International Journal of Agriculture Innovations and Research
Volume 9, Issue 6, ISSN (Online) 2319-1473
Manuscript Processing Details (dd/mm/yyyy):
Received: 11/05/2021 | Accepted on: 29/05/2021 | Published: 14/06/2021

Development of a Self-Propelled Cost-Effective Herbicide Boom Sprayer

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Abstract – **The common herbicide application technology used in Nigeria is the Knapsack sprayer. Though designed for small farms and gardens, all scales farms in the country utilize the Knapsack sprayer. This is due to the exorbitant cost of imported Self-propelled boom sprayers and the attendant lack of spare parts and maintenance technicians when imported. Apart from exposing the operator to poisonous chemicals, the Knapsack sprayer is very laborious and has very low coverage with unsteady pumping and irregular walking steps. It is obviously ineffective for sized farms. This study developed a cost-effective Self-propelled Herbicide Boom Sprayer with greater coverage, reduced exposure to chemicals and better uniform application. Components were selected locally to ensure availability of spare parts and maintenance technicians. The prototype machine was constructed at the Welding and Fabrication Workshop of the Department of Agricultural and Bio-resources Engineering, Ahmadu Bello University, Zaria. It is essentially a mini-truck modified with locally available components to a Self-propelled Herbicide Boom Sprayer. A gear reducer is mounted in-between the gearbox and axle of the mini-truck to deliver operational farm spraying speeds at the wheels. The vehicle engine also powers the spray pump mounted at the back. The pump draws herbicide from a 100-liter's capacity plastic tank to five impact nozzles set on a boom mounted at the rear end of the vehicle chassis. The Prototype was built at the cost of one million two hundred and three thousand (₦1,203,000:00), naira only.**

Keywords – **Herbicide, Knapsack, Sprayer, Cost, Coverage, Health.**

I. Introduction

Weed control is vital to agriculture, because weeds decrease yields, increase production costs, interfere with harvest, and lower product quality. Weeds also impede irrigation water-flow, interfere with pesticide application, and harbor disease organisms. Weeds are thus, a constant fact of life in farming. Farmers must combat weeds in order to improve productivity. Manual weeding is laborious, time consuming and burdensome. The supply of labor in rural areas has been significantly reduced in many African countries due to migration to urban areas which has led to less weeding of crops (10); with huge increase in the cost of labour. Thus, manual weeding is no more economical. Chemical weeding is easy to apply, economical and more effective. It has become the practice. Akobundu (2009) explains that chemical weed control is playing an increasing role in Nigerian agriculture due to the increasing cost and widespread unavailability of the labour required to carry out traditional practices (4).

Chemical herbicides as an alternative to hand-weeding can be used before planting to remove weeds from a field. They can be applied to the bare soil at-planting for residual control of germinating weed seeds, and they can be directly applied to weeds during the growing season. Residual herbicides applied to the soil before the crop and weeds emerge from the ground remain active in controlling germinating weeds until the critical period of weed competition has passed (9). Despite criticisms that herbicides leave toxic residues in the environment, chemical control has been identified as a better alternative to manual weeding because it is cheaper, faster, and gives better control as well as increases biological yield and decreased weed biomass (16).

