Fabrication and performance evaluation of a solar-operated pesticide sprayer

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Abstract: In Bangladesh for spraying purposes there are two types of sprayers are used, one is hand-operated and the other is a fuel-operated sprayer. A worker can't use the hand-operated sprayer nonstop for more than 5-6 hours and needs fuel for fuel fuel-operated sprayer which is costly, an environmental pollutant and in rural places availability of fuel is not easy. An investigation was made to fabricate a solar pesticide sprayer, evaluation the performance of the sprayer and comparing it with the hand-operated sprayer. The solar-operated pesticide sprayer consists of a 12-volt 20-watt capacity solar panel, a 12-volt DC battery, a DC motor, a pump and a 16-liter tank to hold the pesticide. The solar sprayer required 5 minutes 18 seconds to apply pesticide in 5 decimal fields. This time was almost half compared to the hand-operated sprayer. The solar sprayer worked at 4-5 bar but hand operated sprayer worked at 1.5-2 bar. The solar panel of the pesticide sprayer produced maximum voltage, current and power at 30^0 inclination angles and the lowest output at 60^0 inclination angles. The proposed sprayer's total cost was US $ 2.13 per ha. On the other hand, the manually operated sprayer costs US $ 4.20 per ha. It was clearly shown that the solar-operated sprayer cost was half compared to the manual sprayer. In full solar intensity after 5 hours of operation, the solar pesticide sprayer can operate for 3-4 hours more which offers the spraying facility at night. This sprayer can be used at farms, gardens and other various locations also it can become more popular in rural areas.

Keywords: solar sprayer, pesticide sprayer, sprayer performance, sprayer fabrication, sprayer evaluation, sprayer cost, sprayer.

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1 Introduction

Bangladesh is an agricultural country and directly or indirectly 70% population of Bangladesh is dependent on agriculture. Compared to the developed countries, the problem of developing countries of Asia is low levels of land productivity with a higher population. Insufficient power availability and very low levels of mechanization in agriculture are the main reasons for lower productivity among others. Metering and ensuring better distribution of inputs, identifying the level of quantity required for the best production, and preventing loss or wastage of inputs applied are the functions of mechanization (Mahesh et al., 2015).

The Mechanization decreases the unit costs for production by input conserving the high level of

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productivity (Chavan et al., 2015). Now a days, the whole world is facing an energy crisis problem. In a country, the greatest challenge for Scientists, engineers, and entrepreneurs is energy -demand (Joshua and Vincent, 2010). If the energy use is extended, the energy must be saved either small scale or a large scale. Today various spraying technologies involve the use of electrical energy, and chemical energy of fuels. But in this sector, instead of direct energy sources mechanical energy can be used and large quantities of energy can be saved. In recent years solar energy has been gaining is one of the most significant and plentiful renewable sources of energy compared to other sources. Sun is enriching agriculture and diminishing environmental degradation is the real source of energy (Behera et al., 2015). 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).

In Bangladesh, to solve the power crisis Solar Energy can be a great source. The 35°N latitude lies between the most favorable region and the most satisfactory conditions is 35°C for solar energy applications (Martín-Domínguez et al., 2005). Bangladesh is located in the north latitude between 20°34' and 26°38' degrees and in the east 88° 01' and 92°41' degrees which is a perfect position for solar energy consumption. An average of 5kW h m-2 solar radiation descends over the land for approximately 300 days per annum in Bangladesh (Ahmed et al., 2020). In agricultural production spraying is one of the vital things. The most efficient and effective technique to protect crops by applying a small amount of liquid through fine droplets is spraying.

The application of pesticides, and insecticides using spraying equipment has produced massive benefits as they kill undesirable pests, and insects by the breakdown of their vital developments through chemical action. Sprayers are exactly designed to spray liquids quickly and simply. Power-operated and hand-operated spraying equipment is being used in Bangladesh. At present, most of the farmers usually use manually operated knapsack sprayers. For the spraying of pesticides on crops like cotton, red gram, the motorized sprayers can cover 1.2-1.6 ha hr^{-1} and the knapsack sprayers can cover 0.4 ha hr-1. Pest attack spreads quickly and are a serious problem.

