DESIGN, CONSTRUCTION AND PERFORMANCE EVALUATION OF A WALK-BEHIND DRIVEN MONO WHEEL AGRO-CHEMICAL BOOM SPRAYER.

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ABSTRACT

The rural subsistence agricultural farmers require a technologically improved boom sprayer for spraying agro-chemicals. This will protect crops from pests and disease attacks to improve yield. Farmers use ordinary knapsack sprayers for spraying by pushing the lever up and down to create the needed pressure for spray. This is time-consuming, accompanied by the operator's drudgery leading to a small area of farmland being covered. This research aimed at increasing field performance capacity with minimal man-hour input to reduce drudgery. The designed equipment was constructed using a 20-litre capacity tank and four (4) precision nozzles for breaking liquid into droplets of effective sizes, distributing them uniformly over the surface to be applied using a slider crank mechanism. This was regulated using a hand-operated pressure regulator to avoid excessive application that might prove harmful and wasteful. At an average forward travel speed of 4 km/hr, the equipment TFC calculated was 1.04 ha/hr. For every 0.31 hectare of field coverage after 18 minutes, only 4 times of refilling was required; the AFC evaluated was 0.89 ha/hr while the FE of the equipment calculated was 86 % having an optimal uniformity of coverage.

Keywords: Agriculture, Boom sprayer, Agrochemicals, Subsistence, Farmer.

1.0 INTRODUCTION

We are living in a world of energy saving. It is easy to predict that energy saving will be of interest in the application of agrochemicals on agricultural fields where chemicals are widely used for controlling plant diseases, insects and weeds on crops because they can save crops from insects and pest attack when applied timely and efficiently. Agro-chemicals, a man-made or natural preparation are used to kill insects, pests, rodents, fungi and weeds. Farmers can save an agricultural crop from their attacks by improving the growing of crops with agrochemical applications. These agro-chemicals are applied to crops with the help of a special device known as a sprayer which provides optimum performance with minimum efforts (Angadi et al., 2017). Also, agrochemicals are costly, therefore, the design of equipment with lower cost for Small and Medium Scale (SMS) farmers with a uniform and effective application becomes essential. The new invention of a sprayer brings a revolution in the agriculture or horticulture sector, this enables farmers to obtain the maximum agricultural output.

According to Gandhare et al. (2015), the main function of a sprayer is to break the liquid into droplets of effective size and distribute them uniformly over the surface or space to be protected. Another function is to regulate the amount of insecticide to avoid excessive application that might prove harmful or wasteful. A sprayer that delivers droplets large enough to wet the surface readily should be used for proper applications. Subbarayudu et al., (2017) stated that there are many advantages of using sprayers such as easy to operate, maintain and handle, it facilitating the uniform spread of the chemicals, capability of throwing chemicals at the desired level, precision made nozzle tip for adjustable stream and capable of throwing foggy spray, light or heavy spray, depending on the requirement. Most SMS farmers use the backpack knapsack sprayer to apply these chemicals on their crops. This is time-consuming with associated human fatigue as a major concern. According to Deshpande *et al.*, (2017); farmers generally use the traditional way of spraying crops with backpack sprayers. These requires carrying the heavy tank at the back and oscillating the lever which requires more effort. The major concern of it operation on farmland is usually time-consuming and accompanied by human fatigue. The conventional sprayer has some difficulties such as it needs a lot of effort to push the liver up and down to create the pressure to spray. For the Nigerian SMS farmers' overcome these difficulties, there exists a need to design and fabricate an economically affordable single-wheel boom sprayer to encourage the mechanization of Small and Medium Scale (SMS) farming activities within the Nigerian agricultural productive sector. This 20–litre tank boom sprayer was designed to be energy-efficient and easy to operate and maintain. The single-wheel boom sprayer is an improvement on the manual knapsack sprayer using a simple technology of non-conventional mechanical energy that minimizes human energy application, increases operators' self-reliance, and reduces weight impact on the soil by the use of a single wheel. The equipment utilizes the slider crank mechanism for it operation. The rotary wheel motion is transmitted by chain and sprocket arrangement to the slider-crank. The slider crank moves in a reciprocating order to generate an in-built pressure within the tank with the aid of a piston. This pressure is released as a force required for agrochemical spraying operations on vegetable and forage, cereal and grains, and root and tuber crop fields with accessible walkways. The specific objective of this research work is to design, construct and evaluate the performance of a fuelless boom sprayer, capable of discharging a boom of agrochemicals of effective sizes with minimal total volume utilization at high operational efficiency for agricultural farm applications.

