or multiple rotational blades to cut a grass surface to a uniform level (Dutta et al., 2016). The mower is easy to operate and consists of a rotating blade and roller. The blade removes the extra grass

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growth on the lawn, and the roller gives minimal pressure to the top surface of the lawn. The blades may be powered by pushing the mower forward to operate the mechanical blades, or by an electric motor, solar power, or a small internal combustion engine to spin the blades. Budding's idea of a lawn mower came after watching a machine in a local cloth mill that used a cutting cylinder mounted on a bench to trim clothes for a smooth finish after weaving (Satwik et al., 2015). Like around the world, Bangladesh's energy needs are rising daily for several reasons, including the country's growing population, the desire for higher living standards, and the country's overall economic and industrial development. In Bangladesh, the power generation system is principally dependent on imported petroleum oil and natural gas (Abdulrazak et al., 2021). Without implementing any policies, Bangladesh's current reserves of natural gas will not meet its current level of consumption demand beyond the next two decades (Das et al. 2013). The current power generation system needs to be diversified to lessen reliance on imported fuel and the pressure on natural gas. At the same time, indigenous energy sources must be explored and developed. It should be noted that environmental concerns are becoming ubiquitous, and using conventional energy produces greenhouse gases that have a negative impact on the climate and human health. In recent years, solar energy has been given more attention for generating power. It is a clean and renewable energy source. In the world today, where technology is merging with environmental awareness, most people are looking for ways to contribute to the relief of their own carbon footprints (Bidgar et al., 2017). The most common types of lawn mowers are powered by gasoline engines, which are hazardous to the environment, thereby leading to global warming and depletion of the ozone layer (Sivaraman and Lindner, 2004). Thus, gasoline-powered mowers create noise due to the loud engine noise, and air pollution due to the combustion in the engine. Hence, alternatives to the use of non-renewable energy and polluting fossil fuels need to be taken into consideration. Solar energy is abundant, free, and non-polluting hence, it is considered one of the most competitive choices of all renewable energy choices (Fang et al., 2018). The sun has always been the primary energy source for life on Earth. Solar energy is renewable energy. It does not require a gasoline refill or occasional replacement of spark plugs. The solar-powered grass cutter is multi-tasking, user-friendly, and eco-friendly with high efficiency when compared to existing products and in an affordable range (Shivbhakta et al., 2024). The design of solar-powered lawn mowers can be seen as an alternate option to popular and environmentally hazardous gas-powered lawn mowers (Venkatesh et al., 2015). Solar lawn mowers are advantageous over gasoline-powered mowers because they eliminate environmental pollution which is responsible for the emission of gases that result in global warming on the earth's surface. Also, with the rate at which petroleum products are increasing day by day, the use of solar energy can be seen as a reasonable practice to the use of renewable energy sources to operate lawn mowers by eliminating the use of gasoline fuels which gasoline engines solely depend on. Therefore, this study aimed to develop and performance evaluation of a solar-powered lawn mower.

2 Materials and methods

The machine was fabricated with locally available materials to minimize the fabrication cost. Some of the components and supplies were unavailable in the local market and had to be imported from outside the city. The materials listed below are needed to fabricate a solar-powered lawnmower:

2.1.1 Solar panel

A solar panel (Figure 1) is a package of solar modules, a photovoltaic panel connected to the assembly of photovoltaic cells. Solar panels convert light into electricity. The solar panel was fixed in front of the handle by four nuts and bolts. A 30 W solar panel (RD30P-36P2M) with dimension 710mm×360mm×30mm was used in the mower. The maximum current and voltage of panel was 1.63 A and 18.36 V respectively. The weight of the panel was 3.1 kg. A slope of 25° to attach the solar panel in its proper position to catch away the sun's rays (Mamun et. al. 2017). The solar panel was connected to the solar charge controller, and solar charge controller was connected to the battery.

Figure 1 Solar panel

2.1.2 Solar charge controller

A solar charge controller (PE-2023) shown in Figure 2 regulates the voltage and current from solar panels. The dimension of the controller was 15 cm×12 cm× 2.3 cm. The maximum output was 12 V. It was positioned between a solar panel and a battery. It serves to keep the battery’s charging voltage at the appropriate level and protects it from overcharging and discharging.