The problem for farmers is large area coverage within a short period of time. In a season, the area covers within a short period of time many of the farmers usually spray 6-8 times using a manually operated or motorized sprayer. The modernization of pesticide spraying machines is important for the agricultural sector (Akhilesh et al., 2016). Discharging the chemicals by the motor-operated pump, a batterie is used for running the motor. But electricity is required for charging the batteries. It is a better possibility for the consumption of solar energy for the generation of electricity and further to utilize the same for spraying (Malonde et al., 2016).

Multipurpose machine based on solar panels pesticide spraying gives maximum work output with minimum effort. According to the crops, the nozzle arrangement can be adjusted and the pump can be used for multiple crops. In this system, solar power is used to operate the motor that’s why it is a pollution-free pump over to the petrol engine spray pump (Kumawat et al., 2018). Solar-operated sprayer pump is pollution free compared to the pump of petrol engine operated sprayer. Superfluous electricity can be stored in batteries and applied to home appliances like glowing CFL bulbs, mobile charging, etc. This study was conducted to fabricate, cost analysis and performance evaluation a solar-operated pesticide sprayer and compare it with hand operated Agro sprayer.

2 Materials and methods

2.1 main components of the solar-operated pesticide sprayer

The solar-operated pesticide sprayer was fabricated with many components. The main components were:

(1) Solar panel

A solar panel is associated assembly of photovoltaic cells. A 12-volt 20-watt capacity solar panel was used in the proposed sprayer. A photovoltaic system contains interconnection wiring of an array of solar panels, an inverter, a battery and or solar tracker.

(2) Pump

A solar-operated water pump uses the sun's energy to supply electricity for the pump that’s why it differs from a regular water pump. A 12-volt DC water pump was used in the sprayer.

(3) DC motor

A DC motor converts the electrical energy of direct current into mechanical energy. The speed of a DC motor can be controlled a wide range, using either a mutable supply voltage or by altering the strength of the current in its field windings. A universal DC motor was used in this sprayer because of its lightweight.

(4) Battery

An electric battery is used to power electrical devices consisting of one or more electrochemical cells with external connections. The cathode is the positive terminal of the battery and the anode is its negative terminal when it supplies electric power. A 12.0 volt / 7.2 Ah DC battery was used in the sprayer.

(5) Storage tank

Storage tanks were used to hold liquids or gases for short or long-term storage. Many shapes of storage tanks are available: vertical and horizontal cylindrical open top and closed top flat bottom, cone bottom, slope bottom and dish bottom. There were 16 L vertical cylindrical open-top storage tanks used in the sprayer.

(6) Nozzle

A nozzle is a device that is used to control the flow rate, speed, direction, mass, shape, and pressure of the stream that emerges from them. The spray deposits and the droplet’s drift ability depend on droplet size and velocity (Nuyttens et al., 2009). In the hollow cone nozzle is a swirl chamber situated between a swirl plate and a swirling core where the swirl plate is surrounded by the swirling core. In the sprayers, the hollow cone nozzle was used because it was very suitable for the foliar application of insecticides and fungicides for its fine droplets.

(7) Bevel gear

Bevel gears are most often riding on 90 degrees apart shafts but can be designed to work at other angles as well. Pitch surface and pitch angle are vital concepts in gearing. The pitch surface is the cylindrical shape of an ordinary gear. The angle between the axis and the face of the pitch surface is the pitch angle.

(8) Multi-meter

Multi-meter is an electrical device. Fluke 179 TRMS digital multimeter was used to measure the electrical current, and voltage.

(9) Pesticides

Any material or mixture of materials proposed to prevent, destroy, repeal or mitigate any pest is called pesticide. Herbicide, Insecticide, Insect Growth Regulator, Nematicide, Termiticide, Molluscicide, Piscicide, Avicide, Rodenticide, Bactericide, Insect Repellent, Animal Repellent, Antimicrobial, Fungicide, Disinfectant (Anti-microbial), and Sanitizer all are pesticide. In general, most pesticides are intended to protect plants from weeds, Fungi, or insects.

(10) Solar energy

Solar energy is an abundantly available renewable energy source that is used for various purposes in the form of solar water heaters, solar power, and solar cookers. Depending on capture and distribution, it is broadly characterized as either active or passive solar. The active solar energy system consists of external sources like motors and circuits to function the system accurately. In this system use of the mechanical instrument increases the system’s accuracy and efficiency. There are no mechanical devices in passive solar energy systems.