2.0 MATERIALS AND METHOD cost and time effectiveness

2.1 Design Considerations

a. The following were taken into consideration when designing the walk-behind mono-wheel operated boom sprayer:
b. Capacity of the agro-chemical storage tank.
c. Agro-chemical wastage minimization using precision nozzles.
d. Adjustable height and width of boom spray to suit various field crop heights.
e. Size and number of nozzles to determine the extent of spray boom (field coverage)
f. The relative effect of sprocket diameter to high-pressure creation inside nozzles
g. Ease of maintenance and availability of original equipment manufacturers' (OEM) spares were adequately considered.

To enhance the reliability, work-ability, and stability of equipment on agricultural fields, the following were considered while designing the equipment:

a. The cost of designed equipment should be low.

b. The Materials of construction should be durable, readily available and efficient.
c. Mode of operation and adjustment of the equipment should be comparatively simple.
d. The equipment should be portable to handle.

e. The equipment should be easy to maintain.

2.2 Component Parts

The main components of the walk behind single wheel agro-chemical boom sprayer are as follows:

a. A 16B – 1 inch 18 size teeth sprocket gear on which the chain passes over.
b. No. 50 size sprocket chain made of steel was used to transmit the rotary tyre wheel motion to the crank mechanism
c. A 3.00 – 17 rim size rotary tyre wheel was used for the motion of the equipment from one place to another.
d. The pump consisted of a piston and cylinder arrangement with a lever which generated a pressure of 2 bar delivered to the spray nozzles.
e. The four (4) spray nozzles converted the pump-generated pressure energy in chemical fluid into kinetic energy for distribution over the desired farmland area.
f. An assembly frame with dimension of 1,200 to 600 mm long and wide respectively, was designed and constructed using an angular iron bar and a $1\frac{1}{2}$ circular hollow steel. This was strong enough to withhold the entire weight of the assemblage without any failure.
g. A 20 litres capacity high density polyethylene plastic chemical tank, were utilized for the purpose of this research work.

2.3 Working Principle

The working principles of this equipment were as follows:

a. Motion transmission by chain and sprockets arrangement.
b. Slider crank mechanism.

c. Rotary motion converted into reciprocating motion

The operator grabs the handle and pushes the rotatory tyre wheel forward which in turn rotates the mounted gear sprocket at equal speed through a chain connection. The corresponding rotary motion of the gear sprocket was converted into an oscillating motion by a crank mechanism arrangement and the tank pump lever to generate an in-built fluid pressure inside the agrochemical tank with the aid of the pump. The in-built pressure sucked in the fluid inside the pump with the aid of the piston and cylinder arrangement. This was forced out to the arranged number of nozzles on the boom shaft through a connected hose line to spray the chemical. The pressure required for spraying was regulated with the aid of a special arrangement at the operator's handle for the equipment. By using this, pumping was stopped while the wheel rotated freely when boom spraying of chemicals was not required. Also, the height, position and angle of the nozzles were adjustable.

2.4 Design Analysis

2.4.1 Selection of Pinion

Minimum no. of teeth available on pinion = 18

Outer dia. Of pinion = 0 mm

Inner dia. Of pinion = 5 mm

Pitch circle diameter (Dp) = $\frac{D0-Di}{2}$ + (Di) ………………….. (1) (Ajit, K. 2012)

$= \frac{80-65}{2} + (65)$

Dp = 72.5mm

Gear Ratio = 1:3

On rotation of the gear sprocket gives three rotations of the pinion sprocket, we required three strokes to generate an adequate amount of pressure.

