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Original Research

DEVELOPMENT AND PERFORMANCE EVALUATION OF A HAND-PUSHED PESTICIDES SPRAYER

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Abstract

Insect, pest and weeds that competes with crops are challenges in crop production systems in Nigeria that results the reduction of both qualitative and quantitative value of the crop yield. A hand-push wheel operated pesticide sprayer was design and developed in the Crop Protection Unit of the Department of Agricultural and Bio-Resources Engineering, Ahmadu Bello University, Zaria. This is to overcome such challenges of the leaver-operated knapsack sprayer that has been the most common technique for applying pesticides in order to suppress such unwanted pests. The components of the developed sprayer include a 16 L plastic tank, a guide wheel, frame, fluid delivery hose and four nozzles attached to an adjustable beam with height depending on the crop height. Laboratory and the field evaluations of the developed sprayer were conducted to determine the spray flow rate, spray volume distribution pattern, swath width, spray overlap, theoretical and field capacities, efficiency and application rate using cone nozzles. Results obtained from laboratory and field trials shows that the pesticide sprayer has an average flow rate that varies from 0.586 to 0.641 L/min with an average swath width of 3.83 m. The results also shows that the sprayer has an average effective field capacity of 1.15 ha/h and field efficiency of 96.65%. Its spray overlap ranged between 30.27 – 31.08 % while the coefficient of variation was 1.46 %, indicating that the variability of spray overlap between adjacent nozzles were in good uniformity. The developed sprayer also consumes less application time at reduce drudgery as the users pushes the sprayer with minimum effort. This makes it suitable for pesticides application for small- and medium farmers.

Keywords: Cone Nozzle, Flow Rate, Pesticides**,** Spray Overlap, Sprayer

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1.0 INTRODUCTION

Weeds, insects and other pests are principally liable for the low crops yields in agricultural production. Pesticides are mostly employed to kill or suppress such unwanted elements in order to permit effective crop growth rate. Application of pesticides is mostly done with the aid of sprayers. These sprayers convert the pesticide formulation, often containing a mixture of water and chemicals into atomized droplets of almost-invisible particles. Effective application of pesticides enhance precision and uniform distribution of the pesticides on the target area (Shivaraja and Parameswaramurthy, 2014).

However, most farmers in Nigeria and other less developed countries uses the lever-operated knapsack sprayers that require constant pumping to operate. This cause muscular and back pains on the operators as the sprayer is associated with drudgery as a result of the heavy load being carried on the operator's shoulders and the continuous pumping of the lever using one hand. It is also labour intensive and time consuming since the area covered per unit time is relatively small (Govinda *et al*., 2017; Issah, 2019). Similarly, the conventional lever - operated knapsack sprayers do not provide constant pressure that would guaranty optimum and quality pesticides application quality. Such pressure fluctuation varies the droplets spectrum, the spray pattern quality, uniformity of pesticide distribution and thus poses a potential risk of drift (Nuyttens *et al.*, 2009 and Robson, 2014).

To overcome the problems associated with the present method, several studies have been conducted to overcome these challenges. For example, Ekom *et al.* (2022) developed a solar-powered knapsack sprayer that eliminates the continuous pumping associated with the conventional knapsack sprayer there by reducing the muscular pains on the operator. Results obtained from this study shows a uniform spray distribution of 20.66 % coefficient of variation. Similarly, 557 ml/min, 0.35 ha/hr and 380.40 l/ha were obtained for spray flow rate, field capacity and application rate, respectively. Results obtained also shows that the developed solar-powered sprayer has greater field capacity than the conventional lever-operated sprayer as its operation has reduced the drudgery involved, saves operators time as well as providing limited comfort for the operator since the sprayer needs to be carried on the back of the operator. This was noted to have significantly increased the performance of the operator by covering more area in less period. Anibude *et al.* (2016) developed an animal-drawn hydraulic boom sprayer that operates with a 3hp petrol engine as source of power. The application rate of the sprayer was 260 L/ha, effective field capacity of 1.04 ha/h, theoretical field capacity of 1.16 ha/h, and field efficiency of 89.6%. The results obtained was also compared with the manually-operated knapsack sprayer had 62% and 37% increase in effective field capacity and field efficiency, respectively. Although this results has reduced drudgery on the farmer, but the maintenance of the animals have added the cost of the pesticides application. In a similar study, Dileep *et al*. (2017) develop pedal operated multipurpose sprayer mounted on a bicycle. The period of operation depends on the efficiency of the reciprocating pump that was used to lift the pesticide. The device was observed to be reliable and convenient especially in rural areas where bicycle is an important source of power for rural transportation. However, the sprayer could not completely eliminate drudgery since the operator need to constantly paddle the wheel of the bicycle.

