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Spray Characteristics Determination of A Novel Prototype Boom Sprayer

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Abstract
The quest for an appropriate weed control technology in Nigeria led to the conversion of a road power mini-truck to a farm-power Self-Propelled Cost-Effective Herbicide Boom Sprayer by installing a 25:1 Gear Reducer between the mini-truck Gearbox and its rear axle. Motion was tapped from the tail of the mini-truck Gearbox through V-belt transmission to an intermediate gearbox to drive the spray pump. A 100-liter capacity Herbicide tank together with a Spray Boom of five impact nozzles and other appurtenances were assembled on the rear frame of the mini-truck to complete the construction of the novel machineat Agricultural and Bio-Resources Engineering Department, Ahmadu Bello University, Zaria. Performance evaluation of the machine was carried out both in the laboratory and in the field, while Analysis of Variance (ANOVA) with Duncan Multiple Range Test (DMRT) through Statistical Analysis Software (SAS), on the experimental results enabled the determination of the spray characteristics of the Prototype, with regard to flow rate, swath, droplet density, droplet size and Spray Volume Distribution Pattern at various heights and pressure settings. ANOVA/DMRT shows spraying at 100 kPa ensures the most uniform deposition when the height above target is 45 cm. The Field capacity at the optimum pressure and height for the most uniform deposition as calculated is 1.3 ha/h. Also, droplet density at the optimum pressure and height is 34 droplets per square centimeter with droplet size of about 400µm VMD. Evidently, the prototype characteristics gives equitable droplet size range, maximum droplet density and uniform spray volume distribution while spraying at 100 kPa.

Keywords: *Spray, Characteristics, ANOVA, Pressure, Height, Optimum*

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I. Introduction

Weed control is a fact of farming. Farmers must combat weeds in order to enhance productivity. Majority farm holding in Nigeria is ≤ 10 hectares and constitute more than 80% of the farmers and mostly fragmentations (Mgbenka and Mbah, 2016) (Takeshima and Salau, 2010). Weed control in Nigeria is bedeviled by lack of appropriate herbicide application technology. Apart from the exorbitant cost, the optimum land size put at ≥ 50 ha for imported Self-propelled and Tractor mounted boom sprayers (Takeshima and Salau, 2010); makes the equipment unsuitable for Nigerian landholdings. Also, the much available herbicide applicator in the country, the Knapsack sprayer, particularly built for spot spraying by small holding farmers (Adeleke et al., 2017), is unsatisfactory for the majority sized farms in Nigeria. This necessitated the design and construction of an appropriate Self-propelled Herbicide Boom Sprayer. Analysis of results of laboratory evaluation of the prototype to ascertain its spray characteristics is the subject of this study.

The developed Self-propelled Cost-Effective Herbicide Boom Sprayer Prototype is shown in Plate 1. Table 1 is the results of the laboratory performance evaluation; which analysis is the subject of this study. The machine is a mini-truck modified to a Boom Sprayer with some locally available components. The components include: One 25:1 Gear reducer, One intermediate Gearbox, Four steel wheels (0.9 m diameter each), One herbicide spray pump (1.5 Kw), One herbicide tank (100 liters' capacity), Spray boom with five impact nozzles, V-belts and pulleys and other connection accessories such as strainers, hoses and clips. The Prototype was subjected to laboratory experimental tests to determine the flow rate, droplet size, droplet density, swath and spray volume distribution pattern at heights (30 cm, 45 cm, 60 cm) and pressures (100 kPa, 200 kPa, 300 kPa) for analysis to ascertain the spray characteristics as guide for the field utilization of the equipment.

