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Development of an Animal Drawn Hydraulic Boom Sprayer

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Abstract: *The pest attack on crop is a serious problem in the Northern Nigeria. The small/medium scale farmers spray in a season using manually operated knapsack sprayers which are laborious, time consuming and posses narrow swath width. And the tractor mounted boom sprayers are too expensive for these farmers. The prototype of an animal drawn hydraulic boom sprayer was developed considering the agronomical and functional requirement for application of chemicals on field crops. The major components include; 100 litres spray tank capacity, mainframe, operator seat, 3Hp petrol engine, piston pump, Boom, ten flat fan nozzles, wheel and axle shaft. The petrol engine was used as the power source for operating the piston pump during spraying and pair of bullocks was used for hauling purpose. Application rate of 260 L/ha was achieved, theoretical field capacity of 1.16 ha/hr, effective field capacity of 1.04 ha/hr and 89.6% field efficiency. Comparing the results with what was obtained using the manually operated knapsacks sprayer represents 62% and 37% increase in effective field capacity and field efficiency respectively.*

Significance: *The finding of the research study presented in this paper could be used to reduce the drudgery faced when using knapsack sprayers and boost agricultural mechanization during the application of liquid chemical on field crops.*

Keywords: *Boom sprayers, field crops, animal traction.*

I. INTRODUCTION

Chemicals are widely used for controlling disease, insects and weeds in the crops. They are able to save a crop from pest attack only when applied on time. They need to be applied on plants and soil in the form of spray, dust or mist and granule. The chemicals are costly, therefore equipment for uniform and effective application is essential (Bindrah and Singh, 1980).The primary aim of crop protection equipment (sprayers) is the reduction in the population of developmental stage of pest which is directly responsible for damage within individual fields and is most efficient when the chemical is applied economically on a scale dictated by the area occupied by the pest and the urgency with which the pest population has to be controlled taking the environment into consideration (Mathews, 1992). The use of mechanical power in Agriculture has been increased due to use of more tractors. Even though the tractor operated boom sprayers is available for spraying but due to low ground clearance, the crop may damage during spraying. Even though draught animal power is in decreasing trend, Northern – Nigerian farmers still predominantly use the bullocks for agricultural purpose. The small/medium farmers are maintaining a pair of bullocks for carrying out field operation. Animal drawn sprayers have been used where farmers have draught animals such as oxen. Mathews (1992) reported an animal drawn sprayer constructed in central Africa, which has the tank, boom and pump mounted on a suitable wheeled frame. The sprayer can be operated even when conditions are too wet to allow the passage of a tractor, and the animal does not damage the crop. The pump is driven by means of a chain drive from one of the wheels on a frame. When this is used, the pump has to be operated from a few yards to builds up sufficient pressure at the nozzle before spraying starts, if wheel slip occurs, spray pressure will decrease. Singh *et al* (2009), Developed and evaluated a bullock drawn sprayer. The sprayer was developed considering the agronomical and functional requirement for application of chemicals on soybean and other field crops. A commercially available pressure vessel of 9498cm^3 was adopted to maintain the required fluid pressure during spraying in the field. Two reciprocating pumps of 127cm^3 swept volumes were provided to create working pressure range of 300-350 kPa inside the pressure vessel at 94-100rpm. The unit was tested for spraying of chemical in the laboratory and on field with pair of bullocks. During laboratory test, the uniformity coefficient of droplets ranged from 2.2 to 2.7 and was within the acceptable level of 4.0 for all the six nozzles. In field testing, the average discharge of six nozzles varied from 481.6 to 529ml/min with average boom discharge of 3.03 l/min at pressure of 343 $\pm$ 2.5 kPa. Effective field capacity and power requirement to operate the sprayer was 0.56 ha/hr and 0.68kW respectively. Kalikar et al. [2013] carried out performance evaluation of bullock cart mounted engine operated sprayer. The engine of 4Hp was used as power source for operating the sprayer and the bullocks were used for hauling purpose. The sprayer units consist of 9 hollow cone nozzles adjustable according to row spacing of crop. During performance evaluation, the field capacity of the sprayer was 1.89 ha/hr and average speed of bullocks cart during spraying operation in cotton crop was 2.8 Kmph. The draft measurement for spraying operation was found to be 804.42N. Mohan, S. [2012] developed an engine operated sprayer, and it was conceptualized that a long pipe attached to pump make it versatile and a small diesel engine can run the pump and make tractor free for other farm operations. Accordingly, a 250 liters plastic tank was fixed on the frame having tires attached on two sides and hook for towing with tractor. An ASPEE-HTP triplex plunger pump was used and operated with 5.5hp 3600 rpm Greaves diesel engine. Veerangouda *et al.*[2010] did performance evaluation on three types of sprayers namely bullock drawn traction sprayer, bullock drawn engine operated sprayer and local cart mounted engine operated sprayer for cotton crop. The bullock drawn traction sprayer is capable to cover 6 rows at a stretch with an average field capacity of 0.66 ha/hr with a power output of 0.68KW. The average quantity of chemical solution sprayed per ha was 441.80 l/ha. The bullock drawn engine operated sprayer is capable to cover 6 rows at a stretch for cotton crop with an average quantity of 585.92 l/ha at an operating pressure of 20kg/cm^2. The average travel speed of unit is 2.84kmph with an average draft of 76.67kg. The field capacity of bullock drawn engine sprayer is 1.19 ha/hr with a power out put of 0.60kw. The field capacity of local cart mounted engine sprayer is 0.66 ha/hr with power output 0.72kw. Among three sprayers tested, the bullock drawn engine operated sprayer worked satisfactorily.