To address some of the challenges associated with previously developed pesticide sprayers, the need to device alternative user-friendly spraying equipment becomes paramount. A hand-pushed pesticide sprayer was, thus, designed and developed in the Department of Agricultural and Bio-Resources Engineering, Ahmadu Bello University, Zaria with the aim of reducing drudgery and operating time that would ultimately reduce spraying cost for a more profitable agricultural production.

MATERIALS AND METHODS

Materials selection

Materials used for developing the hand-pushed pesticides applicator include: a 16L plastic pesticide tank, 4 plastic cone nozzles, a pneumatic spoke bicycle wheel, 2 × 2 mild steel angle iron, treated steel sprocket and chain, 2 × 2 round steel pipe, treated steel shaft, metal pipe boom, and a rubber hose. The developed hand-pushed pesticide sprayer (Plate 1) sprayer consists of pesticide tank, a guide wheel, frame, fluid delivery hose and four nozzles attached to an adjustable boom depending on the crop height, pneumatic spoke bicycle wheel, lance and 2 sprockets:

Plate 1: Pictorial representation of the developed hand-pushed pesticides sprayer

Pesticide tank – A knapsack sprayer was purchased from a local pesticide dealer in Sabon Gari Market of Sabon Gari Local Government Area, Kaduna State. The sprayer whose tank was used for this study was manufactured by A Ptraders, Guntur – Andhra Pradesh, India. The tank has an inbuilt pump assembly system that reciprocates to facilitate the flow of the liquid pesticide through the outlet hose. Its function in this design is to serve as the container of the pesticide as well as spray a desired quantity of pesticide for delivery to the target point through the spray nozzles attached to a boom. The pesticide tank was made of plastic material and has a capacity of 16 liters. This capacity was considered because a majority of farm holdings in Nigeria are less than 2.5 ha (Akinyele, 2009). Table 1 shows the manufacturers specifications of the selected pesticide tank.

Table 1: Pesticide Tank Specifications

S/N	Components	Specifications
1	Tank capacity	16 L
2	Pump cylinder inner diameter	40 mm
3	Displacement volume	87.25 ml
4	Cut-off valve passage diameter	5 mm
5	Lance length	72.5 mm
6	Nozzle type	Hollow cone
7	Spray angle	78°
8	Pump discharge	610-896 mm
9	Pressure	0.2 – 0.4 MPA
10	Flow rate	1.3 – 1.6 L/min

Construction Details

The hand-pushed pesticide sprayer has simple structure consisting of a wheel, piston pump, pump, nozzle, frame, tank, pipe, crank shaft, sprockets, chain drive, and boom where the nozzles were fixed (Plate 2). It is trolley-like structure containing one wheel at front side of frame. A set of sprocket is mounted on the shaft to transmit power in order to actuate the pump from the wheel that is connected to crank shaft by chain drive. The crank shaft is then connected to piston pump with connecting rod. The nozzles are mounted on boom placed on the front side of the sprayer having flexible pipe which is move or turn any direction. The height of the boom could be adjusted to a desirable position. The whole assembly is connected to handle that enable the operator to push the equipment easily.