Plate 1: The Prototype Self-Propelled Cost-Effective Herbicide Boom Sprayer

Table 1: Summary of Laboratory Performance Evaluation Results

No.	HEIGHT	PRESSURE	REP	COVS	DROPLET DENSITY	FLOW RATE	SWATH	DROPLET SIZE
1	30	15	1	30.6708	34	7583	3.5	400
2	30	15	2	29.3663	28	13600	3.8	300
3	30	15	3	30.1172	27	17500	3.9	250
4	30	30	1	27.1254	35	7583	4	400
5	30	30	2	27.6271	29	13600	4.2	300
6	30	30	3	26.734	27	17500	4.3	250
7	30	45	1	23.8893	33	7583	4.8	400
8	30	45	2	23.8912	28	13600	5	300
9	30	45	3	23.7168	26	17500	5.1	250
10	45	15	1	15.2579	33	7582	3.6	400
11	45	15	2	15.4206	29	13601	3.7	250
12	45	15	3	15.2112	28	17501	3.9	200
13	45	30	1	15.6853	34	7584	3.9	400
14	45	30	2	15.94	29	13601	4.1	250
15	45	30	3	15.65	27	17501	4.2	200
16	45	45	3	15.915	35	7584	4.9	400
17	45	45	1	15.2777	28	13601	5	250
18	45	45	2	15.2978	26	17501	5.2	200
19	60	15	3	16.3421	35	7582	3.5	400
20	60	15	3	16.7142	29	13602	3.7	250
21	60	15	1	16.4685	27	17502	3.8	250
22	60	30	2	28.8026	34	7582	4	400
23	60	30	3	28.7281	28	13602	4.1	300
24	60	30	3	28.022	27	17502	4.3	200
25	60	45	1	30.2728	35	7581	4.8	400
26	60	45	2	30.4054	29	13602	5	250
27	60	45	3	30.4326	28	17502	5.1	250

The afore-mentioned table 1, is the summary of the laboratory performance evaluation results showing values of flowrates, swaths and droplet spectrum as well as the Coefficient of Variation (COV) of the 27 replication for the Flow Volume Distribution Pattern; for each of the experiments at the three pressures 100 kPa (I bar); 200 kPa (2 bar); and 300 kPa (3bar); at the three heights (30 cm, 45 cm, and 60 cm). This study processed the resultsusing SAS aided ANOVA/DMRT to ascertain the spray characteristics of the Prototype.

II. Experimental Procedure

This study employed Statistical Analysis Software (SAS) to carry out Analysis of Variance (ANOVA)/Duncan Multiple Range Test (DMRT), on the laboratory evaluation results recorded in table 1, to understand and ascertain the comprehensive spray characteristics of the prototype. Analysis of variance (ANOVA) as a statistical technique was used to check the impact of the height above target and various pumping pressures on the spray parameters namely: Flow rate, Swath, Droplet Density, Droplet Size and the Coefficient of Variation (COV) of the Patternator readings for the spray volume distribution pattern. It compared the means establishing if there were differences. Its results were then run by Duncan Multiple Range Test (DMRT) to pinpoint the means that are statistically different thereby render the spray characteristics of the prototype. The said resuklts were firstly written into Excel spreadsheet and then inported int SAS for ANOVA and DMRT processes. Analysis results are displayed for interpretation.

III. Results And Discussions

Spray Volume Distribution Pattern

Table 3.1 is ANOVA/DMRT anlysis result showing the effect of height above target and pressure on spray volume distribution pattern of the self-propelled herbicide boom sprayer prototype. The upper section of the table displays results for height variations, while the lower section displays the results for pressure variations.

Table 3.1: Effect of variations in Height and Pressure on Spray Volume Distribution Pattern of the Self-Propelled Herbicide Boom

Treatment	COV %
Height (cm)	
30	27.01a
45	15.51b
60	25.13a
SE±	1.372
Pressure (kPa)	
100	20.61
200	23.23
300	23.81
SE±	1.372

Means followed by the same letter within the same treatment group /column are statistically similar using DMRT at 5% level of significance.

The differing Coefficient of Variation (COV) at the various heights shows that varying the height above target at different levels on the self-propelled herbicide boom sprayer prototype significantly affects the performance of the spray volume distribution pattern of the prototype. The least COV of 15.51 % is achieved at 45 cm height. This height exhibits the most uniform spray deposition and becomes the height of choice for the prototype. At the heights of 60 cm and 30 cm the spray volume distribution of the prototype varied greatly that the heights do not offer any uniformity in deposition. The use of pressure at 100kpa, 200kpa and 300kpa was not significant with respect to spray distribution volume of self-propelled herbicide boom sprayer prototype in all the test fields as the values are statistically the same. However, the least COV of 20.61 % is achieved at the pressure of 100 kPa which is the rated pressure for impact nozzles (Jones 2006). Hence, spraying at 100 kPa assuredly ensures the most uniform deposition when the height above target is 45 cm.

