DEVELOPMENT OF A SELF-PROPELLED BOOM SPRAYER FOR SMALL AND MEDIUM SCALE HERBICIDE APPLICATION

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A THESIS SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF DOCTOR OF PHILOSOPHY (PhD) DEGREE IN AGRICULTURAL ENGINEERING

DEPARTMENT OF AGRICULTURAL AND BIO-RESOURCES ENGINEERING, FACULTY OF ENGINEERING, AHMADU BELLO UNIVERSITY ZARIA, NIGERIA

NOVEMBER, 2021

DECLARATION

I declare that the work in this thesis entitled **"Development of a self-propelled boom sprayer for small and medium scale herbicide application"** has been carried out by me in the Department of Agricultural and Bio-Resources Engineering. The information obtained from the literature has been properly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another diploma or degree at this or any other institution.

AMONYE MICHAEL CHUKWUEMEKA ---------- ----------
Name of Student Signature Date

CERTIFICATION

The thesis entitled **"DEVELOPMENT OF A SELF-PROPELLED BOOM SPRAYER FOR SMALL AND MEDIUM SCALE HERBICIDE APPLICATION"** by Amonye Michael Chukwuemeka met the regulations governing the award of the degree of Doctor of Philosophy (PhD) in Agricultural Engineering, Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation

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Dean, School of Postgraduate Studies	Signature	Date

DEDICATION

To my late father:
Gabriel Amonyeaneze Chukwuma Muonagor

In your absence since 1977, GOD has fully answered your wish for me.

Alhamdulillah

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ABSTRACT

This project produced and evaluated a Self-propelled boom sprayer for small and medium scale herbicide application; with reduced drudgery and better effective herbicide application than the commonly used application machine in Nigeria, the knapsack sprayer. The knapsack sprayer was developed for spot spraying and its small coverage limits it to effectively attend to sized farms. Apart from exposing the operator to poisonous chemicals, using knapsack sprayer is very laborious as the operator is required to carry the chemical tank at the back while pumping at a steady rate and ensuring regular walking steps for efficient application. The alternative imported self-propelled herbicide boom sprayers are very costly coupled with lack of spare parts and maintenance technicians when imported. Hence the need for an appropriate boom sprayer for small and medium scale herbicide application in Nigeria. The sprayer was developed using locally available materials. A *Daihatsu Hijet* mini-truck, which spare parts are all locally available and maintenance technicians also readily available with fuel consumption of about 0.27 liters per hour, was deployed as the prime mover and converted to farm vehicle by the installation of 25:1 ratio gear reducer in-between its gearbox and axle to deliver operational farm spraying speeds at the wheels. Other components which include a spray pump, an herbicide tank, five impact nozzles, hoses and strainers amongst others, were also sourced locally. Laboratory and field performance evaluation of the sprayer were carried out. For the laboratory evaluation, two factors namely the height of nozzles above target and pumping pressure; which influence spray parameters were varied at three levels in a completely randomized experiment while the spray parameters of flow rate, spray

volume distribution pattern, droplet size and swath were determined. The experiment were carried out at pumping pressures: (100 kPa, 200 kPa, 300 kPa) and at heights of nozzles above target: (30 cm, 45 cm, 60cm), while the spray parameters were determined. Analysis of Variance (ANOVA) with Duncan Multiple Range Test (DMRT) of the experimental results were done using Statistical Analysis Software (SAS). Linear regression model was also employed to further understand the results using MS Excel 2010. Employing impact nozzles, while spraying at 100 kPa and nozzle height above target of 45 cm setting, the machine achieved the most uniform deposition and produced the requisite droplet range of about (300 – 400 µm VMD) recommended for herbicide application. Field evaluation at nozzle height above target of 45 cm and at the three speeds indicate the maximum Application Rate, Effective Field Capacity and Field Efficiency are respectively 1,625 l/ha, 0.43 ha/h and 67%. The least Application Rate, Effective Field Capacity and Field Efficiency are respectively 1,156 l/ha, 0.3 ha/h and 47%. The cost estimate for the construction of the prototype is one million five hundred and three thousand two hundred naira (₦1,503,200:00), only. The introduction of this machine into the agriculture mainstream offers our farmers an alternative herbicide applicator with less drudgery and more uniform deposition and coverage than the knapsack sprayer and at an affordable rate compared to imported large scale herbicide boom sprayers.