(11) Solar charge controller

A solar charge controller is a device used to control the voltage and current from solar panels. It was located between a solar panel and a battery. It was maintained the battery with proper charging voltage and also protected from overcharging and discharging.

(12) Assembly process

The cast iron was used to make the base structure. The necessary parts were fixed in the determined places and the connections were made in the workshop. The solar panel was fixed in a position so that it could absorb sufficient sunlight. A controller was connected to the solar panel and a battery so that the battery was charged. A DC motor was connected to the battery. The pump was working with the help of the DC motor and the mechanical energy was converted to the hydraulic energy. The hydraulic energy pulled the pesticides and came out from the nozzle through the piping system.

(13) Working principle of solar operated sprayer

Solar operated system contains solar panel, battery, pump and sprayer. The solar panel output was 20 volts and power were supplied to the charging unit. The charging unit charged the battery. Here fertilizer can be stored in a tank. Electricity was generated through the solar cells and stored in the battery, when the sun rays were falling on the solar panel. The pump was operated by the electric power from the battery and pesticides were sprayed out through the sprayers from the tank.

Solar energy obtained by the sun is converted to electrical energy using solar panels by the photovoltaic effect. The converted energy was used to charge a deep-cycle battery. A deep cycle battery was used so that the battery was capable of being charged and discharged in several times. A lead-acid accumulator was used for that purpose. Compare to the properties of conventional batteries, the lead-acid battery has high current availability, contact voltage, longer life and more ability to charge. The battery and DC pump were connected through a protection circuit. The DC pump was used because of less noise, longer lifetime, maintenance free, motor speed could be varied in a larger extent by varying the supply voltage and is self-lubricated.

The spraying liquid was sucked from the tank by the pump and sprayed through a nozzle. lightweight material was used to make sprayer tank in order to reduce the weight of the tank. The 16 liters capacity tank was connected to the sprayer pipe with an adaptable nozzle. The flow output could be controlled by adjusting the nozzle. The whole structure was carried conveniently at the back of the human body with the help of shoulder straps. This sprayer is the best option of economically challenged farmers and facing electrical problems like load shedding.

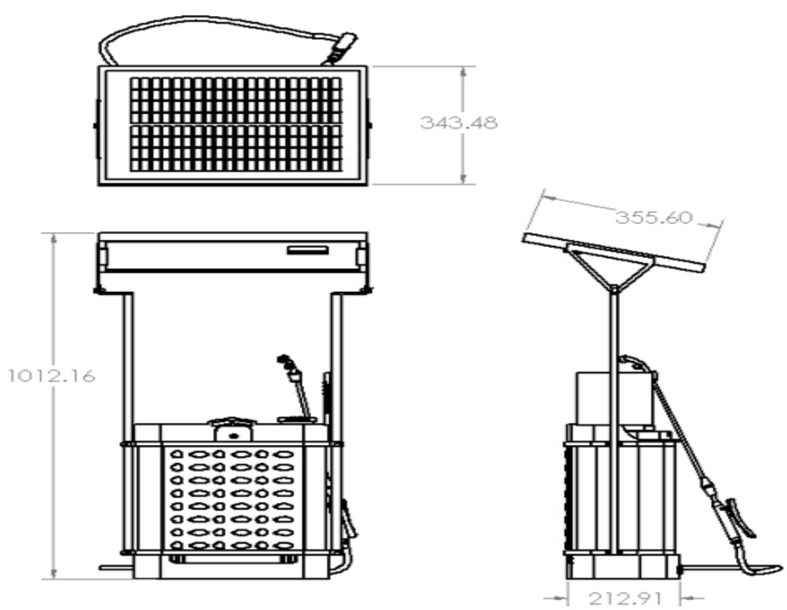

Figure 1 Schematic view of developed pesticide sprayer (Units are in mm)

Figure 2 3-D isometric view of developed sprayer

2.2 Measurement of voltage and current

The solar panel absorbs solar energy which holds photovoltaic cells. In these cells, the solar energy was converted into electrical energy. The converted electrical energy stores the voltage in the DC battery and drives the spray pump by the battery. The voltage and current were measured at different angles of the solar panel. The solar panel set up the sunlight at 30^0, 45^0, 60^0 and flat angles and measured voltage and current with the help of a multimeter.