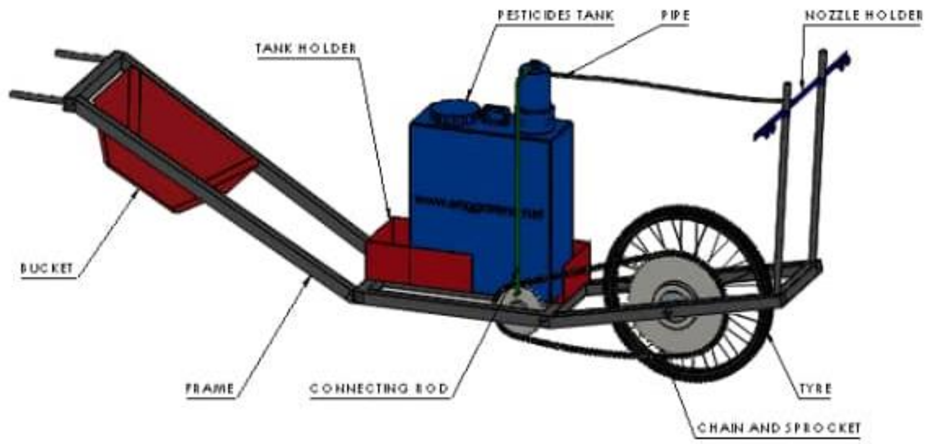

Plate 2: Sketch of the developed hand-pushed pesticides sprayer

Principle of operation of the developed hand-pushed pesticide sprayer

The frame of the developed hand-pushed pesticide sprayer is mounted on a stand with a bicycle-type traction wheel. It carries the pesticide tank that was connected with four hollow cone spraying nozzles through the boom that was made with a flexible rubber hose. The frame was designed such that its vertical height could be adjusted based on the crop height (between 30 – 110 cm) from the ground level. While the pesticide is being pumped through the boom, the pump is being actuated by an offset slider-crank mechanism, which gets its power from the guide wheel. This is being achieved by a simple push by an operator. The guide wheel transfer power to the attached driving sprocket which in turn drives a smaller sprocket attached to a through the chain drive system. The rotary motion of the smaller sprocket is then converted into the reciprocating motion by the slider crank mechanism thereby actuating the pump installed in the tank. Pesticides from the tank would thus be lifted through the action of the pump and transmitted in varying spray patterns through the pipe/lance to the nozzle before reaching the target.

Instrumentation

The instrument used to evaluate the performance of the sprayer were: 100 ml measuring cylinder, stopwatch, patternator, a 5 m measuring tape, 20 L bucket, pegs and sets of hollow cone Nozzles.

Performance evaluation of the hand-pushed sprayer

Performance evaluation of the developed sprayer was conducted in the laboratory and the field to determine the spray flow rate, spray volume distribution pattern, swath width, spray overlap, theoretical and field capacities, efficiency and application rate.

Laboratory evaluation:

Laboratory evaluation of the developed hand-pushed pesticides sprayer was carried out to determine the spray flow rate (discharge rate), spray volume distribution pattern (spray distribution pattern), swath width and spray overlap. The sprayer was operated at four different boom heights of (30, 40, 50 and 60 cm)

Spray Flow Rate – Spray discharge rate was measured using measuring cylinder to evaluate the amount of pesticides discharge from each of the nozzle and to determine the variation between the discharge rates of each nozzle within 60 seconds. This was replicated thrice. The sprayer was stopped, and each pesticide collected from the nozzle were measured using calibrated measuring cylinder (Bhanagare, 2015).

Spray volume distribution pattern - The spray volume distribution pattern was determined using patternator. Spraying nozzles were suspended above the patternator, where the discharge was collected and recorded.

Swath width - The swath width is the horizontal distance covered by the spray droplet on the patternator. It was determined by measuring the total distance covered by spray on the groove of the patternator.

Spray Overlap - The spray overlap of the pesticides sprayer was determined using different coloured water. It is the width covered by any two adjacent nozzles divided by the width covered by a single nozzle. Spray overlap is usually expressed in percentage. Other factors that determine spray overlap are the boom height spray pattern, type and spacing between the nozzles as recommended by FAO (1994).

Field evaluation:

The performances of the field trials of the developed sprayer was carried out in the Experimental Farm of the Institute of Agricultural Research (IAR) Farm of the University.