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ABBREVIATIONS, UNITS AND SYMBOLS

A	Area
ANOVA	Analysis of variance
Ar	Application rate
BS	Bending stress
c	Bending coefficient
cm	Centimeter
cm^2	Square centimeter
COV	Coefficient of Variation
CPWC	Critical period of weed competition
C_r	Tank capacity
CRD	Completely randomized design
CRR	Coefficient of rolling resistance
D	Deflection
D_A	Allowable deflection
DMRT	Duncan multiple range test
E	Modulus of Elasticity
EFC	Effective field capacity
F	Maximum load on tyre
F_r	Radial load
FE	Field efficiency
GPa	Giga paschal
hr	Hour
ha	Hectare
ha/h	Hectare per hour
I	Moment of Inertia
k	Radial Coefficient
kg	Kilogram
km	Kilometer
km/h	Kilometer per hour
kPa	Kilo paschal
kW	Kilowatt
L	Liter
l/ha	Liter per hectare
l/min	Liter per minute
M	Mass

	M_b	Bending moment
	m	Meter
	mm	Millimeter
	m/s	Meter per second
	MPa	Mega paschal
	N	Revolution per minute
	NA	Not available
	Nth	Nozzle throughput
	₦	Naira
	P	Pump output
	PH	Pressure/Height
	PPP	Public private partnership
	PRR	Power to overcome rolling resistance
	Q	Average discharge in liters
	r	Radius
	S	Speed
	SAS	Statistical analysis software
.;;	T	Time
	TFC	Theoretical field capacity
	L_t	Total load
	v	Velocity
	V	Volume flow rate
	VMD	Volume median diameter
	w	Angular velocity
	W	Swath
	X	Span
	µm	Micron
	µ	10^{-6}
	π	pi
	%	percent
	≤	Less than or equal to.
	≥	Greater than or equal to.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Any organism which feeds on and damages cultivated plants, attacks plant products in the field or in storage, causes a nuisance or transmits pathogenic organisms to plants, man or domestic animals and livestock is regarded as a pest. Notable pests include insects, fungi, viruses, nematodes, weeds, rodents and birds. Alabi and Banwo (2006) reported that pests are as old as the cultivation of plants for food production and that the food for man is also food for the pests. It also states that pest attack on crops can come at any point in the long chain of crop production and that crop losses due to pests each year in Nigeria is estimated at 5 – 40%.

Buba and Suleiman (2004) explained that weeds as group of plant species that are undesirable and that they can be competitive in the early stages of the crop growth and when uncontrolled, can cause more yield loss and time consuming in their removal. It further reports that worldwide crop losses from all pests have been estimated to exceed 140 billion U.S. dollars annually and explains that though the economic loss caused by weeds has not been estimated, weeds may cause higher problems than insects, since besides competing with crops; they harbor insects, disease and other pests. It itemizes the general effects of weeds in agriculture as follows: (a) Reducing crop yield (b) Reducing Produce quality (c) Interfering with harvest equipment and other machinery, and (d) Harboring other pests**.**

In the 19th century, pest control was revolutionized by the introduction of synthetic pesticides. This has been found to provide means of reducing pest populations massively in a more effective and large-scale manner than had ever been possible before (Alabi and Banwo, 2006). Pesticides are available for different pest situations. Pesticides were introduced into the Nigerian farming systems because pests and diseases damage had been identified on a worldwide basis to be a major constraint to increased crop and animal production with estimated loss of 30% and 33% or more in many crops and animal production respectively on annual basis. Consequently, to attain food sufficiency, the Nigerian government encourages farmers to use improved seeds, fertilizers and the use of some recommended agro-chemicals or pesticides (Udoh and Umoh, 2011).

Falade and Labaeka (2016) reported that weed is a limiting factor to crop production and the attainment of food security in Nigeria and that uncontrolled weed growth in maize in Nigeria caused 18-60% yield loss; 51% in Sorghum, 28-100% in rice, 48-90% in cassava, 70-91% in yam, 35-83% in cowpea, 4053% in soya bean, 54% in groundnut and 60% loss in wheat. Schonbeck, (2013) states that weeds are the most costly category of agricultural pests and that worldwide, weeds cause more yield loss and add more to farmers' production costs than insect pests, crop pathogens, root-feeding nematodes, or warm-blooded pests (rodents, birds, deer, and other large grazers). In particular, weeds are a constant fact of life in vegetable crops,