2.4.2 Selection of Gear Sprocket

Plate 1 Gear sprocket

$\frac{1}{3} = \frac{tp}{tg}$

$\frac{1}{3} = \frac{18}{tg} = tg = 18 \times 3$

$tg = 54$

$\frac{tp}{tg} = \frac{Dg}{Dp} = \frac{3}{1} = \frac{Dg}{72.5}$ ………………… (2) (Ajit, K. 2012)

Dg = 218mm

Pitch = $\frac{number\ of teeths\ on\ pinion}{pitch\ circle\ diameter\ of\ pinion} = \frac{18}{72.5}$ = 0.25mm

2.4.3 Selection of Chain

Chain type: roller chain with ISO Chain no. 05B pitch = 0.25 mm

Length of chain, L = K.P

Where:

K is the No. of chain and P represents the pitch of the chain teeth

No. of chain, K = $\frac{T1+T2}{2} + \frac{2x}{P} + \frac{T2-T1}{2\pi} \times \frac{P}{X}$ … (3) (Ajit, K. 2012)

$\frac{18+54}{2} + \frac{2 \times 478}{0.25} + \frac{54-18}{2\pi} \times \frac{0.25}{478};\ K = 36 + 3824 + 0.00299$

K = 3860 mm

L = K × P

L = 3860 × 0.25; L = 965 mm;

L = 96.50 cm

2.4.4 Design of structural frame

Plate 2. Dimensioned structural frame

The total Discharge of pesticide through four nozzles is 36.73lit/hour

Length of Frame = 1200 mm

Width of Frame = 600 mm

Height of Frame = 775mm

2.4.5 Nozzle Selection

Design consideration

A_2=cross sectional area of outlet nozzle, m^2

d_2 = diameter of outlet nozzle in mm

N = speed of the small sprocket in, rpm

V_2 = outlet velocity/s

Q = discharge, m^3/s

2.4.6 Area of the nozzle required:

$A_2 = \frac{\pi}{3}(d_1{}^2 - d_2{}^2)$ ………… (4) (Ajit, K. 2012)

$= \{(10 \times 10^{-3})^2 - (1\times10^{-3})^2\}$

$= 7.77 \times 10^{-5}\ m^2$

2.4.7 Required inlet velocity of fluid (chemical)

$V_1 = \frac{\pi d_1 N}{60}$ ……………………….. (5)

$= \frac{3.14 \times 10 \times 10^{-3} \times 250}{60}$

= 0.130m/s

2.4.8 Required outlet velocity of fluid (chemical)

$A_1V_1 = A_2V_2$ ………………….. (6) (FAO, 2004)

$= 7.8 \times 10^{-5} m^2 \times 0.130 = 7.77 \times 10^{-5} \times V_2$

V_2 = 77.5m/s

2.4.9 Required outlet velocity per nozzle

$\frac{V_2}{4} = \frac{77.5}{4}$ = 19.37m/s

2.4.10 Required maximum discharge volume per nozzle

$Q = A_1V_1$ …………………….. (7) (FAO, 2004)

$= 7.8 \times 10^{-5} m^2 \times 0.130$

$= 1.43 \times 10^{-5} m^3/s$

= 0.01020 lit/sec

= 0.612 lit/min

= 36.73 lit/hr

Discharge of one nozzle is 9.18 litres/hour

2.5 Machine Capacity

While calculating the actual and Theoretical Field capacities (TFC) of the equipment, the sum of the time consumed for real work done and lost time during turning between seedbeds rows, and refilling of the tank, maximum forward travel speed and the width of the monowheel boom sprayer were taken into consideration according to (Sharma, *et al.*, 2010) to determine the field efficiency of the equipment.

2.5.1 Actual Field Capacity (AFC) = $\frac{A}{T}$ ha/hr ……………….. (8)

Where;

A = total area of land covered is 0.31 ha

T = Total time taken

T = time for turning + time for refilling + time for actual work

= 3 sec × 20 + 30 sec × 4 + 1080 sec = 0.35 hr

AFC = $\frac{0.31}{0.35}$ = 0.89 ha/hr

2.5.2 Theoretical Field Capacity (TFC) ha/hr

This was calculated by (Sharma, et al., 2010).

TFC = $\frac{Speed \times boom\ width}{10}$ ………………… (9)

= 1.04 ha/hr

Where;

Average forward travel speed = 4 km/hr

Boom width = 3 m

2.5.3 Field Efficiency (FE) %

This represented the ratio of AFC to TFC expressed in % according to (Sharma, et al., 2010).