Effective field capacity - The Effective field capacity is the measure of the actual area covered during spraying operation at a specific time. This was determined as given in Eqn. 1 (Bhanagare, 2015; Sharma and Mukesh, 2010):

$$C_e = \frac{A}{T} \qquad (1)$$

where:

C_e = Effective field capacity, ha/hr
A = Area covered, ha
T= Total Spraying time, h

Theoretical Field Capacity - The theoretical field capacity of the developed sprayer was determined using Eqn. (2) as reported by Sahay (2008).

$$TFC = \frac{Speed \times width\ of\ Sprayer}{10}$$

Speed (km/h) = wheel diameter (cm) × operator speed (rpm) × 0.00189
Wheel diameter = 60 cm, operator speed = 30 rpm
Speed = 60×30×0.00189=3.40 km/h
Sprayer width = 3.50 m

$$\therefore TFC = \frac{3.40 \times 3.50}{10} = 1.19 ha/h$$

Application Rate - the application rate was determined as follows (Ashish *et al.*, 2014)

$$Application\ rate\ \left({}^{l}/_{ha}\right) = \frac{Volume\ rate({}^{l}/_{hr})}{Area\ rate\ (\frac{ha}{hr})} \qquad (3)$$

Field Efficiency – the field efficiency of the sprayer was computed using the following expression, (Alhassan *et al.*, 2023)

$$Field\ Efficienc = \frac{Field\ Capacity}{Theoretical\ Field\ Capacity} \times 100 \quad (4)$$

The performance evaluation was conducted considering the four hollow cone nozzles.

RESULTS AND DISCUSSION

The results of the performance evaluation of the developed hand-pushed pesticide sprayer were presented under the following sub-headings.

Laboratory Evaluation

The results of the laboratory performance evaluation of the hand-pushed pesticide sprayer are presented below:

Spray Flow rate – Results obtained shows the spray flow rates effect of the spray nozzles being highly significant on the spray flow rate while the pump type was not significant at 5 % probability level as presented in Table 2.

Table 2: Pesticide Discharge per Nozzle

S/N	Nozzle Identification Number	Average Flow Rate (L/min)	Coefficient of Variation (%)
1	N1	0.628	2.02
2	N2	0.586	1.75
3	N3	0.641	1.87
4	N4	0.617	1.79
Average		**0.618**	

N1, N2 … N4 are four sprayer nozzles fitted on the boom at 55 cm spacing

Results obtained shows that the average flow rate from the four cone nozzles varies from 0.586 to 0.641 L/min. while the cumulative average flow rate was 0.618 L/min (0.0103 L/s). The operation pressure was 0.25 MPa at the operator's forward speed of 3.40 km/hr. The flow rate determined was significantly less than the mean flow rate recorded by the convectional knapsack sprayer of 0.023 L/s, Yallappa *et al*. (2016). This indicated that the developed hand-pushed sprayer is economical as its flow rate reduces wastages of pesticides.

Similarly, the coefficient of variation for the average discharges rate among the nozzles were 2.02 %, 1.75 %, 1.8 7% and 1.79 % for the four spray nozzles N1. N2, N3 and N4, respectively. These results were within the acceptable variation range as recommended by Gomez and Gomez (1984). The decrease in the coefficient of Variation from 2.02 %, to 1.75 % shows the variability in discharge rate decreases significantly to optimal discharge rate of 0.586 L/min.

Spray Volume Distribution pattern **-** The spray volume distribution pattern of the nozzles was assessed using the coefficient of variance (CV) as presented in Figure 1. Higher to low percent CV was adopted as disperse to uniform spray distribution pattern. The cone nozzles of the developed sprayer were observed to produce a more uniform spray distribution pattern as it recorded a lesser coefficient of variation (CV) of 20.66 % compared with CV of 43.08 % recorded for the conventional lever - operated knapsack sprayer with the same type of nozzle.