Common herbicide spraying technologies employed across the globe are the large scale Self-propelled and tractor mounted boom sprayers and the common Knapsack sprayers, ideally suited for small farms and gardens. It is reported that the minimum land area needed to make tractor deployment economically viable is 50 hectares but small and fragmented landholdings account for 80 percent of total landholdings in Nigeria (22). More than 80% of farmers in Nigeria cultivate farms that are less than 10 hectares and mostly fragmentations (15). Thus, apart from their scarcity, Self-propelled and Tractor mounted boom sprayers are not suitable for weed control in Nigeria due to our fragmented landholdings. When imported, their utilization become constrained by unavailability, scarcity of spare parts, lack of maintenance technicians, and huge cost. The cost of importation of the large scale machinery is beyond the financial strength of our large scale farmers. For instance, Apache Sprayer AS1040 Self-Propelled Sprayer manufactured by Equipment Technologies, Australia sells for $350,000 (₦126,000,000:00), (8). As a result, Nigerian farmers employ the lever operated knapsack sprayer as the only option. But its operation is laborious, unsteady and cover small swath leading to poor weed control when employed on fairly sized farms. Salkade *et al.* (2014) reports that though the lever operated Knapsack sprayer is the most commonly used type of sprayer, the problems associated with its use include: i). Back pain and exertion of the user due to its heavy weight and manual pumping. ii). When the pressure inside the spray cylinder increases, the width of spray increases, thereby causing the wastage of pesticides. iii). When Pressure in the tank fluctuates, it causes the flow to become turbulent which is highly undesirable. iv). Herbicide/Pesticide get into the eyes of the user causing irritation. The study also reports that though tractor-mounted sprayers are efficient, they do not find a place in rural agriculture as their capacity outweighs the field's economy of scale. They are also very expensive, and not affordable by the average farmer in developing countries (21).

Succinctly put, the much available and affordable equipment in the country, the Knapsack sprayer, particularly built for spot spraying by small holding farmers (1), are very suitable for its designed economic size of backyard gardens and very small farms but are unsatisfactory for the majority farm sizes in Nigeria. Also the efficient and satisfactory self-propelled and tractor mounted boom sprayer are not readily available and grossly unaffordable. They are also inappropriate for small holder farming system in Nigeria. Thus, while the Knapsack sprayers are cumbersome, unsteady and unsafe with poor swath, the Self-propelled and tractor boom sprayers which are good and efficient, apart from being unsuitable for Nigerian fragmented landholdings, are too costly for an average Nigerian farmer to afford. Nigeria requires a particularly cost-effective boom sprayer that offers capacity and good level of protection to meet the crop protection demands of medium and large-scale farms in the country. The study developed a Self-propelled herbicide boom sprayer that is far less laborious than the knapsack sprayer with reduced exposure to chemical, while covering large swath for application in medium and large scale farms in Nigeria. It is also appropriate for Nigeria's fragmented landholdings.

II. Literature Review

Literature review shows there are many studies and companies developing and manufacturing Self-propelled boom sprayers across the globe. Notable among them are John Dere Company which manufacture Self Propelled Sprayers in the United States of America (USA) and MA Agriculture, manufacturers of United Kingdom's favorite self-propelled Sprayer called Bateman RB35. A high clearance pesticide applicator was developed in China, to protect tall crops (6). Similarly, in Ludhiana, India, a high clearance power sprayer was developed for cotton (13). In Brazil, Penido *et al.*, (2019) developed and evaluated a remotely controlled and monitored self-propelled sprayer in tomato crops (18). All the studies are found in foreign countries. Pesticide Boom Spraying technologies have greatly advanced in these countries. There is no study or work on Self-propelled pesticide boom sprayers in Nigeria. The foreign products are very costly and not affordable for weed control in Nigeria. Hence the need for the study.

III. Materials and Methods

Four locally available, cost effective prime movers: Qlink Motorcycle, Jiangsu Cargo Tricycle, Bajaj passenger tricycle and Daihatsu Hijet mini-truck, were compared for effective power, ground clearance and track for ease of adaptability as vehicle for the boom sprayer. Daihatsu Hijet mini-truck was chosen. Other design considerations guided the selection of important components to modify the mini-truck; to meet operational demands as a Self-propelled herbicide boom sprayer. Consequently, the study installed a 25:1 ratio gear reducer between the vehicle gearbox and rear axle to bring down the speed of the mini-truck from the road speed of about 80 km/h to about 3.2 km/h spraying speed. The ground clearance was increased using steel wheels in place of the tires. This is to get the sprayer height above common crops' heights at the Critical Period of Weed Competition (CPWC) to safeguard the crops during post emergence application. The hubs of the steel wheels were used to increase the track and ensure the wheels move in between two ridges. Motion was tapped from the vehicle gearbox to an intermediate gearbox which powers the spray pump. Other spray components including pump, tank, and boom with nozzles are all connected by hoses and installed on the frame to achieve the prototype Self-propelled Cost-Effective Herbicide Boom Sprayer for herbicide application on medium and large scale farms in Nigeria. Major components employed in the study are depicted in Plate 1.

