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Original Research Article

Design, Fabrication and Testing of a Multi-Nozzle Engine Powered Sprayer

*Gana I. M[1], Hassan A. M.[1], Adedokun S. K[1], Mudansiru H.[1]

[1]Department of Agricultural & Bioenvironmental Engineering Federal Polytechnic Bida, Niger State

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***Corresponding author:** Gana I. M

Department of Agricultural & Bioenvironmental Engineering Federal Polytechnic Bida, Niger State

Abstract

In Nigeria, backpack sprayers are commonly used to apply herbicides and pesticides. This method is inefficient and requires a lot of labor, thus it's not good for large-scale operations. As a result of the chemical's tendency to leak, the operator is frequently wet, exposed to poison, and the process is generally unfriendly to the environment. To overcome these issues, a 26-liter multi-nozzle engine-powered sprayer was designed and fabricated. The machine sprays finely atomized liquids (insecticides, fungicides, and herbicides). The tank, frame, pump, transmission unit, and boom are the main component parts of the machine. The result of the laboratory testing revealed that the area covered by spraying is uniform, with a uniformity coefficient of 91.24 percent. The field trial of the machine was carried out by varying the speeds to four levels: 1 km/h, 2.1 km/h, 2.58 km/h, and 4.25 km/h. The result revealed that the application rate ranges from 43.92 l/h to 186.64 l/h. It decreases with an increase in the speed of operation. The theoretical field capacity ranges from 0.12 to 0.51 while the actual field capacity ranges from 00.0653 ha/h to 0.4014 ha/h. As the speed increases, so does the capacity. A speed of 2.58 km/h yielded the maximum field efficiency of 97.2 percent. In general, it decreases as the speed of operation increases. The machine can help with some of the issues that come with spraying using backpack sprayers. It provides good crop protection as well as increased production.

Keywords: Chemical, efficiency, multi, nozzle, sprayer.

INTRODUCTION

Insects, birds, rodents, viruses, and pests attack agricultural crops in the field, harming or killing them. It is necessary to safeguard and protect them against such threats. Crop protection is the science and practice of preventing and managing crop-damaging plant diseases, weeds, and other pests. Chemical, biological pest control, barrier-based approach, animal psychology- and biotechnology-based approach can all be used to attain this goal. According to Udaybhaskar *et al.* (2018), chemical crop protection is more effective, has immediate effects, is low in cost, and reduces human drudgery. Chemicals can be administered to the crop in a variety of ways, including dusting, spraying, and granulating. Insects, mites, and fungus and bacterial diseases on plants are controlled with sprays and dust; insects on animals, such as lice and flies, are controlled with chemical weed killers or herbicides; and weeds are controlled with chemical weed killers or herbicides. To promote adhesion and wetting of waxy surfaces, spreading-sticking agents or surfactants are routinely added to spray mixes. According to Basavaraj et al. (2020), a sprayer is a mechanical device that sprays liquids such as herbicides, insecticides, and fungicides. The pesticides are commonly used to boost agricultural yield by reducing insect and pest infestations. Spraying is one of the most effective and efficient methods for protecting crops by dispersing a little amount of liquid in fine droplets. Some of the spraying techniques reported by Malonde et al. (2018) include aerial spraying, which is done with the help of a small helicopter controlled by a remote. Another form of sprayer that is advantageous to farmers with big farms is the aerial sprayer. For small and medium-sized farms, this technology is outrageously costly. A compressed air sprayer is a compact hand-carried sprayer. It's great for treating tiny areas on the spot. Another form of sprayer is a backpack sprayer, which has a tank capacity of around four gallons of liquid. As the operator goes along, a hand-operated pump pressurizes sprayers and sprays material. Its application is confined to small spaces accessible via a walkway. The tank capacity of the skid-mounted sprayer, on the other hand, is up to 200 gallons. These sprayers are small enough to go on an ATV or electric cart. They can also be installed on wheels and towed by hand or by a small tractor. The pump is driven by a small electric or gas motor. A hose reel and gun, or a boom with nozzles, may be included in the device. Some of the drawbacks of various mention spraying techniques include; the operator must carry the entire weight of the pesticide-filled tank for backpack spraying, which causes tiredness and hence limits labor capacity. Furthermore, hand muscles can hurt during spraying, causing adequate pressure to be lost. As a result, it has an impact on the pressure of the droplets. The engine-powered sprayer, on the other hand, is frequently imported, is costly, and spare parts are difficult to come by (Ade et al., 2005). On the other hand, the aerial spraying wastes fertilizer and leaves certain crops unprotected, making it impractical for small farms. The goal of the research is to design, fabricate, and test the performance of a multi-nozzle engine powered sprayer.