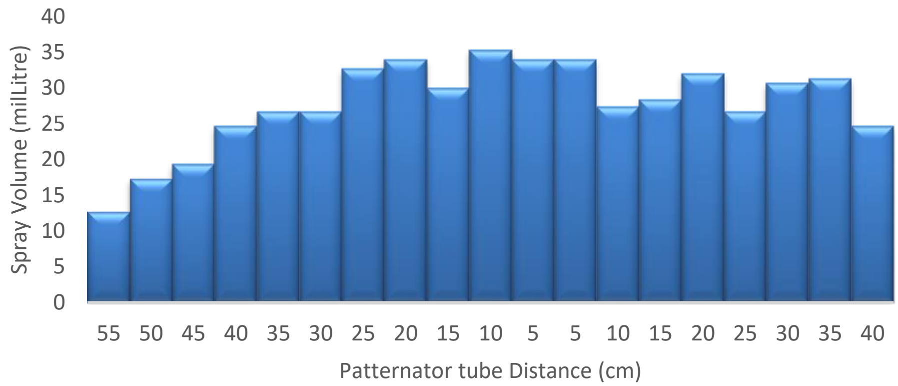

Figure 1: Spray Volume Distribution Pattern of the Hand-Pushed Sprayer

Swath width **–** The average swath width measured on the patternator was 3.83m.

Spray Overlap - . The spray overlap of the developed hand-pushed sprayer was determined on a 45 cm boom height and 55 cm nozzle spacing spray while the measurement was taken within 25 m distance at an interval of 5 m as shown in Table 3.

Table 3: Spray Overlap of the Hand-Pushed Pesticides Sprayer

Overlap Points	Overlap (cm)			Average Overlap (cm)	CV (%)
	N1 – N2	**N2 – N3**	**N3 – N4**		
5 m	21.23	22.07	21.67	21.66	
10 m	20.56	21.74	21.26	21.19	
15 m	20.83	21.38	22.02	21.41	
20 m	21.72	20.98	21.36	21.35	
25 m	22.01	21.17	21.64	21.61	
Average Overlap	21.27	21.47	21.56	21.43	
Average Overlap (%)	30.27	30.51	31.08	30.36	1.46

N1 – N2, N2 – N3, N3 – N4 are the adjacent four cone nozzles that were fitted on the boom of the sprayer at 45 cm intervals

The average spray overlap of the developed hand-pushed pesticides sprayer ranged between 30.27 – 31.08 % at a boom height of 45 cm and nozzle spacing of 55 cm (Table 3). This range falls within the acceptable range of 30 – 100 % as recommended by FAO (1994). Similarly, the coefficient of variation of the spray overlap was 1.46 %, indicating that the variability of spray overlap between adjacent nozzles were in good uniformity.

Field Capacity - The actual field capacity of the developed sprayer was determined using Eqn. (1) as reported by Bhanagare (2015) and Sharma and Mukesh (2010). To compute the actual field capacity, the actual time taken for pesticide application and time lost for other activities such as filling of tank and turning time were considered.

The area covered for pesticide application is 1ha, while Total Time Taken = 2.82 min. + 1.21 min. + 48.14 min = 52.17 min. = 0.8695 hr. (i.e. time of refilling the tanks + time of turning + time of actual work).

Thus from Eqn. 1:

$$Field\ Capacity = \frac{1}{0.8695} = 1.15ha/h$$

Application rate – the pesticides application rate was determined from Eqn.3. Application volume rate equals average flow rate L/h = 0.618 X 60 = 37.08 L/h; while the area rate of pesticides application equals the field capacity of the sprayer; thus:

$$Application\ rate\ \left({}^{l}/_{ha}\right) = \frac{37.08\left({}^{l}/_{hr}\right)}{1.15\ (\frac{ha}{hr})}$$

$$= 32.24\ l/ha$$

Field Efficiency - Field efficiency of the developed sprayer was determined using the expression in Eqn. (4).

$$Field\ Efficiency = \frac{Field\ Capacity}{Theoretical\ Field\ Capacity} \times 100$$

$$= \frac{1.15}{1.19} \times 100 = 96.65\%$$

CONCLUSION

A hand-pushed pesticides prayer was designed to address some of the challenges associated with the convectional lever-operated knapsack sprayers that are commonly used by most farmers in Nigeria. It was fitted with four nozzles and an adjustable boom height that could fit crops of different heights. The sprayer has an average flow rate that varies from 0.586 to 0.641 L/min with an average swath width of 3.83m. It also has an average effective field capacity of 1.15 ha/h and field efficiency of 96.65% with a coefficient of variation was 1.46 %, indicating that the variability of spray overlap between adjacent nozzles were in good uniformity. The developed sprayer also consumes less application time at reduce drudgery as the users pushes the sprayer with minimum effort.

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