$$P = V \times i \tag{1}$$

Where, *P*= Power (watt);

V= Voltage (volt);

i= Current (amp)

2.3 Field application

2.3.1 Experimental site

The experiment was conducted in the area of Kornai village in Dinajpur district. It is located 413 km (25°37′N 88°39′E / 25.617°N 88.650°E) north-west of Dhaka Bangladesh. The experiment was applied in the Aman rice field from 14/09/2019 to 16/09/2019. The experiment was conducted in three experimental plots. The plot size was selected in 5 decimals. Solar-operated sprayers and hand-operated sprayers were used in the selected area.

2.3.2 Pressure measurement

A pressure gauge was set up between the nozzle and spray gun to measure the flow rate of the selected nozzle at different pressures. The range of the pressure gauge was 0 to 100 psi (0 to 7 kg cm^{-2}). The pressure gauge was set by using a T-joint. The T-joint was made in a local workshop with suitable dimensions. The pressure was measured when the pesticide was applied in the field.

2.4 Application time measurement

The solar-operated sprayer was used to apply pesticides in the selected field. This process was applied three times and measured the spraying time by a stopwatch. The hand-operated sprayer also was used in the field and measured the spraying time by stopwatch for the same process.

2.5 Sprayer-cost analysis

A Simple cost analysis of solar operated sprayer was done. The analysis included: the device’s actual cost, and annual cost (fixed cost and variable cost). The annual fixed cost included: depreciation, interest on investment and TIS (Taxes, Insurance and Shelter). Variable cost included: repair and maintenance cost, labor cost and electricity cost. Interest 13%, taxes, insurance and shelter (TIS) 3%, repair and maintenance cost 0.025%, 8 hrs. operation per day, 300 hrs. annual use and 10 yrs. The estimated life span of the machine was assumed (Kepner et al., 1978). Using the following formulas, the cost was calculated:

The annual depreciation cost:

$$D = P - \frac{S}{L} \quad (2)$$

Where, D = Depreciation ((US \$/yr);

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

S = Selling price (US \$);

L = Time between buying and selling (yr)

Interest on investment was calculated by:

$$I = (P+S/2) \times i \quad (3)$$

Where, I = Interest on investment;

P = Purchase price of the machine;

S = Selling price;

i = Current interest rate.

Total cost per year:

Total cost = Annual fixed cost + Variable cost

3 Results and discussion

3.1 Measurements of voltage, current and power for different angles of solar panel

The solar panel was set up in the sunlight at 30^0, 45^0, 60^0 and flat angles. The sunlight reflects the solar panel and voltage and current were measured with the help of a multi-meter in the field. The measured voltage, current and power values are given below.