Materials and methods

Materials selection

A plastic pump (polyethylene), 2 mm mild steel, 2-inch angle iron, pulley, and shaft are some of the materials utilized in the multi-nozzle sprayer's construction.

Design Consideration

Machine cost, durability, energy efficiency, chemical toxicity, field capacity, availability of construction materials, versatility of machine use, maintenance considerations, and ergonomics were all factors considered in the design of the machine.

Description of the Machine

The major component parts of the developed machine are as follows

Chain and Sprockets

A chain 1.3 meters long, made up of several stiff links, was used. Pin joints connect the two halves, allowing them to wrap around the driving and driven wheels with the necessary flexibility (sprocket). The sprockets are threaded into the chain's matching recesses. As a result, the sprockets and chain are forced to move in lockstep, ensuring a perfect velocity ratio. A chain is used to prevent sliding. 180 mm and 60 mm sprocket gears were employed. Plate I, as well as Figures 1 and 2, depict the chain and sprocket arrangement.

Crank

The crank was used to transfer motion from the prime mover to the connecting rod. As shown in Plate I and Figures 1 and 2, it is a circular disc with an eccentricity at which the crank's rotating motion is translated into reciprocating or linear motion of the connecting rod.

Connecting Rod

The connecting rod's main job is to translate rotational motion into reciprocating or linear motion. The connecting rod transforms the rotating action of the crank to the reciprocating motion of the pump and extension rod, as indicated in Plate I and Figures 1 and 2.

Pump

The piston and cylinder configuration are employed in the pump. It has a lever that controls the reciprocating motion of the piston. The pump has a 2-bar pressure and a 2 l/min per minute discharge

Spray Boom

The fluid's pressure energy was converted into kinetic energy using a spray boom with four impact nozzles. It is a precise device that allows liquid to be dispersed into a spray and distributed across a large area. Plate I and Figures 1 and 2 depict it.

Wheel

A pair of motorbike wheels with a diameter of 56 cm were employed. The pneumatic rubber tire is held in place by a metal hub, wire tension spokes, and a metal or carbon fiber rim. Plate I and Figures 1 and 2 depict it.

Frame

The machine frame is composed of mild steel angle iron with a diameter of 50 mm. Its primary purpose is to transport and support the entire assembly. Plate I and Figures 1 and 2 depict it.

Tank

The tank is made up of mild steel materials with capacity of 26 liters. It is shown in Plate I and Figures 1 and 2.