In order to cover large area and to avoid labour scarcity the animal drawn hydraulic boom sprayer has been developed for field crops at Agricultural Engineering Department, Bayero University, Kano. The animal drawn boom sprayer has been tested and its performance evaluation has been carried out during the year 2015.

II. MATERIALS AND METHODS

2.1 Design Consideration: Boom length, draught requirement and source, operating pressure, number of nozzle/nozzle spacing, ridge height, width and spacing were taken into consideration during the prototype sprayer development.

2.2 Selection Of Materials

The criteria for materials selection for the various components of the prototype sprayer was based on their availability of the materials in the local market or the environment, suitability of the materials for the working conditions in services and the cost of the materials (Khurmi and Gupta, 2007).

Table 2.1 shows the materials selected for the main components.

S/N	Components	Materials Selected
1	Main frame	Mild steel angle iron
2	Tank	Galvanized sheet
3	Spray boom	Mild steel square pipe
4	Traction wheel	Mild steel flat bar
5	Axle shaft	Carbon steel round bar
6	Nozzles	Plastic
7	Belts	Rubber
8	Draft pole	Galvanized steel pipe
9	Operator seat	Mild steel angle iron
10	Engine seat	Mild steel angle iron

2.3 Establishment of Design Parameters and Components

2.3.1 Size of Frame: The size of the main frame in terms of length, width and height was established with respect to ridge size, number of ridges per swath and stability of the implement. The size of the frame members were selected base on strength, rigidity and weight limitations for the comfort of the draught animal.

2.3.2 Minimum Permitted Weight of Bull: The minimum permitted weight of bull for draught was chosen as 1500N (Goe and Mcdowell, 1980). This implies that, for a pair of bulls (assuming the same weight) will be twice the minimum permitted weight. That is;

Wt = Wp x 2

Wp = Minimum permitted weight

Wt = total weight of bulls.

2.3.3 Tank: The tank was designed by considering the shape, volume capacity and weight.

Shape of the tank: The shape of tank was chosen to be cylindrical based on the fact that cylindrical shape fits in tightly into the tank holder on the main frame. Figure 3.1 shows the tank shape.

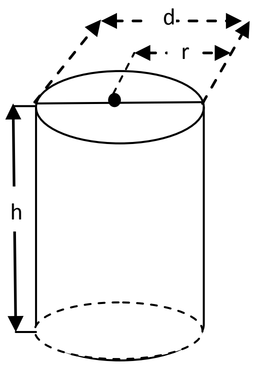

Figure 1: Diagram showing the shape of the tank

Tank capacity: The tank capacity was determined using the following mathematical expression as given by Spiegel (1968);

$C_t = \pi r^2 h$ …………………………… (1)

Where;
C_t = tank capacity
π = constant (pie)
r = tank radius
h= tank height

Total volume of tank material

Total volume of materials used for the tank is given as

$$Vtm = (2\pi r2 + 2\,\pi rh) \times thickness\ of\ the\ material \ldots (2)$$

Weight of the Tank Material

Tank weight was determined by considering the density of the tank material (galvanized sheet metal). Thus;

$W_t = V_{tm} \times \rho_t$

Where,
W_t = weight of empty tank
ρ_t = density of tank material.