Figure 2 Solar charge controller

2.1.3 Battery

A battery (Figure 3) is energy storage device. A (HMC 12N9-4B SMF) rechargeable sealed lead acid battery was used in the mower. The battery's voltage and current were 12 V and 9 A, respectively. The maximum power of the battery was 108 watts. The DC battery is the main powerhouse of the system, which composed of electrochemical cells, and it’s charged by the solar panel. It stores energy through electrochemical reactions. This energy was supplied to the DC motor for the rotation of the grass-cutting blade during the operation. A controller was provided between solar panel and battery to control the current flow.

Figure 3 Battery

2.1.4 DC motor

A DC motor (Figure 4) is an electrical motor that uses direct current (DC). A DC motor speed can be adjusted by varying the field current or the voltage supplied to the armature. It was used for rotating the cutting blade. A 775 model DC motor was used in the machine. The RPM and voltage of the motor were 21000 and 12 V, respectively. The torque and rated power were 0.2 Nm. and 150 watts. The motor shaft was connected to the blade shaft with the help of coupler.

Figure 4 DC motor

2.1.5 Front-wheel

The front (Figure 5) wheel was attached to the mainframe to run the machine in a particular direction, with the entire load of the machine on it. The diameter of the wheel was 20 cm, and width was 3.5 cm.

Figure 5 Front wheel

2.1.6 Rear caster wheel

The rear caster wheel (Figure 6) was attached to the machine to support the movement at any direction easily with the entire load of the machine on it. The diameter of the rear caster was 11 cm and width was 3.5 cm.

Figure 6 Rear caster wheel

2.1.7 Coupler

A coupler (Figure 7) was a holding device that was used for connecting the motor shaft to the blade shaft. The coupler was made of steel. The steel coupler of 5.4 cm (2.1 inches) diameter was attached by nuts and bolts to the shaft of the motor to hold the cutting blades. The weight of coupler was 88.2 grams.

Figure 7 Coupler

2.1.8 Push handle

A handle was attached to the main frame at suitable position. Stainless steel pipe was used as the handle of the machine. The Handle was made on the back sides of the machine so that the machine to operate easily and control its turning. The length of the handle was 42 cm, and diameter was 2 cm.

2.1.9 Clamp

Using inward pressure, a clamp is a fastening tool that holds or secures things firmly together to prevent movement or separation. The clam was used to hold DC motor with the main frame. By this whole clamp, the height adjustment of the blade was done up and down by losing or tightening the nut in the main frame. The height of grass was controlled 5 mm to 115 mm by this clamp.

2.1.10 Cutting blades

Cutting blades were the primary components of a grass cutter machine for shearing the grass. These were usually made of tough and malleable metals as they are required to bear high-speed contact with a variety of objects. This machine uses two types of rectangular stainless-steel blades. One type of blade size, Figure 9(a) was 110 mm ×18 mm × 0.5 mm, and each weighed 6.3 gm. Another type of blade, Figure 9(b), size was 110 mm × 18 mm × 1 mm, both had holes, diameter 6 mm, and each weighed 8.1 gm.