Plate 1: The Developed Multi-Nozzles Engine Powered Sprayer

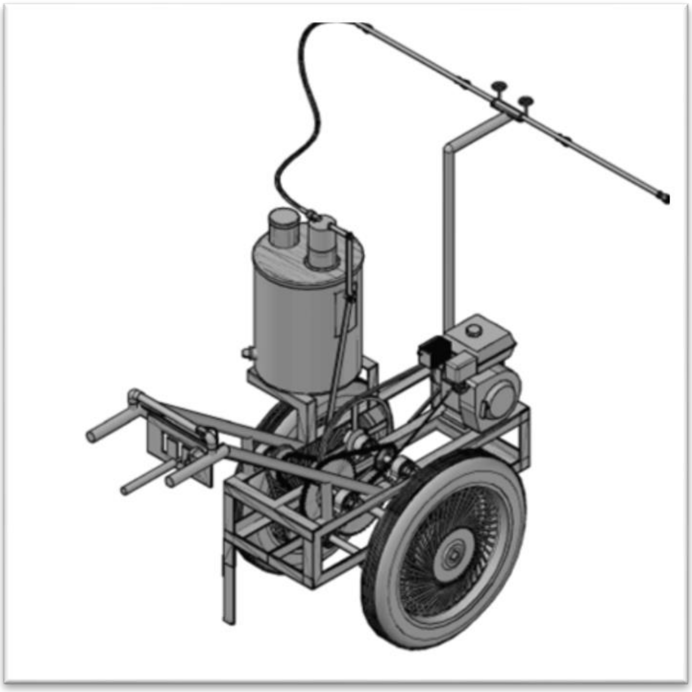
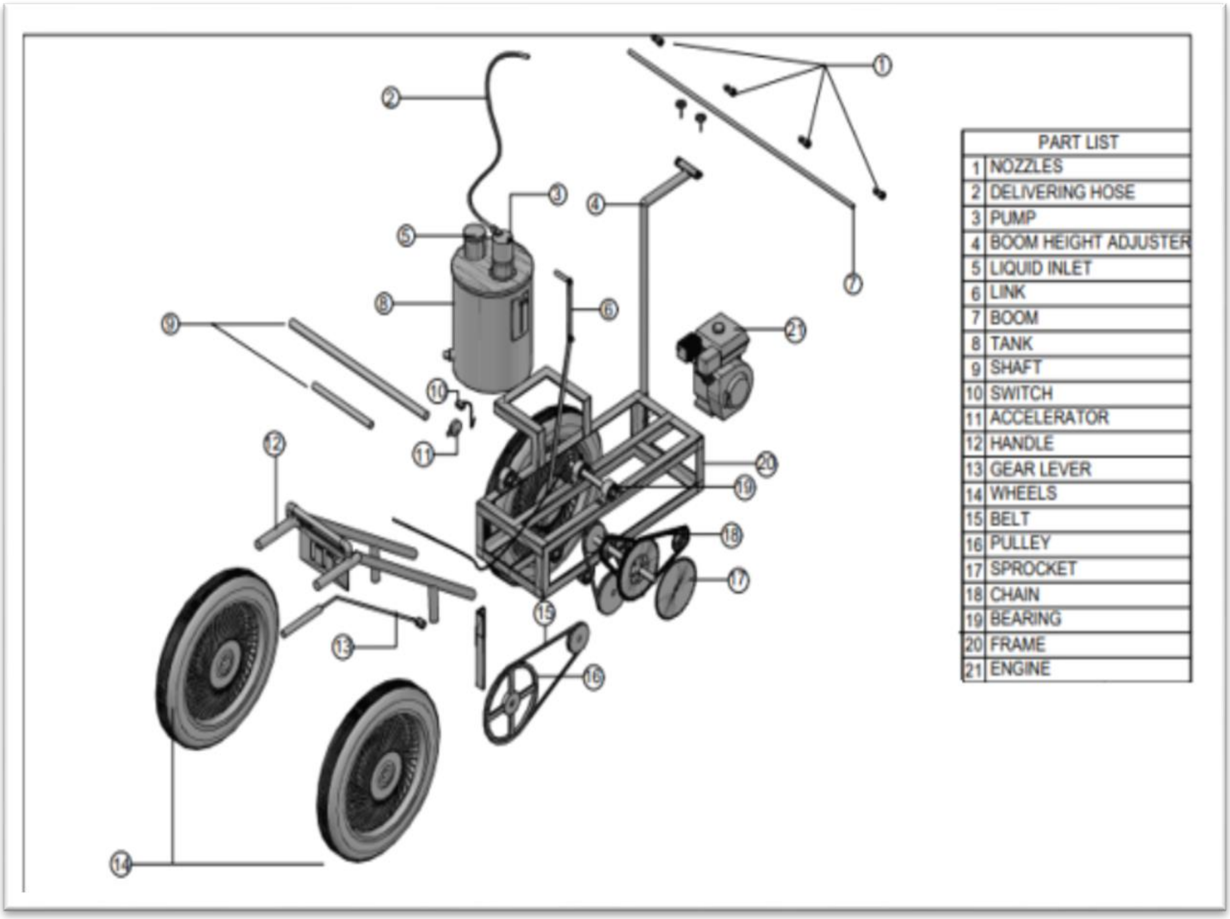


Figure-1: Auto CAD Drawing of the Multi-Nozzles Engine Powered Sprayer



PART LIST	
1	NOZZLES
2	DELIVERING HOSE
3	PUMP
4	BOOM HEIGHT ADJUSTER
5	LIQUID INLET
6	LINK
7	BOOM
8	TANK
9	SHAFT
10	SWITCH
11	ACCELERATOR
12	HANDLE
13	GEAR LEVER
14	WHEELS
15	BELT
16	PULLEY
17	SPROCKET
18	CHAIN
19	BEARING
20	FRAME
21	ENGINE

Figure 2: Exploded View of the Developed Multi-Nozzles Engine Powered Sprayer

Design Analysis

To determine and select the appropriate machine part, design analysis and calculations were conducted. This entails calculating figures to help in material selection.