FE = $\left(\frac{0.89\frac{ha}{hr}}{1.04\frac{ha}{hr}}\right) \times 100$ ……………………. (10)

FE = 86 %.

3.0 RESULTS AND DISCUSSION

Table 1. Boom Sprayer Total Nozzles Discharge Output per Mililitre in One Minute (ml/min)

Replicates	Nozzles Discharge (ml)				Average discharge Per Nozzle (ml)	Total Discharge (ml)	Discharge per nozzle (ml/min)
	N1	**N2**	**N3**	**N4**			
R1	610	608	609	611	610	2.438	0.610
R 2	612	610	611	610	611	2.443	0.611
R 3	611	611	612	611	611	2.445	0.611
R 4	612	611	611	612	612	2.446	0.612
R 5	611	612	612	611	612	2.446	0.612

The rate of discharge from each nozzle was measured to determine the amount of chemical discharged while spraying. This was done for each 5-meter interval of 30-meter forward distance covered to determine variations that would occur between the discharge rates for each nozzle at each 5 m interval, the discharge from each nozzle was collected using a bag and measured using a measuring cylinder. The time taken to cover each interval was recorded, this was used to calculate the discharge rate for each nozzle. The trial for each interval was replicated five times. Results obtained revealed that the total volume of agrochemical discharged and calculated in litres by each nozzle for all trials falls within the range of the calculated required maximum discharge volume as given in equation 7.

Table 2. Swath Widths and Nozzle Adjustment Angles at Different Boom Heights

Replicates	Boom Heights (cm)	Swath width (m)	Nozzle angle (◦)
1	125	0.97	44.25
2	105	0.88	43.06
3	85	0.66	41.83
4	65	0.57	38.25
5	35	0.44	31.70

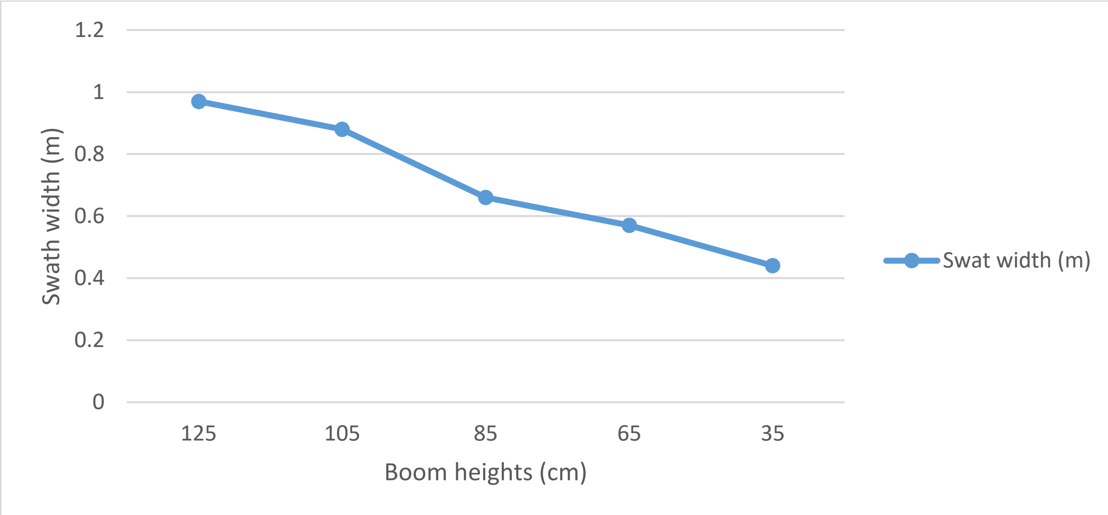

Figure 1: Variation Swath Width with Boom Height

From figure 1, the swath width of the spray increases with increasing boom heights of the equipment. The increase in swath width covered as experienced was directly dependent on the height of the boom spray.