Plate 1. Major components employed in the study.

3.1. *Design Considerations*

3.1.1. *Farm Sizes:*

The majority farm holding in Nigeria is between 0.5 -10 ha and constitute more than 80% of farmers in Nigeria (15). The applicator is primarily for use by majority Nigerian farmers. Maximum farm size of 10 hectares is selected.

3.1.2. *Spraying Time:*

80 % of Sorghum seeds germinate within 10 to 12 days. (19). Pearl millet seed germinates in 2 to 3 days. (11). Study by Ekeleme *et al.,* (2008) recommends pre-emergence herbicides application variously on maize, sorghum, cowpea, and soybean; within two to three days after sowing (7). It is targeted that spraying of entire farm land shall be concluded within three days of planting. The spraying shall be done during six hours each day, three hours in the morning and three hours in the evening when the weather is expected to be cool and temperature low. This gives a total spraying time of 18 hours.

3.1.3. *Row Spacing:*

It is reported that for maize, three seeds/stands are usually sown about 3-4 cm deep on the ridges, 75 cm apart with an intra-row spacing of 50 cm (24). International Sorghum and Millet Collaborative Research Support Program recommends row to row spacing of 60-90 cm between rows and 15-30 cm in the row (12). For cowpea, a spacing of 75 cm between the rows and 20 cm between plants within the rows is used for the medium maturing varieties; spacing of 50 cm between the rows and 20 cm between the plants within the row is used for early maturing varieties. The recommended spacing for groundnut is 75 cm between the rows and 25 cm between the plants within the rows (17). The design extended the track of the Boom Sprayer to 150 cm to allow vehicle passage in between two ridges (75 cm apart).

3.1.4. *Vehicle Ground Clearance for Post Emergence Application:*

It is reported that about the Critical Period of Weed Competition (CPWC), the height of corn is about 20.32-30.48 cm (8-12 in) (Monsanto Company, 2013). Tann *et al.* (2011) reports that during the CPWC for rice, the height of the crop varieties ranged from 20-24 cm (7-10 in) (23). Also the height of various varieties of cowpea generally ranges from 14.3 – 30cm (5 -12 in) from 3-11 weeks after transplanting (2). The design employs steel wheels to increase the vehicle ground clearance from 16 cm (6.3 in) to 35.56 cm (14 in), to safeguard crops during post emergence application.

3.1.5. *Spraying Speed:*

Reports indicate tractor ground spraying speeds of (1.6, 2.8, 3.5 and 4.0 km/h) (10). Correlating, Ahrens (1990), reports tractor spraying speed of 1.6, 3.2, and 4.8 km/h) and states that 3.2 km/h is about the maximum speed that can be maintained in small farms especially on rough grounds (3). The study installed a 25:1 ratio gear reducer between the gearbox and axle of the mini-truck in order to achieve the requisite range of low speeds at the wheels.

3.2. *Calculation of Spray Values*

3.2.1. *Boom Width:*

The Boom width is calculated as in Matthews (1979) using recommended speed of 3200 m/hr (0.89 m/s) to treat the 10-hectare farm size, within eighteen hours or three days after planting.

$$\mathrm{W} = \frac{A}{TS}\, m \quad (14) \qquad (1)$$

$$\mathrm{W} = \frac{10\, x\, 10000}{18\, x\, 3200}\, m \;\; = 1.736 = 1.74\, m$$

Where,

W = Boom width or swath (m);

A = Area requiring treatment (m^2);

T = Time Available (h);

S = Vehicle Speed (m/h).

3.2.2. *Pump Output:*

The pump output, nozzle throughput and number of nozzles are calculated as in Matthews, (1979). Application Rate of conventional tractor Boom sprayers is between 47 to 282 l/ha (5). Average Application rate of 164.5 l/ha and the conventional nozzle spacing of 50 cm is employed in the computation.