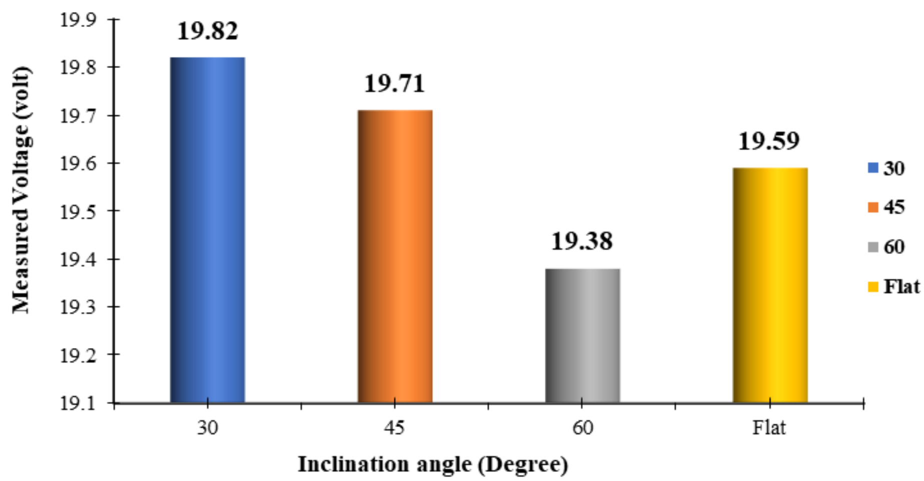

Figure 3 Relation between inclination angle and measured voltage

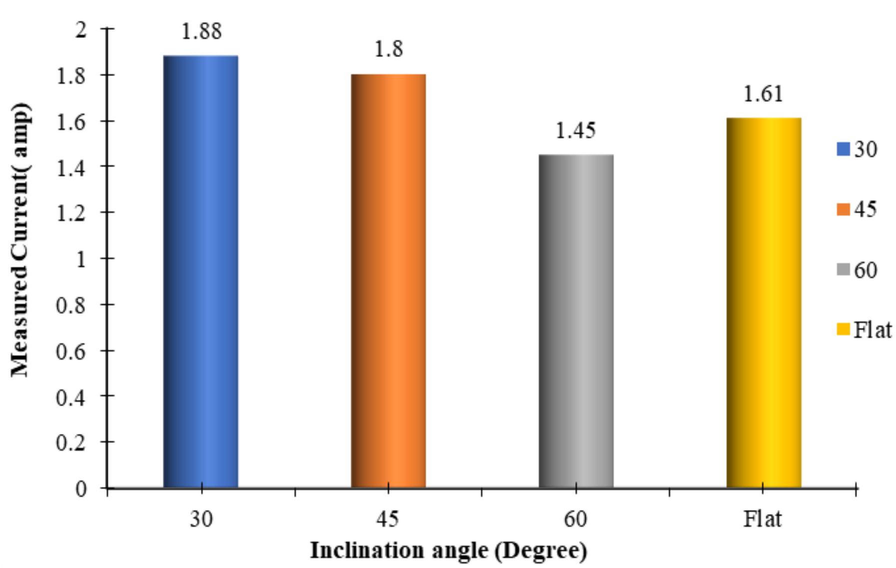

Figure 4 Relation between inclination angle and measured current

The experimental data (Figure 3) shows the relation between angle and voltage. The figure shows that the maximum voltage was produced at 30^0 angles and the lowest voltage at 60^0 angles of the solar panel, in flat angle average voltage was produced. According to Wholesale Solar (2012), the maximum amount of solar radiation, the tilt angle should be adjusted seasonally at 15^0 more than the latitude angle. The results of this experiment were closer with the value. The solar panel at 30^0 angles supplied an average voltage was 19.82 volts and at 60^0 angles was 19.38 volts.

Figure 4 shows the relation between angle and current. The figure shows that the maximum current (1.88 amp) was produced at 30^0 angles and lower current (1.45 amp) was produced at 60^0 angles of the solar panel and at flat angles produced average current (Ajao et al., 2013). The optimum tilth angle for the solar panels was found 22^0 in Ilorin, Nigeria. The tilth angle is an angle at which the solar panel should be positioned with the horizontal plane to generate maximum power. In this experiment, the optimal tilth angle for the solar sprayer was 30^0.

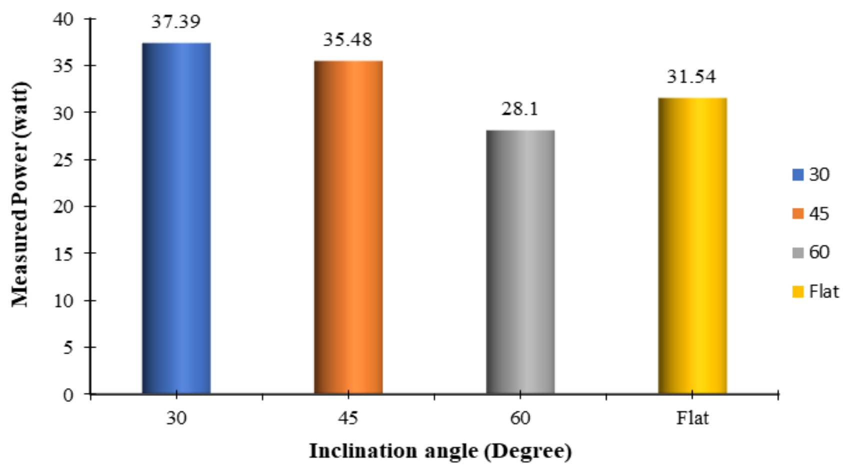

Figure 5 Relation between inclination angle and measured power

Figure 5 shows the relation between the angle and power. The figure shows that the maximum power was produced at 30^0 angles and the lowest was produced at 60^0 angles of the solar panel and at the flat angle was supplied average power. The solar panel at 30^0 angles supplied average power of 37.39 watts and at 60^0 angles power was 28.10 watts. The power generated by a solar panel is dependent on the angle at which it is tilted, the prevailing weather conditions and the orientation of the solar panel (Ajao et al., 2013). To get maximum energy from solar energy, the solar panels should be inclined at optimal tilt angle and seasonal adjustment of the panel. The value obtained from the experiment carried out clearly showed that, the voltage, current and power increase flat to 30^0 and decrease 30^0 to 60^0 inclination angle of the solar panel.