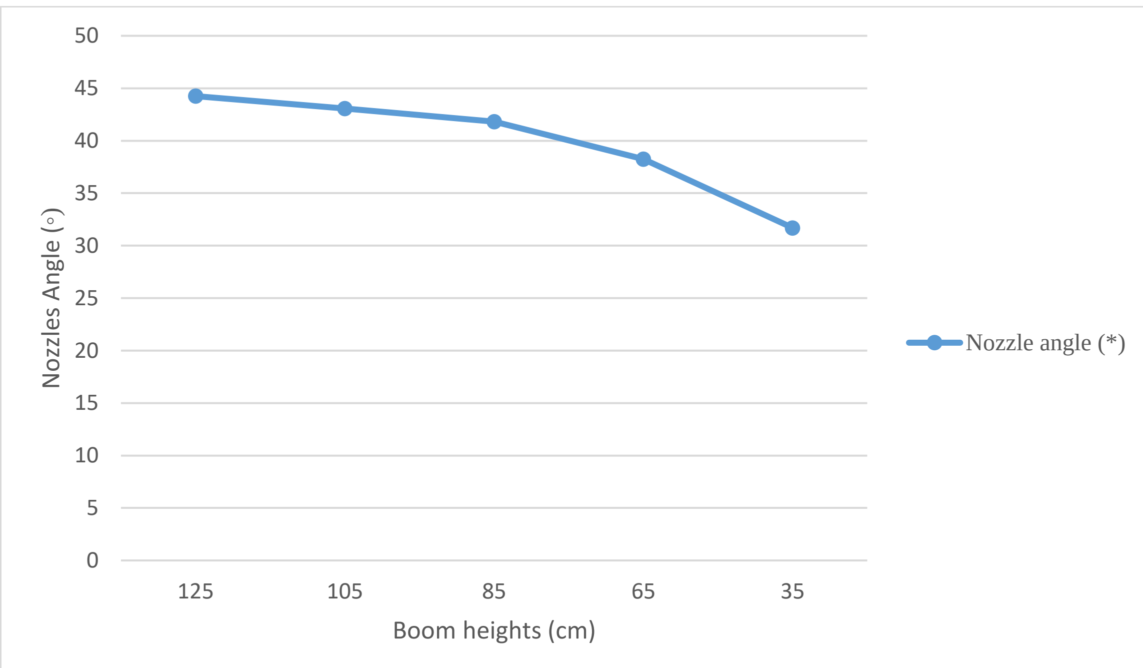

Figure 2: Variation of Nozzle Angles with Different Boom Heights

From Figure 2, the nozzle angle varies with the boom height of the equipment. These variations in angular inclinations of nozzles for every corresponding varying height of the boom ensured optimum swath width spray coverage. According to Sravan (2015), nozzles having boom spray angles less than 110° could reduce the risk of spray drift when using boom nozzle heights of greater than 50 cm. As the spray angles of the mono wheel boom sprayer was less than 110°, the effect of drifts experienced were minimum at height greater than 50 cm.

The mono-wheel boom sprayer nozzle performances were evaluated based on the uniformity of its boom coverage and spray patterns over a maximum area of 0.31 ha. With a TFC of 1.04 ha/hr, the AFC of the equipment was evaluated to be 0.89 ha/hr, while the FE was calculated to be 86 % based on the sum of times consumed for real work done, lost time during turnings between seedbeds rows, refilling of tank, maximum forward travel speed and the width.

4.0 CONCLUSION

Based on the result achieved, the single wheel boom sprayer when operated at an average speed of 4 km/hr forward travel speed, the average nozzle discharge rate variation along travel distance and attained an optimum discharge rate among the nozzles within 15-20 m distance. With a tank capacity of 20 litres, only 4 times of refilling was required during it field operation of 18 minutes with an optimal uniformity of coverage. The sprayer's forward speed and spray application were synchronized such that when the sprayer attained the optimal uniform discharge along all nozzles it maintained its uniformity till the next tank refilling operation.

RECOMMENDATIONS

Based on the research work carried out and it obtained result from field performance evaluations, the following recommendations were given. The monowheel boom sprayer worked satisfactorily under evaluated field conditions and it can also be used for row crops. The equipment's operational drudgery was minimal making it suitable for subsistence agro-farmers. Owing to its adjustable boom height, it has useful applications in vegetable crop fields, groundnut, and soya-bean and oilseed crops at varying heights. It can only be successively used for spraying agrochemicals of water-soluble formulations.

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