2.3.4 Boom Size: The Boom size in terms of length was established based on field capacity, speed and time using the expression given by Mathews (1992) thus;

$$L = \frac{A}{t \times S} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3)$$

Where,
A = Area to be covered (ha)
S = Spraying speed (Km/hr)
T = Time taken to cover an area (hr)
L = Length of boom.

2.3.5 Pump Selection: The pump was selected based on the pressure required to be maintained at the nozzle, type of spray materials to be sprayed and the volume of spray liquid to be delivered per unit time (l/min) (Kaul and Suleiman, 1990).

2.3.6 Determination of Pump Output: The pump output in liter/minute was determined in accordance with Kaul and Suleiman (1990) thus;

$$Pump\ output = \frac{S \times AR \times V}{600} \ldots \ldots \ldots .. (4)$$

Where,
S = Swath width = boom length (m)
AR = Application rate (L/ha)
V = Velocity = spraying speed (km/hr)

2.3.7 Nozzles and Nozzles Spacing: It is important to select nozzles that develop the desired spray pattern. The following points mentioned by Kaul and Suleiman (1990) were carefully considered during the selection of the appropriate nozzles.

a. The type of spray operation.
b. Approximate pressure to be used for spraying
c. Nozzle spacing.
d. Type of spray pattern
e. Approximate speed of travel.

2.3.8 Determination of nozzle flow rate: The nozzles throughput in litre/minute was determined in accordance with Kaul and Suleiman (1990)

$$\text{Nozzle throughput} = \frac{PO \times NS}{BL} \dots\dots (5)$$

Where,
PO = Pump Output (L/min)
NS = Nozzle spacing (meters)
BL = Boom Length (meters)

2.3.9 Description of the Machine/ operation: The prototype sprayer is made basically of the main frame, spray tank, pump/prime mover, traction wheel, boom, nozzles and flexible rubber hose. The main frame is mounted on the axle shaft with two traction wheel and carries the spray tank, pump/prime mover and boom assembly. The spray tank is connected to the nozzles with the aid of distributing flexible rubber hose via the pump. At the rear end of the frame, is bolted the boom on the boom riser which carries the nozzles. The chemical in the spray tank flows by the gravity to the pump and sends the chemical with a pressure monitored on the pressure gauge to the nozzles. The prime mover (engine) which is the power source gives power to the pump with the aid of v-belt and pulleys. A pair of bullocks is used as draught for pulling the prototype while the spraying operations are on-going.

Plate 1: Assembled Prototype Sprayer

Plate 2: Assembled Prototype Sprayer

2.3.10 Determination of Application Rate: The spray liquid application rate was determined using the mathematical expression as given by Kaul and Suleiman (1990).

$$Ap = \frac{V_t}{A_t} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.(6)$$

Where,
A_p = Application rate (L/ha)
V_t = Total volume of effective spray (L)
A_t = Total Area treated (ha)

2.3.11 Nozzle Discharge rate: Nozzle discharge test was done to know the amount of liquid discharge from each nozzle and to check the variation between the discharge rates of each nozzle. Liquid was pumped at the same time interval and discharge was collected from each nozzle at the same time by tithing big white polythen leathers on each nozzle. After 60 secs the valves were closed and each liquid collected from the nozzle was measured with the aid of graduated measuring cylinder. Coefficient of variation was used to analyze the discharge rate within the nozzle (plate 3)

Plate 3: Measurement of Nozzle Flow Rate

2.3.12 Field Discharge and Time: All relevant field times used for the performance analysis were recorded during the test. The sprayer tank was field with a known quantity of spray liquid. The sprayer was then run until all the designated portion of the field was sprayed. The time and amount of spray liquid were noted. The spraying was done in three replicated. The data collected was employed to determine the effective field capacity, theoretical field capacity and field efficiency.