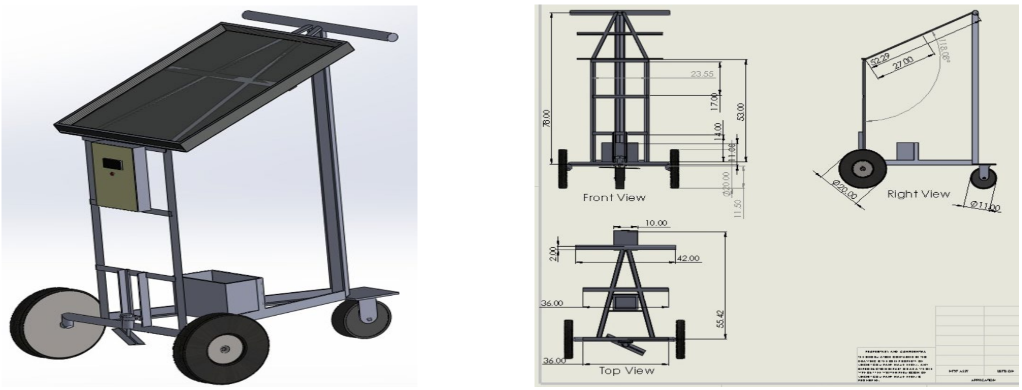
(a)Blade-1 (b) Blade-2

Figure 9 Cutting blades

2.2 Fabrication of the solar-operated lawn mower

Fabrication of the solar-powered lawn mower was done at Vai-Vai Workshop in Gopalganj Bazar, Agricultural and Industrial Engineering Lab-4, Dinajpur, Bangladesh. The main frame was made of Mild Steel angle bar and Mild Steel flat bar. The main frame was isosceles triangular shape. This machine had two isosceles triangular shapes shown in Figure 10(a). In top triangular shape, two equal sides, each side was 54 cm length, and other side was 23 cm length. In bottom triangular shape, two equal sides, each side was 48 cm length, and the other side was 23 cm length. In this machine, the front Mild Steel angle bar was 53 cm height from the front wheel. The front two wheels were connected by a rod with a length 45 cm and diameter of 2.4 cm. The handle shown in Figure 10 was 88 cm in height from the ground. The Stainless-steel pipe was used as the handle of the machine. The length of the handle was 42 cm and the diameter was 2 cm. The perfect coupler shaft shown in Figure 10(a) was made by a lathe machine. The coupler was made of steel. The Coupler was used for connecting the motor shaft to the blade shaft. One end of the coupler was connected to the motor shaft, and the other end was connected to the blade shaft. The Mild Steel plate bar was used for battery case, perfectly adjusted the solar panel, and the solar charge controller in the main frame.

A slope of 25° is required to attach the solar panel in its proper position to catch sun's rays. The motor clamp and the cover for the motor were made of a stainless-steel plate. All the joints were made by welding to make the motor clamp and the safety cover strong and rigid, and to reduce the vibration at the time of operation. The safety cover was strongly attached to the motor clamp of the machine by welding using nuts and bolts. For strengthening the joints, welding was necessary. A step-down 300V arc welding machine was used for the necessary welding. The motor was installed in the motor case. Solar panel, solar charge controller, battery, adjustable handle were installed in the main structure frame. A switch and rubber handle were installed on the body. A flexible cable was used outside the frame to give a connection between the solar panel, solar charge controller, motor, switch, and battery of 12V-9A. A coupler was attached to the shaft of the motor to hold the cutting blades. The coupler was attached with blades by 4 nuts and bolts. The whole machine shown in Figure 10(a) was found to weigh 16.4 kg by measuring with a weighing balance. The dimension of the machine is shown in Figure 10 (b).



(a) Prototype view (b) Schematic views

Figure 10 Prototype and schematic views of the machine (Units in mm)

2.3 Working principle of the machine

The model had a solar PV panel mounted in such a way that it could receive solar radiation with maximum insolation. The solar panel would convert the sun's radiation into electricity which was achieved with the help of the photoelectric effect; hence acting as the primary source of power. This electrical energy was stored in a battery with the help of a solar charger while in operation. The function of a solar charge controller was to increase the current from the panel while the battery was charging for efficient and fast energy storage. It also disconnected the solar panel from the battery when it was fully charged or connected to the panel when the battery charge was low. The system was operated with the help of an electrical switch which helps in connecting the circuit with the direct current (DC) motor to the battery. The DC motor system provides the required torque to drive the rotating cutter blade coupled with the help of a mechanical coupler to its shaft to shear the grass. This had been achieved by the effective effect of the cutting blade action and the forward movement of the machine. The revolving front and back wheels ensure easy maneuverability of the machine. The electrical energy of the battery was converted to mechanical energy through a blade that was designed to achieve the requisite cutting operation. The electric circuit confirms power transfer from the battery to operate the DC motor, while the solar panel harnesses the solar energy to continuously recharge the battery.

The cutting blades use power from the DC motor. The electric motor forms the machine's heart and provides the blade's driving force. When the power switch is turned on, the motor is powered by the battery's electrical energy, which then causes the blades to move. The mower is driven forward by its revolving blades, which continuously chop the grass.