Determination of the Sprayer (Boom) Width

The width of the sprayer was calculated using a relationship reported by Gbabo et al. (2019) as given in equation 1

$$Ef = \frac{CE}{CT} \qquad (1)$$

But $$CT = S \times W \qquad (2)$$

Therefore $$EF = \frac{CE}{S \times W} \qquad (3)$$

Then $$W = \frac{CE}{S \times EF} \qquad (4)$$

Where, EF is field efficiency (decimal), CE is effective field capacitors (ha/hr), S is field speed (km/h), $T$is the theoretical field capacity (km^2/hr), W is the width of the boom (m).

Determination of Sprayer Nozzle Spacing

The spacing of the nozzle on the boom was obtained as reported by Shankar *et al.* (2017) and is given as

$$w = nd \qquad (5)$$

$$d = \frac{w}{n} \qquad (6)$$

Where d is the distance between nozzles (cm), n is the number of nozzles on the boom, w is the width of the boom (m)

Determination of Sprayer Pump Pressure

The determination of pump pressure will help to calculate the application rate during the spraying process. It was determined as reported by Shankar *et al.* (2017) and is given as

$$fr = \frac{v}{t} \tag{7}$$

Where, $fr$is flow rate (lit/min.), v is volume of discharge, t is time consumed (min).

Determination of the Tank Dimension

The sprayer tank is cylindrical in shape, and the dimension was calculated as follows;

$$A_c = \pi {r_t}^2 h_t \tag{9}$$

$$r_t = \sqrt{\frac{A_c}{\pi \times h_t}} \tag{10}$$

Where, A_c is the volume of the tank which is taken as application rate per acre (m^3), r_t is the radius of the tank (m), h_t is the height of the tank (m) and π is constant.

Determination of Power Required by the Machine

The power required by the machine was calculated as reported by Shanker *et al.* (2017) and is giving as

$$P_T = P_w + P_{mr} \tag{11}$$

Where P_T is the total required by the machine (watts), P_w is power required for traction (watts), P_{mr} is the power required to operate the pump (watts).

Determination of Power Required for Traction

The power required for traction was obtained as reported by Shanker *et. al* (2017) and is giving as

$$P_w = F \times V \tag{12}$$

$$P_w = N \times C_\pi \times V \tag{13}$$

$$P_w = M_T \times g \times C_\pi \times V \tag{14}$$

But,

$$M_T = M_f + M_R + M_L + M_h + M_{st} + M_m + M_t + M_b \tag{15}$$

Where P_w is the power required for traction (watts), V is the walking speed in field (m/sec), N is the normal force (N), C_π is coefficient of rolling resistance for wheel in field (0.10-0.35), M_T is the whole mass of the machine (kg), g is acceleration due to gravity (9.81 constant), M_T is total mass of the machine members (kg), M_f is mass of the frame members (kg), M_R is mass of the connecting rod members (kg), M_L is mass of the gearing lever members (kg), M_h is mass of the handle pipe (jg), M_{st} is the total mass all shafts (kg), M_m is mass of the motor (kg), M_t is mass the tank (kg) and M_b is mass of the boom members (kg).

Determination of Mass of the shafts

The mass of the wheel shaft, driven shaft, gear shaft and crank shaft was determined as reported by Gbabo et al. (2019), and is given as:

$$M_s = \rho_s V_s \tag{16}$$

$$M_s = \rho_s (\pi r^2 h) \tag{17}$$

But

$$r = \frac{d}{2} \tag{18}$$

Where, M_s is the mass of the shaft (kg), ρ_s is density of mild steel (km/m^3), V_s is the volume of the shafts (m^3), π is constant, r is the radius of the shaft (m), h is the height of the shaft (m) and M_{st} is total mass of all shafts.

The diameter of the solid shaft subjected to pure bending with little or no axial loading as reported by Khurmi and Gupta (2005) and given as

$$d^3 = \frac{16}{\pi \times S_s} (K_b \times M_b) \tag{19}$$

Where, d is shaft diameter, S_s is allowable shear stress which is 40MN/m^2 for shaft key ways, K_b is combine shock and fatigue factor applied to bending moment.
Let $K_b = 1.5$

Power required operating the Pump

The power required to operate the pump was determined as reported by Shanker *et. al* (2017) and is giving as.

$$P_{mr} = \frac{2\pi NT}{60} \tag{20}$$

But $$T = F \times l \tag{21}$$

Where P_{mr} is the power required to operate the pump (watts), π is constant, N is the number of strokes required to operate four nozzles sprayer (40-120 stroke/min), T is torque require to operate pump (Nm), F is the maximum load require at the end of lever of the sprayer (N), l is length of the lever (m).