Droplet Density

The effect of height above target and pressure on droplet density of the self-propelled herbicide boom sprayer prototype generated by ANOVA/DMRT is presented in Table 3.2. The upper section of the table displays results for height variations, while the lower section displays the results for pressure variations. Droplet density refers to the number of droplets per unit area on the surface and is expressed as the number of droplets per square centimeter. The use of height at 30cm, 45cm and 60cm does not affect the performance of droplet density of the self-propelled herbicide boom sprayer prototype.But variations in pressure significantly affect the performance of droplet density. Spraying at 100 kPa pressure significantly produced the highest droplet density of 35 droplets / cm2; followed by 200 kPa while 300 kPa significantly produced the least droplet density of 27 droplets / cm2; of the self-propelled herbicide boom sprayer prototype.

Table 3.2: Effect of variations in Height above target and Pressure on droplet density of the Self-Propelled Herbicide Boom Sprayer Prototype

Treatment	Droplet Density (Number/cm^2)
Height (cm)	
30	30.00
45	30.00
60	29.77
SE±	0.236
Pressure (kPa)	
100	34.22a
200	28.55b
300	27.00c
SE±	0.236

Means followed by the same letter within the same treatment group /column are statistically similar using DMRT at 5% level of significance.

Existing standards set for unmanned aerial sprayers and which applies to other sprayers; for the coverage of spray droplet density is that the density of droplet coverage per square centimeter should reach 15 or more (Chen *et al.*, 2020). Evidently, the prototype boom sprayer achieves the set standard at all pressure and height levels.

Flow Rate

The ANOVA/DMRTanalysis results of variation in height and pressure on flow rate of self-propelled herbicide boom sprayer is presented in Table 3.3. The upper section of the table displays results for height variations, while the lower section displays the results for pressure variations.

Table 3.3: Effect of variations in Height above target and Pressure on flow rate of the Self-Propelled Herbicide Boom Sprayer Prototype

Treatment	Flow Rate (ml/min)
Height (cm)	
30	12894.7
45	12895.0
60	12894.8
SE±	0.29
Pressure (kPa)	
100	7582.6c
200	13601.0b
300	17501.0a
SE±	0.29

Means followed by the same letter within the same treatment group /column are statistically similar using DMRT at 5% level of significance.

The variation of height at different levels did not produce any significant different with respect to flow rate of self-propelled herbicide boom sprayer prototype. However, variations in pressure significantly affects the performance of flow rate of the self-propelled herbicide boom sprayer prototype. Applying pressure at 300 kPa significantly produced the highest flow rate of 17.5 l/min, followed by the flow rate of 1.36l/min at 200 kPa while spraying at 100 kPa produced the least flow rate of 7.6 l/min; of the self-propelled herbicide boom sprayer prototype. The sprayer flow rate is related to the Application rate (A_r) by equation 4.1, as given by Harcy and Hill (2006).

$$\textbf{Application rate (l/ha)} = \frac{\boldsymbol{600\ x\ total\ sprayer\ output\ (l/min)}}{\boldsymbol{Swath\ width\ (m)\ x\ travel\ speed\ (km/h)}} \quad - \ \mathbf{3.1}$$

The total sprayer output from the five nozzles when sprayed at the rated pressure of 100 kPa for impact nozzles is 7.582 l/min x 5 nozzles = 37.91 l/min. The speed to attain impact nozzle's rated pressure of 100 kPa is 0.89 m/s (3.2 km/h). This is the ground wheel speed at Gear 1. At this speed and at 45 cm optimum height above target, the total sprayer output and swath width are 37.91 l/min and 4.0 m respectively. Employing equation 3.1, the calculated Application Rate is:

$$\textbf{Calculated Application rate (l/ha)} = \frac{\boldsymbol{600\ x\ 37.91}}{\boldsymbol{4\ x\ 3.2}} = \mathbf{1777}\ \boldsymbol{l/ha}$$

Swath
Table 3.4 shows the effect of height above target and pressure on swath of self-propelled herbicide boom sprayer, generated by ANOVA/DMRT.

Table 3.4: Effect of variations in Height above target and Pressure on swath of the Self-Propelled Herbicide Boom Sprayer Prototype

Treatment	Swath (m)
Height (cm)	
30	3.71c
45	4.12b
60	4.98a
SE±	0.016
Pressure (kPa)	
100	4.11c
200	4.28b
300	4.42a
SE±	0.016

Means followed by the same letter within the same treatment group /column are statistically similar using DMRT at 5% level of significance.