Gianessi, (2009) reported that crop yields are generally very low due to weed competition, as a result of untimely and ineffective weed control stemming from the hand weeding executed by the few household members. On most farms, weeding usually competes with other farm activities and is postponed to a later date. Farmers will not weed crops that are sown first until they complete the seedbed preparation and sowing of all other fields. This usually results in delayed weeding. Gianessi, (2009) further stated that late weeding results in crop losses, especially if it is carried out after the critical period of weed competition and gave an example of poor weed management in cassava fields in Kenya in 2004, which caused an average yield gap of 5 t/ha and restricted production in farmers' fields by 11.6 t/ha. The study also posited that a lot of constraints limit the effective use of hand weeding, including limited cash for hiring labour and labour not being available for hire during peak periods asserting the supply of labour 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.

Buba and Suleiman, (2004) reported that there are four weed control methods which include:

i. Traditional Method: This includes the use of bare hands, hoe, cutlasses, animal drawn implements and other tools.
ii. Mechanical Method: This includes the use of implements such as harrows, spike weeders and rotary hoes.
iii. Chemical Method: It involves the use of various types of natural or synthetic substances. These include herbicides, insecticides, rodenticides, nematicides, acaricides, fungicides and bactericides.

iv. Integrated Method: This is based on a complete understanding of the population dynamics of the pest so that; appropriate control strategies can be developed. As a result of this, came the integrated pest management system defined as Pest management system in the context of the associated environment and the population dynamics of the pest species and utilizes all suitable techniques and methods in as compatible a manner as possible and maintains the pest population at levels below those causing economic injury.

Several constraints limit the effective use of hand weeding, including limited cash for hiring labour and labour not being available for hire during peak periods. Time and experience shows that chemical application is the most efficient weed control measure. This is collaborated by the work of Cherati *et al*, (2011) on the evaluation of the efficiencies of traditional, mechanical and chemical weed control methods in rice fields which shows that chemical treatment was the best treatments because in all sampling stages, it gives the least dry weight of weed produced. The important uses of agricultural sprayers include: (a). Application of herbicide for weed control. (b): Application of fungicides for disease control. (c): Application of insecticides for insects' control (d): Application of micro-nutrients into the soil and (e).Application of pre-harvest chemical to defoliate or condition crops for mechanical harvesting. (Shani, 2004)**.** Due to the significant reduction in the supply of labour in rural areas, Akobundu (2009) explained that chemical weed control is playing an increasing role in Nigerian agriculture as a result of the increasing cost and widespread unavailability of the labour required to carry out traditional practices. 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 (Olatunji *et al.*, 2016).

Major crop protection spraying technologies 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. Takeshima and Salau, (2010) reported that the minimum land area needed to make tractor deployment economically viable is 50 hectares. Small and fragmented landholdings account for 80 percent of total landholdings in Nigeria. On the hand, Mgbenka and Mbah, (2016) states that majority farm holding in Nigeria which constitute more than 80% of farmers in Nigeria cultivate farms that are less than 5 hectares and mostly fragmentations. Thus, deployment of Self-propelled and Tractor mounted boom sprayers for weed control in Nigeria is not realistic for Nigerian landholdings. Their utilization in Nigeria is also constrained by unavailability, huge cost, scarcity of spare parts and lack of maintenance technicians.

1.2 Statement of the Problem

Poratkar and Raut (2013) reported that the major equipment currently employed for herbicide application in Nigeria is the lever operated knapsack sprayer and that the cost of alternative tractor mounted and self-propelled boom sprayer are beyond the financial strength of average Nigerian farmers. The study also stated that farmers (both small, and medium scale), are currently using lever operated backpack sprayer which requires constant pumping that results in muscular disorder. Its further reported that the backpack sprayer cannot maintain constant pressure, resulting in drifts/dribbling and that developing adequate pressure is laborious and

time consuming. Pumping to operating pressure is also time-consuming and moreover, very small area is covered while spraying. So, more time with the associated arduous labour are required to spray the entire land.

Also, Salkade *et al.* (2014) stated that 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 and self-propelled 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.