Pump Output

The pump output, nozzle throughput and number of nozzles are calculated as reported by Udaybhaskar *et al.* (2017)

$$P = \frac{WA_rS}{600} \tag{22}$$

Where, P is the pump output ltr/min, W is the boom width or swath (m), Ar is the application rate (l/ha) S is the travel or walking speed in m/h,

Nozzle Throughput

The Nozzle throughput is given as Udaybhaskar *et al.* (2017) and is given as

$$N_m = \frac{Po}{Nn} \tag{23}$$

Where, N_m is the pump output ltr/min, Po is pump output (l/min), Nn is the number of nozzles

Working procedure of the machine

The chains and belts are attached to the proper pulleys and sockets. The pulley's keys are tightened to secure the shaft. The machine is coupled to the tank assembly, which contains the tank, delivery tube, and reciprocating pump. The external coupling is then attached to the machine's frame. After that, the boom and the hose (delivery tube) were attached to the machine frame. The boom is equipped with four identical nozzles. The sprayer tank is filled with liquid chemicals that will be applied. Fuel and oil levels were checked. The gear lever is moved to neutral, and then the engine is started. To spray a field or farmland, engage the gear lever and accelerate. Set the gear to spraying so the pump can reciprocate and pump liquid into the boom. The boom now allows liquids under pressure to pass through its outlets (nozzles), where the liquid is forced out as a fine spray and sprayed over the required area.

Testing of the machine

Two sets of tests were conducted on the machine; the first test is the laboratory test, while the second test is the field test, as reported by Udaybhaskar *et al.* (2017).

Laboratory Test

The sprayer's uniformity coefficient was determined in a lab setting with the sprayer in a static position. The spray's area was divided into squares of equal size. A can is placed in the square's middle to represent the precipitation that has fallen on the area. As there is 30 cm between the spray guns, the cans are spaced 15 cm apart. In the spray area, a total of 24 cans are arranged in a trapezoidal configuration with three rows of arrangement. According to Udaybhaskar *et al.* (2017), the uniformity coefficient is computed using the following formula.

$$Cu = 100\left(1.0 - \frac{\sum X}{mn}\right) \tag{24}$$

Where, Cu is the uniformity coefficient, m is the average value of all observation (average application rate) (mm), n is the total number of observations, X is the numerical deviation of individual observations from average application rate (mm).

Field Test

Field trials were conducted at the Experimental Farm of the Federal Polytechnic Bida's Department of Agricultural and Bioenvironmental Engineering. Experiments on a bean plant were carried out to evaluate the machine's performance. The trial was split into twelve 30m x 60m areas. To determine its performance, the machine was run at four different speeds: 1, 2.1, 2.58, and 4.2 km/h.

Travelling speed

Two poles, 25 meters apart, were used to calculate speed. At least one long side of the test plot was parallel to the poles. The machine's speed was calculated in kilometers per hour based on the time it took to travel 25 meters.

Application Rate

The application rate of the sprayer was determined as reported by Gandhare *et al.* (2015) and is given as

$$A = \frac{Fr \times n \times 60}{\mathrm{d} \times S} \qquad (25)$$

Where, A is application rate in ltr/ha, Fr is flow rate in ml/min, $S$is travel or walking speed in km/hr, d is distance between nozzle in cm, n is number of nozzles on the spray boom.

Spraying Efficiency

This is the ratio of the area sprayed to the total area covered by the multi-nozzle's sprayer expressed in percentage. This was determined using the expression reported by Malonde *et al* (2016) and given in the following equations

$$E_s = \frac{A_s}{A_{Tc}} \times 100 \qquad (26)$$

Where E_s is spraying efficiency in %, A_s is area sprayed in m^2, A_{Tc} is total area covered in m^2.