The upper section of the table displays results for height variations, while the lower section displays the results for pressure variations. Variations in height above target of the self-propelled herbicide boom sprayer prototype significantly affects the performance of swath width of the machine. Elevating the sprayer at the height of 60 cm produced the highest swath of the self-propelled herbicide boom sprayer followed by height of 45 cm while at the height of 30cm produced the least swath. Also, applying pressure at varying rate significantly affects the performance of swath width of the self-propelled herbicide boom sprayer. Applying pressure at 300 kPa significantly produced the highest swath followed by pump pressure of 200 kPa while the pumppressure of 100 kPa produced the least swath of the Self-Propelled Herbicide Boom Sprayer prototype. Thus, the highest Swath of 5.2 m is recorded at the highest height above target of 60 cm and highest pressure of 300kPa. Similarly, the lowest swath of 3.5 m is recorded at the lowest height above target of 30 cm and lowest pressure of 100 kPa. A swath width of 4.1 m is achieved when the prototype sprays at the 45 cm height recommended by paragraph 3.1 for the most uniform spray volume distribution and at the rated pressure of 100 kPa for impact nozzle. Since the ground wheel speed to attain the rated pressure of 100 kPa is 0.89 m/s (3.2 km/h); the Field capacity when the prototype is run at the rated pressure and at the optimum height for the most uniform spray volume distribution pattern; as calculated in (Udaybhaskar et al.,2018),

$$\textbf{TFC} = \frac{\boldsymbol{W\ x\ S}}{\mathbf{10}}\ \boldsymbol{ha/hr} \quad (\textbf{Udaybhaskar}\ \boldsymbol{et\ al.}, \mathbf{2018}) \ ---\mathbf{3.2}$$

= 4.1 x 3.2/10 = 1.3 ha/h.
Where,
TFC = Theoretical Field Capacity in hectare per hour (ha/h)
W = Swath (m)

S = Vehicle Speed (km/h)

Droplet Size

Table 3.5 shows ANOVA/DMRT analysis result for variations of height above target and pressure on droplet spectrum of self-propelled herbicide boom sprayer prototype. The upper section of the table displays results for height variations, while the lower section displays the results for pressure variations.

Table 3.5: Effect of variations in Height above target and Pressure on droplet size of the Self-Propelled Herbicide Boom Sprayer Prototype

Treatment	Droplet Size (µm VMD)
Height (cm)	
30	300.00
45	300.00
60	300.00
SE±	5.826
Pressure (kPa)	
100	400.00a
200	272.22b
300	227.78c
SE±	5.826

Means followed by the same letter within the same treatment group /column are statistically similar using DMRT at 5% level of significance.

Spraying at the heights of 30 cm, 45 cm and 60 cm respectively does not show any significant different on droplet spectrum of the boom sprayer in all the test fields. The values are statistically the same. However, pressure variations significantly affect the performance of the droplet spectrum. ASABE S572.1 standard uses eight droplet classification categories which include coarse sprays as droplet spectrum (341-403 µm VMD) and very coarse sprays as droplet spectrum (404-502 µm VMD). The standard also assigns their deployment for systemic herbicides and soil herbicides respectively (ASABE, 2018). Thus, the choice spectrum for herbicide application is produced at the pressure of 100 kPa which yields the highest droplet spectrum (>400 µm VMD). It is followed by 200 kPa while 300 kPa significantly produced the least droplet spectrum (200-250 µm VMD). Evidently, the prototype characteristics gives equitable droplet size spectrum, maximum droplet density and uniform spray volume distribution while spraying at 100 kPa.

IV. Conclusion

ANOVA/DMRT operations on the laboratory experimental results shows spraying at 100 kPa ensures the most uniform deposition when the height above target is 45 cm. Hence, spraying herbicide at height above target of 45 cm and pumping pressure of 100 kPa is the recommended setting for the optimal performance of the prototype. The Field capacity at the recommended setting as calculated is 1.3 ha/h. The prototype achieved droplet densities between 27 drops/cm^2 to 35 drops/cm^2 and droplet size between 200 µm VMD and 400 µm VMD at the various speeds. The total sprayer output from the five nozzles when sprayed at the rated pressure of 100 kPa is 7.582 l/min x 5 nozzles = 37.91 l/min. The ground wheel speed to develop 100 kPa pressure is Gear 1. At this speed and at 45 cm optimum height above target, the total sprayer output and swath width are 37.91 l/min and 4.0 m respectively. Evidently, the prototype characteristics gives equitable droplet size range, maximum droplet density and uniform spray volume distribution while spraying at 100 kPa. The study has ascertained pertinent spray characteristics of the prototype as a guide for field utilization of the equipment.

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