Plate 4: Prototype Being Tested On the Field

III. RESULT AND DISCUSSION

Table 1: Performance Parameters of the Prototype Sprayer

	S/N	Parameters	Value
Functional	1	Number of nozzle and spacing, mm	10 × 500
	2	Swath width, m	5.3
	3	Mean pressure, bar	2
	4	Discharge rate, ml/min/nozzle	730 – 960
Performance	5	Quantity of solution sprayed, l	65
	6	Effective time, (min)	12.89
	7	Lost time, min	2.07
	8	Total time, min	14.96
	9	Field size or Area treated, ha	0.25
	10	Forward speed, km/hr	2.19
	11	Field capacity, h/hr	1.04
	12	Field efficiency, %	89.6

Table 2. Discharge rate of individual nozzle

Test	Discharge, ml/min										Mean Discharge ml/min		C.V%
	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10			
1	700	800	750	950	800	850	950	700	750	750	800	8.0	
2	780	800	850	950	800	850	950	800	700	750	823	8.23	
3	750	850	800	100	800	850	950	700	750	750	820	8.20	
Average	740	816	800	960	800	850	950	730	730	750	814	8.14	9.93%

N1, N2 …N10 are ten flat fan nozzles fitted on the boom of sprayer at 500 mm spacing used for spraying of pesticides on field crops.

The field size, test duration, spray pressure, swath, discharge, speed of operation, field capacity and other relevant information are given in Table 1. The average discharge rate of 814 ml/min was observed at an operating pressure of 2 bars at the forward speed of 2.19 km/hr. The operating pressure was maintained constant by locking the throttle lever. During spraying operation, the quantity of pesticide solution sprayed was 65 litres on 0.25 hectares of land which gave an application rate of 260 L/ha. The field capacity of 1.04 ha/hr was calculated with field efficiency of 89.6%. During field trials, it was observed that uniformity in spraying was achieved as the bullock power was utilized only for traction purpose. Comparing the application rate of the prototype sprayer with that of the conventional knapsack sprayer, as given by Malik *et. al* (2012), shows that the 260 l/ha application rate of the prototype sprayer compared with 200 l/ha from the knapsack sprayer represents a 23% increase in application rate. Also that the 1.04 ha/hr field capacity and 89.6% field efficiency of the prototype sprayer compared with 0.4 ha/day and 56% from the knapsack sprayer represents a 62% and 37% increase in field capacity and efficiency.

During the discharge rate test of individual nozzle Table 2, the average discharge of nozzles varied from 960 to 730 ml/min with the average boom discharge of 8.14 L/min at a pressure of 2 bars. The discharge rate decreased for the nozzles mounted at both ends of boom as compared to nozzle mounted in the middle of boom. It was due to increase in frictional force during flow of liquid to reach both ends of the boom. The coefficient of variation for the average of nozzle discharges was 9.93%, which showed that the variation in discharges of the nozzle was particularly good when it is less than 10% for field operation (Norbdy, 1978) and (Gomez and Gomez, 1984)

IV. Conclusion And Recommendations

4.1 Conclusion

The animal drawn hydraulic boom sprayer with piston pump maintained the nozzle pressure of 2 bar during the spraying of chemical on field crops at average speed of 2.19 km/hr with a pair of bullocks. The average discharge of the ten nozzles varied from 730 to 960 ml/min with boom discharge of 8.14 L/min at nozzle height of 500 mm from the plant canopy. The maximum difference in discharge rates among the nozzles was 9.93%, and within the limit of 10% for the field test. Effective field capacity, application rate and field efficiency were 1.04 ha/hr, 260 l/ha and 89.6% respectively. Results obtained from the prototype sprayer revealed that field capacity, application rate and field efficiency represents an increase of 62%, 23% and 37% respectively when compared with knapsack sprayer. The prototype sprayer applied the pesticide behind the operator, which minimized the chances of exposure of chemical to the man and animals.

4.2 Recommendations

In course of field test, it was observed that the volume of solution during spraying wasn't proportional to the speed of animal thereby resulting in under-dosing. And if the animal stops moving for sometime spraying is constant resulting in over-dosing some areas.

To further improve on the developed sprayer, the following suggestions are recommended for future development.

a. In-cooperation of a control switch or valve that will aid in stopping the spraying whenever animal is stopped or during turning.
b. A better nozzle body should be used for better discharge efficiency and reduction of leakage.
c. The material used in the construction of the tank should be changed to plastic to prevent corrosion, while tank capacity should be increased to reduce number of refilling.
d. Width of the wheel should be increased to improve balance, while pneumatic tires should be used to improve upon traction.

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