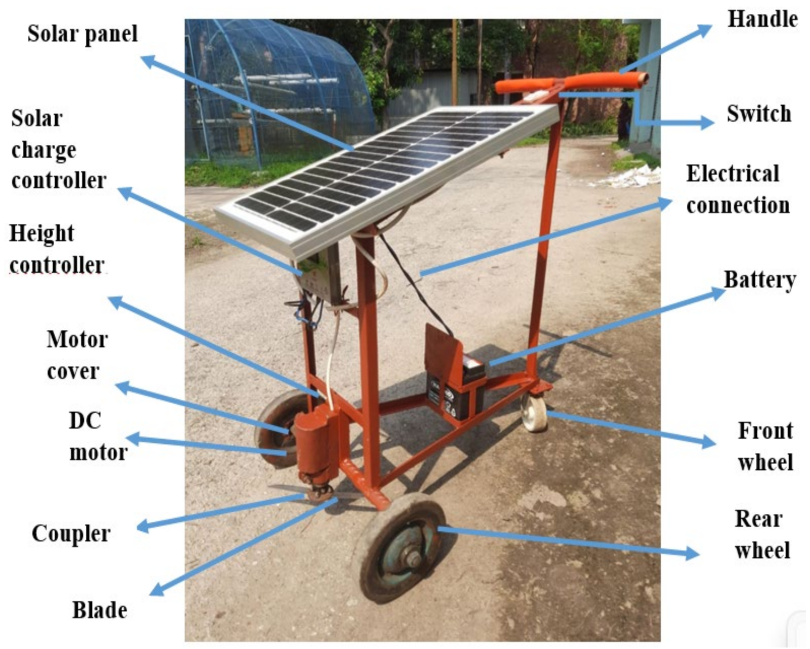


Figure 11 Developed solar-powered lawn mower

Front view

Top view

Right view

Left view

Figure 12 Different views of solar-operated lawn mowers

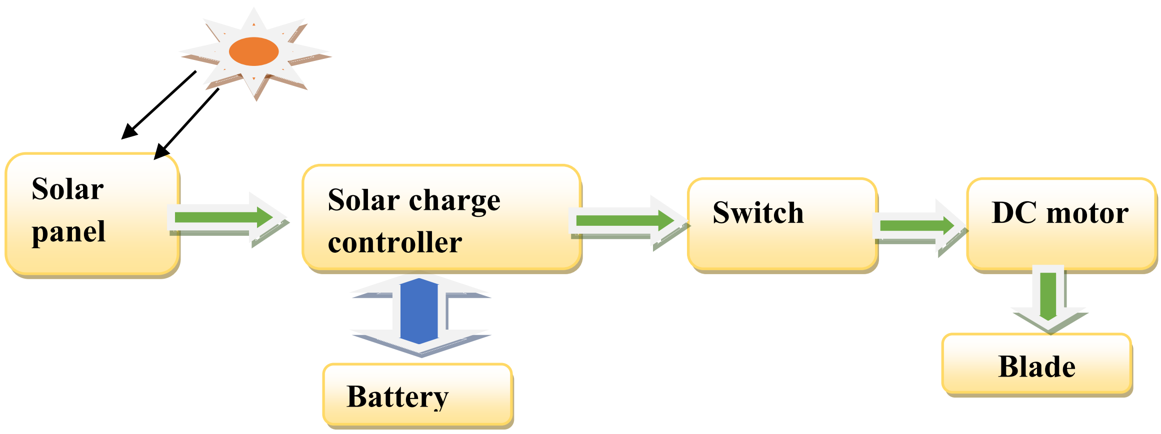


Figure 13 Block diagram of the working principle of the lawn mower

2.4 Evaluation of the machine

2.4.1 Field experiment of the solar-powered lawn mower

Field experiments were carried out outside of laboratory settings. They randomly assign subjects to either treatment or control groups to test claims of causal relationships. The field experiment was taken in the HSTU campus, Dinajpur" over different fields. The machine was applied to the field and measured the cutting area in determining time. The time was recorded by the stopwatch.

2.4.2 Theoretical field capacity

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

$$TFC = \frac{SW}{C} \quad (1)$$

Where,

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

W = Cutting width (m);

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

C = Constant, 10.

By measuring the distance traveled and the amount of time required, the speed of operation was determined as:

$$S = \frac{L}{t} \quad (2)$$

Where,

S = Forward speed of operation, ms^{-1};

L = Distance traveled, m;

t = Time taken, s.

2.4.3 Actual or effective field capacity

The effective field capacity of a machine is the average rate at which the machine actually covers. The effective field capacity can be calculated using the following equation (Berger et al., 1978).

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

Where,

EFC = Effective field capacity (hahr^{-1});

T = total time for the reaping operation (hr);

A = area of land reaped at the specified time (ha).

2.4.4 Field efficiency

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

$$Field\ efficiency\ (\%) = \frac{EFC}{TFC} \times 100 \quad (4)$$

Where,

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

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

2.4.5 Measurement of revolutions per minute of the machine

The rpm of the motor with and without the blade was measured by using a tachometer (Model DT-2234BL, Taiwan) and recorded.

2.4.6 Cutting efficiency

To determine the cutting efficiency, firstly the area marked test area with grass was measured. After completing the mowing operation, the area of cut and un-cut grass was measured from the test area. The cutting efficiency was computed of the lawnmower by using the following equation.

$$C_{eff} = \frac{A_c}{A_c + A_u} \times 100 \quad (5)$$

where,

C_{eff} = Cutting efficiency (%);

A_c = Area of cut grasses;

A_u = Area of uncut grasses.