3.2 Measurements of spraying time and pressure of the sprayer

The field test of the proposed sprayer and hand-operated sprayer were applied in the rice field and measured pressure and application time. The data are given below.

Table 1 Data of spraying time and pressure of the sprayer

Sprayer	Area	Pressure	Spraying time	Average time
Solar sprayer	5 decimals	4-5 bar	4 min 51 sec 5 min 36 sec 5 min 28 sec	5 min 18 sec
Manual hand operated sprayer	5 decimals	1.5-2 bar	10 min 15 sec 10 min 58 sec 11 min 10 sec	10 min 48 sec

In the above table, the data showed that the solar-operated pesticide sprayer worked at 4-5 bar pressure, and required 5 minutes 18 seconds to cover the spraying of 5 decimal areas. On the other side, the hand-operated sprayer works at 1.5-2 bar pressure and was required 10 minutes 18 seconds to cover the spraying of 5 decimal areas. It was shown that the proposed sprayer required almost half the time compared to the hand-operated sprayer for same area spraying. The solar-operated sprayer required time to spray an average 4 hours 22 minutes per hectare. On the other hand, the hand-operated sprayer required 8-hour 52 minutes. It was shown that the hand-operated sprayer required to double the time compared to the proposed sprayer for the same area covering. By the use of this sprayer farmers can spray more area at the same time compared to the knapsack sprayer which is helpful because pest attack spreads quickly. The solar-operated sprayer use is more economical, time-saving, pollutant-free and eco-friendly.

3.3 Basic comparison between hand-operated sprayer and solar-operated pesticide sprayer

Basic parameter comparison between the hand-operated sprayer data and the solar-operated pesticide sprayer data was given below.

Table 2 Comparison of parameters

Parameter	Hand operated sprayer	Proposed sprayer
Weight	4 – 7 kg	8.75 kg
Discharge	0.8 – 1.5 Lit min^{-1}	2 – 2.8 Lit min^{-1}
Product cost	US $ 18.33	US $ 36.56
Maintenance cost	Low	Low
Pressure	1.5 – 2 bar	4 – 5 bar

Table 3 Cost analysis of solar-operated pesticide sprayer

Cost factors/items	Unit	Amount
A. Cost of the sprayer	US $/Unit	
Sprayer	US $	19.65
Solar	US $	8.23
Controller	US $	1.37
Construction cost	US $	7.31
Total Cost	US $	36.56
B. Life of the Sprayer	Year	10
C. Annual use	hrs	300
D. Annual fixed cost		
Depreciation	US $ yr^{-1}	3.29
Interest (13%)	US $ yr^{-1}	2.61
Taxes, Shelter, Insurance (3%)	US $ yr^{-1}	1.10
Total	US $ yr^{-1}	7
Total	US $ hr^{-1}	0.023
Total	US $ ha^{-1}	0.101
E. Variable cost		
Repair and maintenance (0.025%)	US $ hr^{-1}	0.0091
Labour (One labour, 3.65 US $ day^{-1})	US $ hr^{-1}	0.46
Total	US $ hr^{-1}	0.47
Total	US $ ha^{-1}	2.03
F. Total Cost (Annual fixed cost+variable cost)	US $ ha^{-1}	2.13

In the comparison of the solar-operated sprayer with the conventional sprayer, it was clearly shown that the proposed sprayer had an average value in all aspects like weight, discharge, product cost, maintenance cost, and pressure.

Weight: Though the weight of the proposed sprayer was more than the hand-operated sprayer, the requirement of manual effort for the operation was eliminated, and obviously it saved human energy.