Actual field capacity

The actual field capacity was calculated by subtracting the time spent doing actual work from the total time spent. It was determined as reported by Malonde *et al* (2016), and is given as

$$A_{AF} = (A_C/T) \text{x}\, 100 \qquad (27)$$

Where, A_{AF} is the actual field capacity (ha/hr), $A_C$is the total area covered (ha), T is the total taken to complete the work (hr),

Theoretical field capacity

Theoretical field capacity was calculated as reported by Udaybhaskar *et al.* (2017), and is given as

$$Th_{FC} = W \times S/10 \qquad (28)$$

Where, Th_{FC} is the theoretical field capacity (ha/hr), W is the Theoretical width (m), S is the speed of spraying (km/hr)

Field efficiency

This is the ratio of actual field capacity to the theoretical field capacity; field efficiency is expressed in percentage Udaybhaskar *et al.* (2017)

$$F_{EF} = (A_{FC}/Th_{FC}) \text{x}\, 100 \qquad (29)$$

Where, F_{EF} is the field efficiency (%), A_{FC} is the actual field capacity (ha/hr), Th_{FC} is the theoretical field capacity (ha/hr),

RESULTS AND DISCUSSIONS

The machine was designed and fabricated, and its performance was evaluated. The result of testing the machine is presented in Table 4.1. From the table, the values for the speed of operation ranged from 1 km/h to 4.25 km/h. The application rate ranged from 186.64 l/h to 43.92 l/h. The highest application rate of 186.64 l/h was obtained from a speed of 1 km/h, while the lowest application rate of 43.92 l/h was obtained from a speed of 4.25 km/h.

Table-1: The Result of Testing of the Machine

Speed (km/h)	Application Rate (L/h)	Pump Output (L/min)	Theoretical Field Capacity (ha/h)	Actual Field Capacity (ha/h)	Field Efficiency (%)
1	186.64	0.3734	0.12	0.0653	54.4
2.1	88.87	0.3734	0.2524	0.2413	95.6
2.58	72.34	0.3734	0.31	0.3013	97.2
4.25	43.92	0.3734	0.51	0.4014	78.7

The actual field capacity ranged from 0.0653 ha/h to 0.4014 ha/h. The highest actual field capacity of 0.4014 ha/h was obtained from a speed of 4.25 km/h, while the lowest actual field capacity of 0.0653 ha/h was obtained from a speed of 1 km/h. The spraying efficiency ranged from 54.4% to 97.2%. The highest spraying efficiency of 97.2% was obtained from a speed of 2.58 km/h, while the lowest spraying efficiency of 54.4% was obtained from a speed of 1 km/h.

Uniformity Coefficient of the Multi-Nozzle Mechanical Spray

The developed machine had a uniformity coefficient of 91.24 percent. This indicates that the spraying coverage is uniform. This result is higher than Michael (2008) recommended satisfactory value of 85 percent (2008).

Effect of Speed on the Application Rate

As the speed rose from 1 km/h to 4.25 km/h, the application rate decreased from 186.64 L/h to 43.92 L/h (Figure 3). This could be owing to the sprayer taking less time to spray the area as a result of its increased speed. This is consistent with the findings of Udaybhaskar et al. (2017), who found that when the operating speed increased from 1.5 km/h to 3.5 km/h, the application rate of a designed wiper sprayer reduced from 423 l/ha to 181 l/ha.