2.5 Cost analysis

The selection of machines for agricultural activities usually depends on the least-cost operation criteria (Oduma et. al. 2019). The cost of the lawn mower consists of (a) fixed costs (depreciation, interest on investment, taxes, insurance, and shelter) (b) variable costs (Fuel cost, labor cost, repair and maintenance cost).

2.5.1 Fixed cost

Fixed cost consists of depreciation and interest on investment and taxes insurance and shelter. The interest on investment was calculated using the formula and taxes, insurance, and shelter could be omitted.

2.5.2 Depreciation

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

$$D = \frac{P - S}{L} \tag{6}$$

Where,

D =Depreciation cost ($\$yr^{-1}$);

P = Purchase price of the machine or implement (\$);

S = Salvage value (\$) ;

L = Life of the machine or implement (yr.).

2.5.3 Interest on investment and taxes, insurance, and shelter

Interest on investment *(IOI)* was calculated using the formula,

$$IOI = \frac{P + S}{2} \times i \tag{7}$$

Where,

i = Current interest rate.

Taxes, insurance, and shelter were calculated at the rate 3% of purchase price (Sanjoy, 2015).

2.5.4 Variable cost

The variable cost is one, which changes when the level of output alters and varies in total in proportion to annual use but is approximately constant per hour. The variable cost of lawn mowers depended on labor and repair & maintenance costs for each field operation. The cost of labor, repair, and maintenance was calculated in $\$hr^{-1}$.

2.5.5 Total operating cost

All calculated fixed costs and variable costs were converted into $\$m^{-2}$, and the summation of fixed and variable costs gave the operating cost of the mower $\$m^{-2}$ (Barnard and Nix, 1979).

$$TC = FC + VC \tag{8}$$

Where,

TC =Total operating cost ($\$hr^{-1}$);

FC =Fixed cost ($\$hr^{-1}$);

VC =Variable cost ($\$hr^{-1}$).

2.6 Comparisons of manual and machine mowing

Nine different areas were selected to study the cutting performance of the mower. Another three different areas were selected to cut the grass using manual labor. Comparative performance was calculated with respect to effective field capacity and cost.

Table 1 Hourly operating cost determination

Cost factor items	Formulas and notations of the factors
Purchase price, *P*	The price of the machine
Machine life, *L*	The time of years the machine will run efficiently
Salvage value, *S*	10% of *P*
Depreciation, *D*	*(P-S)/L*
Interest rate, *i*	13%
Interest on investment, *IOI*	$\frac{P+S}{2} \times i$
Cost of shelter, property & sales Taxes, *T*, Insurance, *I*	3% of *P*
Repair and maintenance cost, *R&M*	75% of *P* in the lifetime
Labor cost	3.34 $\$day^{-1}$
Annual use	300 hr

3 Results and discussion

3.1 Field performance of the lawn mower

The performance of the lawn mower machine was evaluated through a field test was mapped out into plots; Nine plots were selected by randomization process and mowed using three types of blades in different heights of cut where each plot was 4 m^2. By the machine, the height of cutting grasses can be controlled from 5mm to 115mm.

3.2 Revolution per minute of the motor

The motor's revolution per minute (RPM) was recorded when the motor was connected to battery of 12V- 9A and switched with or without the cutting blade. The rpm was measured by using a tachometer. The motor rpm varies between 10400 and 20154. Fifteen readings of rpm were recorded, and the average rpm was found to be 15430.

3.3 Cutting performance of the lawn mower

The performance study for the lawn mower of an experimental area of 2m x 2m (including grass). The grass could be cut at desired height. The cutting efficiency was found 98%.

3.4 The time required to charge the battery.

The battery rating was 9 ampere-12 volt and the current produced by the solar panel was 1.63A. The calculated theoretical charging time was 5hr 31 minutes.

3.5 Backup time of lawn mower

The DC motor was 12V and at loaded 3Ah

Power of motor, $P = VI = 12 \times 3 = 36$ W

Battery rating = 12V - 9Ah

Battery power, $P = VI = 12 \times 9 = 108$ W

$$Backup\ of\ lawn\ mower\ time = \frac{108}{36} = 3hrs$$

The motor was rated 12 V and 3 A. Power stored in battery 108 W hr^{-1}. Backup the lawn mowing time was measured 3 hrs.