Discharge: The discharge of hand operated sprayer was about 0.8 to 1.5 lit min^{-1}. In the hand-operated sprayer, the operator operates until a sufficient amount of pesticides is deposited. The discharge of the solar-operated sprayer was about 2 to 2.8 lit min^{-1} and it eliminated the spraying time.

Pressure: The pressure of hand operated sprayer was about 1.5 to 2 bar which was not sufficient for the crops which was tall in height. The solar-operated sprayer had a pressure was about 4 to 5 bar. The moderate pressure achieved by the proposed device could efficiently be sprayed.

3.4 Sprayer cost analysis

The proposed solar sprayer was fabricated at a low cost. The solar sprayer cost was estimated in Table 3 and the cost of the hand-operated sprayer was estimated in Table 4.

Table 4 Cost analysis of hand-operated sprayer

Cost factors/items	Unit	Amount
A. Cost of the sprayer	US $/Unit	
Sprayer	US $	1.83
Total Cost	US $	1.83
B. Life of the Sprayer	Year	10
C. Annual use	hrs	300
D. Annual fixed cost		
Depreciation	US $ yr^{-1}	1.65
Interest (13%)	US $ yr^{-1}	1.31
Taxes, Shelter, Insurance (3%)	US $ yr^{-1}	0.55
Total	US $ yr^{-1}	3.51
Total	US $ hr^{-1}	0.012
Total	US $ ha^{-1}	0.104
E. Variable cost		
Repair and maintenance (0.025%)	US $ hr^{-1}	0.0046
Labour (One labour, 3.65 US $ day^{-1})	US $ hr^{-1}	0.46
Total	US $ hr^{-1}	0.46
Total	US $ ha^{-1}	4.10
F. Total Cost (Annual fixed cost+variable cost)	US $ ha^{-1}	4.20

The fabrication cost of the solar-operated sprayer was US $ 36.56, an annual fixed cost of US $ 0.101 per ha and a variable cost of US $ 2.03 per ha. The total spraying cost of the solar-operated pesticide was US $ 2.13 per ha. On the other hand, the cost of the hand-operated sprayer was US $ 18.33 and the annual fixed cost was US $ 0.104 per ha, the variable cost was US $ 4.10 per ha. The total spraying cost of the hand-operated sprayer was US $ 4.20 per ha. The cost of the solar-operated sprayer was half of the hand-operated sprayer. That clearly showed that the solar-operated sprayer was more cost-effective.

4 Conclusion

An attempt was made to fabricate a sprayer to utilize inherently existing solar energy in spraying operations. Electricity was produced through the solar cells when the sun rays were falling on the solar panel and were stored in the battery. The pump was operated by the electric power in the battery. Therefore, fertilizers were sprayed out through the sprayers from the tank. The solar panel, solar charge controller, and other parts were set up in the sprayer at the workshop. The solar sprayer was tested in the field and measured the voltage, current and power at 30^0, 45^0, 60^0 and flat angle. The maximum voltage, current and power produced at 30^o inclination angle. At 30^o inclination angle, the supplied voltage was 19.82-volt, the current was 1.88 amp and the produced power was 37.39 watts. The minimum output was supplied at 60^o inclination angle. At 60^0 inclination angle, the supplied voltage was 19.38 volts, the current was 1.45 amp and the produced power was 28.10 watts.

The constant voltage supplied by the solar charge controller and spraying operation was carried out with the use of a selected pump and nozzle. The proposed sprayer was compared with the hand-operated sprayer. The proposed sprayer worked pressure at 4 to 5 bar and hand operated sprayer worked at 1.5 to 2 bar. The pesticide application time required in solar solar-operated sprayer was 5 minutes 18 seconds to cover 5 decimal areas. On the other hand, a manual sprayer required 10 minutes 48 seconds for the same area. In the proposed sprayer, the pesticide application time was required half time compared to the hand-operated sprayer. The proposed sprayer's initial cost was US $ 36.56 and it was expected for 10 years. The sprayer's total cost was US $ 2.13 per ha. On the other hand, the manually operated sprayer costs US $ 4.20 per ha. It was clearly shown that solar operated sprayer cost was half compared to the manual sprayer. Considering with hand-operated sprayer, the proposed sprayer's Efficiency and accuracy are very high. The outcomes of the proposed experiment can play an important role in changing the socio-economic status of rice growers and product processors in Bangladesh.

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