Pump Output: $P = \frac{WArS}{600}\ l/min$ (14) (2)

Hence

$$P = \frac{1.74 \text{ x } 164.5 \text{ x } 3.2}{600} = 1.53\ (L/\text{ min})$$

Where,

W = Boom width or swath (m);

Ar = Application rate (l/ha);

S = Vehicle Speed (m/h).

3.2.3. *Nozzle Throughput*

The Nozzle throughput is given by (14) as:

$$N_{TH} = \frac{Pump\ Output\ (L/min)}{Number\ of\ Nozzles} \quad (3)$$

$$N_{TH} = Pump\ Output\ (L/min) \text{ x } \frac{Nozzle\ spacing\ (m)}{Boom\ Lenght\ (m)} \quad (14) \quad (4)$$

N_{TH} = 1.53 x (0.5/1.73) = 0.44 l/min

3.2.4. *Number of Nozzles*

The Number of nozzles is also given by (14) as:

$$\text{Number of nozzles} = \frac{Pump\ Output\ (L/min)}{Nozzle\ throughput} \quad (5)$$

Number of Nozzles = 1.53/0.44 = 3.5 ≈ 4 nozzles

Where,

N_{TH} = Nozzle Throughput (L/min);

P = Pump Output (L/min);

n = Number of nozzles;

ns = Nozzle spacing (m);

B = Boom length (m).

3.3. *Motion Transmission*

Plate 2 shows the Gear Reducer located in-between the mini-truck gearbox and the rear axle. The Gear Reducer receives motion from the gearbox and transmits to the rear axle.

Plate 2: The Boom Sprayer underneath showing Gear Reducer installed in-between the vehicle gearbox and axle.

Also, an intermediate Gearbox is introduced and linked by pulleys to receive motion from the mini-truck gearbox and transmit to the Pump. The transmission is such that at Gear 1, Gear 2 and Gear 3, the pump pressure is 100 kPa, 200 kPa and 300 kPa respectively. The spray pump is actuated and disengaged at will, through the gear lever of the intermediate Gearbox.

IV. Description of the Boom Sprayer Prototype

The developed Self-propelled Cost-Effective Herbicide Boom Sprayer Prototype is shown in Plate 3. The machine is essentially 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 Chemical pump (1.5 Kw), one Chemical tank (100 liters), Spray boom with five impact nozzles, v-belts and pulleys and other connection appurtenances like strainers, hoses and clips.

Plate 3. The Prototype Self-Propelled Cost-Effective Herbicide Boom Sprayer.

The mini-truck has a 32 Kw, 3-Cylinder inline petrol engine which drives the Sprayer in direct drive, through its gearbox, an intermediate Gear Reducer and the rear axle to achieve low farm speeds at the wheels. The engine also powers the Spray Pump through V-belt transmission. A double grooved pulley attached to the output shaft of the Gearbox transmits motion through V-belts to the intermediate Gearbox which delivers motion to the Spray pump. The Gearbox lever is used to start and stop the pump as and when necessary. Hoses connect the Spray pump to the 100-liter capacity pesticide tank and also to the boom nozzles at the back of the vehicle frame.

The Boom Sprayer prototype moves on four steel wheels each of 90 cm diameter, offering better ground clearance to allow post-emergence application without destroying the growing crops. The 12.7 cm width of the wheel hub extends the vehicle track to 150 cm to permit movement in between ridges.

V. Conclusion

Design analysis of locally available components for the proposed Self-propelled Herbicide Boom Sprayer were done. The prototype was constructed using locally available components. The prototype was evaluated both in the laboratory and in the field. Laboratory evaluation shows most uniform Spray Volume distribution pattern at 45 cm height and at the various pressure levels. Highest droplet density and requisite droplet spectrum for herbicide application were achieved at 100 kPa pressure level. Laboratory evaluation indicates prototype optimal performance is achieved at 45 cm height and 100 kPa pressure. Field evaluation gave maximum application rate, effective field capacity and field efficiency respectively as 1,625 l/ha, 0.43 ha/h and 75%. The machine was built at the cost of one million two hundred and three thousand (₦1,203,000:00) naira. The spare parts are locally available while maintenance technicians abound everywhere in the country.

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