3.6 Cost analysis of the developed machine

Because if the machine were made at a high price, it would not be acceptable to the people. The fabrication costs are given in Table 3.

Table 2 Field performance of the solar-powered lawn mower

SL no	Thickness of blade (mm)	Number of used blades	Height of cut (mm)	Time required (s)	Operating speed (km hr^{-1})	Theoretical field capacity (ha hr^{-1})	Effective field capacity (ha hr^{-1})	Field Efficiency (%)
1	0.5	4	15	60	1.309	0.03142	0.02395	76.22
2	0.5	4	30	56	1.309	0.03142	0.02564	81.61
3	0.5	4	45	52	1.309	0.03142	0.02769	88.13
4	0.5	2	15	62	1.309	0.03142	0.02326	74.01
5	0.5	2	30	59	1.309	0.03142	0.02441	77.68
6	0.5	2	45	55	1.309	0.03142	0.02614	83.21
7	1	2	15	63	1.309	0.03142	0.02286	72.75
8	1	2	30	61	1.309	0.03142	0.02367	75.33
9	1	2	45	57	1.309	0.03142	0.02526	80.41
				Average				=78.82

Table 3 Cost of machine

Material/Instrument name	Cost ($)
Solar panel	13.79
Battery	8.36
Solar charge controller	5.43
DC motor	5.02
Blades (3 types)	2.59
Wheels (3)	7.11
Switch	0.33
Mainframe (MS angle, rod, nut-bolt)	12.54
Electric wire	2.51
Construction cost	12.54
Others cost	1.67
Total cost	71.89

The total fabrication cost of the solar-powered lawn mower machine was $71.89.

Table 4 Total cost estimation of machine and manual

	Machine mowing cost			Manual mowing cost
Cost items	($$year^{-1}$)	($$hr^{-1}$)	($$m^{-2}$)	($$m^{-2}$)
Fixed Cost				
Depreciation	6.47	0.022		
IOI	5.14	0.017		0.0056
TIS	2.16	0.0072		
Total Fixed Cost	13.77	0.046	0.0019	
Variable Cost				
1. R&M	5.39	0.018		
2. Labor		0.42		
Total Variable Cost		0.44		
Total Cost of mowing		0.48	0.0019	0.0056

3.7 Comparisons of manual and machine mowing

Table 5 Time required for mowing by a labor.

Trial no.	Experimental area (㎡)	Time required to cut grass. (second)	Avg. experimental area (㎡)	Avg time required (s)	Avg time required (hr)	Mowing (㎡ hr-1)
1	2 m × 2 m	204s	4	193	$\frac{193}{3600}$ = 0.0536	$\frac{A}{T}$ =74.63
2	4 m × 1 m	190s				
3	2 m × 2 m	185s				

The required time of cutting grasses by the lawn mower machine was 247.64 ㎡hr^{-1} and the required time of cutting grasses by a laborer was 74.63 ㎡hr^{-1}. From the study, it was seen that the machine mowing was three times faster than manual mowing. In manual mowing, it was very difficult to cut the grass at the same height of the whole field but in machine mowing, it was easy to cut the grass at the same height of the whole field (Ibe, 2017). By the machine, the height of cutting grasses could be controlled from 5mm to 115mm. The use of the manual cutting method is associated with a high cost of execution. This is because the cost of employing humans to cut grass covering a given area is usually more than the cost of using a lawn mower (Sivagurunathan et al., 2017). The comparative cost of the machine mowing was 0.0019 $\$m^{-2}$ and manual labor mowing was 0.0056 $\$m^{-2}$. It was also seen that machine mowing was almost three times more cost-saving than manual mowing.

4 Conclusion

The electric power in the battery operates the motor and rotates the blade and cutting grass. The arrangement of the lawn mower was set up very carefully and the frame structure was made in the workshop. In the field performance investigation, it was found that the average effective field capacity 247.64 m^2 hr^{-1}, Field efficiency 78.82% and cutting efficiency was 98%. The cost of the cutting operation was 0.0019 $\$m^{-2}$. In comparison to manual operation, the machine cuts were 247.67 m^2 hr^{-1}. The comparative cost of machine mowing was 0.0019 $\$m^{-2}$ and manual labor mowing was 0.0056 $\$m^{-2}$. It revealed that the mowing by the lawn mower was almost 3 times faster and cost-saving than manual mowing. It can also be operated even without the presence of sunlight as the rechargeable battery can provide the power supply for up to three hours after being fully charged. This machine was suggested for different areas such as playgrounds, college campuses, gardens, and agricultural fields that have lawns.

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