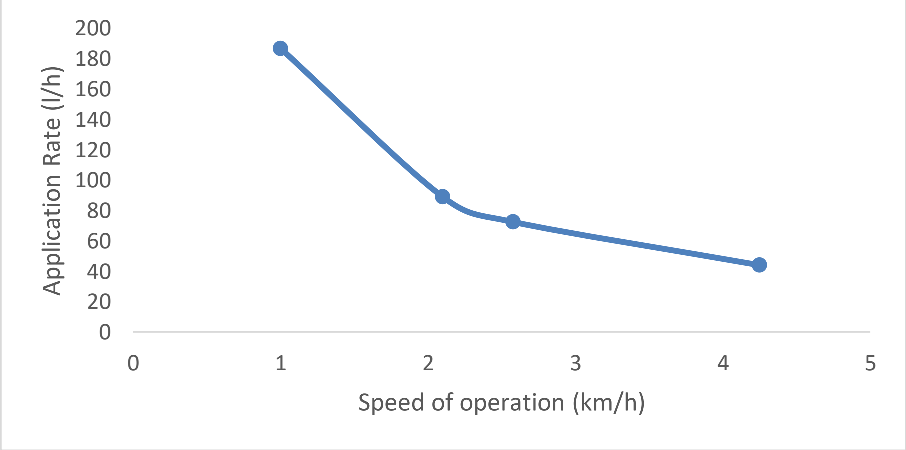


Figure 3: Effect of Speed on the Application Rate

Effect of Speed on the Field Capacity

As the speed increases from 1 km/h to 4.25 km/h, the theoretical field capacity improves from 0.12 to 0.5 ha/h, whereas the effective field capacity increases from 0.0653 to 0.4014 ha/h. This could be as a result of increased operating speed covering more areas. This is in line with the findings of Udaybhaskar et al. (2017), who found that increasing the forward speed from 1.5 to 3.5 km/h increases the theoretical and effective field capacity of a designed wiper sprayer.

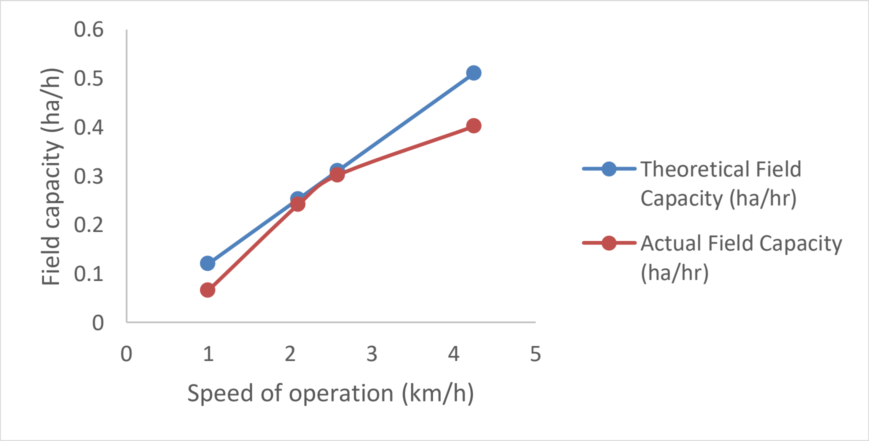


Figure 4: Effect of Speed on the Field Capacity

Effect of Speed on Spraying Efficiency

According to Figure 5, field efficiency increased from 54.4 percent to 95.6 percent as speed increased from 1 km/h to 2.1 km/h, then remained nearly constant as speed increased to 2.58 km/h, and then decreased to 78.2 percent as speed increased to 4.25 km/h.

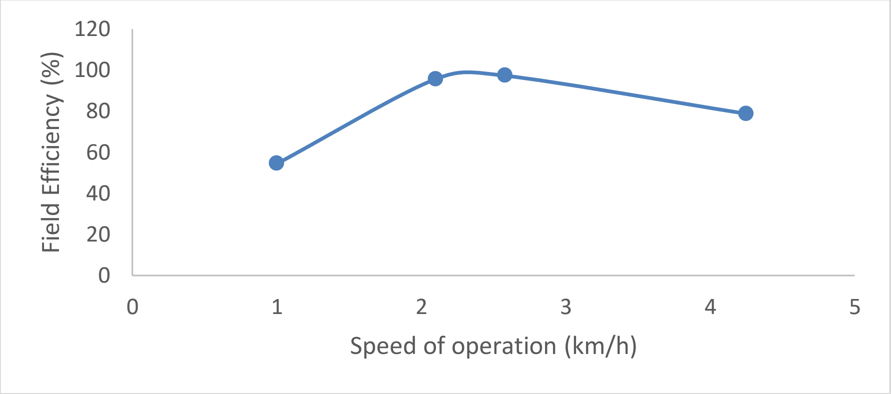


Figure 5: Effect of Speed on Spraying Efficiency

The initial gain in field efficiency could be due to a reduced effective field capacity from 1 km/h to 2 km/h, but as the speed increases, the sprayer's field efficiency declines as the theoretical time consumption grows. This is consistent with Udaybhaskar et al. (2017), who found that when forward speed increases, field efficiency of sprayers falls due to an increase in theoretical time consumption.

CONCLUSIONS

The development of this machine would address the major drawbacks of current sprayering techniques. By converting the effort of manual operation in a knapsack sprayer into a motor-powered sprayer, it will improve rapid and stress-free spraying operations while also improving the tank capacity as compared to the knapsack sprayer. Having two to four nozzles for wide-area spraying increases efficiency and productivity.

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