Adeleke *et al.,* (2017) reported that the Knapsack sprayer, which was built for spot spraying by small holding farmers are very suitable for its designed economic size of backyard gardens and very small farms. However, the knapsack sprayer is not appropriate for the majority farm holding in Nigeria, classified as between 0.1 and 4.99 hectares by Mgbenka and Mbah, (2016). The afore-stated shortcomings of the knapsack sprayer ensue delay of operations and deposition of wrong dosage which apart being a waste of herbicide and labour, results in poor effect of herbicide application and low level of crop protection. These in turn lead to weed resistance and higher incidence and impact of weeds, food poisoning, decreased yield and

financial loss leading to rural poverty. Chemical under and over doses constitute serious flaws and damages in herbicide application. It is also well known that many herbicides can accumulate in living species causing long-term and chronic effects to the victim (Damalas and Koutroubas, 2016).

Also, the efficient and satisfactory self-propelled and tractor mounted boom sprayers are grossly unaffordable and uneconomical when deployed to land holdings less than 50 hectares, more so when small and fragmented landholdings account for more than 80 percent of total landholdings in Nigeria. Succinctly put, while the Knapsack sprayers are cumbersome, unsteady and unsafe with poor swath to effectively address majority Nigerian farm holdings, the self-propelled and tractor mounted boom sprayers which are good and efficient cannot be procured by the average Nigerian farmer. They are also beyond the field capacity for majority farm holding in Nigeria. The implication is that crop protection is impacted negatively. There is a subsisting gap for a matching herbicide spraying technology for small and medium scale herbicide application in Nigeria.

1.3 Aim and Objectives of the Study

Aim

The aim of this study is to produce and evaluate an alternative herbicide spraying equipment that will reduce drudgery involved in using the knapsack sprayer and the cost involved in procuring imported self-propelled boom sprayers.

Objectives

i. To design the components of a Self-propelled herbicide boom sprayer for small and medium scale herbicide application in Nigeria.

ii. To fabricate the components of the machine using locally available materials for the construction

iii. To carry out laboratory and field evaluation of the machine.

iv. To analyze the results using Analysis of Variance (ANOVA) and DUNCAN multiple range test.

v. To further interpret the results using linear regression analysis.

1.4 Justification of the Study

The expected gains from the successful development of this equipment are enormous and justify financial input and research work towards the realization of the project. These gains include:

i. Effective application of herbicides leading to loss reduction and improved productivity and food security in Nigeria.

ii. Reduction of drudgery and Safety Enhancement: The employment of a motorized vehicle eliminates drudgery and exposure to drifting pesticide experienced in the use of knapsack sprayers.

1.5 Scope

The scope of this work covers understanding the two most prominent application technologies 1). Knapsack sprayer and 2). Self-propelled boom sprayers used for herbicide application in Nigeria. Study of available power sources that can be used to develop

alternative applicator. The design and construction of alternative herbicide application machine using locally available materials while curtailing the shortcomings of the two conventional applicators. Laboratory experiments on a spray patternator to determine spray output parameters when pertinent factors are varied. Analyze the results employing Analysis of Variance (ANOVA) with Duncan multiple range test (DMRT) and further analysis using linear regression model to determine best fit for the spray parameters. Field performance evaluation of the prototype.

CHAPTER TWO

LITERATURE REVIEW

2.1 Weeds

Weeds are commonly defined as plants that are unwanted where they grow. This negative perception emerged with agriculture and relates to the damage they cause to crops. In addition to direct competition with crops (or parasitism), weeds cause indirect damage by harboring insect pests and crop pathogens. Direct losses caused by weeds vary from crop to crop and from one agro-ecological zone to the other for the same crop (Vissoh *et al.*, 2004). Weeds have been a problem since the beginning of agriculture, and until the advent of herbicides during the 1940s; the traditional practices have been hand-weeding, cultivation and toleration. In most developing countries like Nigeria, weeds are still largely managed by traditional practices. However, the increasing cost of labor and the glaring ineffectiveness of manual weeding especially for medium and large farms; may see a shift to greater use of herbicides and reduced tillage in the future (Martin and Pol, 2009).

Vissoh *et al.*, (2004) reported that weed problems are also reflected in the costs of hiring labour to carry out land preparation and weeding and that out of the total labour input of African women in rice production, 40–60% is spent on weeding. The study also indicates that about 60% of the time in farming is spent on the first clearing of the farm and on weeding,

representing 140–190 man-days per ha and that the detrimental effects of weeds in Africa far exceed the world average. Vissoh *et al.,* (2004) further reported the example of spear grass *(Imperata cylindrica)* interference which can cause crop yield losses as high as 80% in cassava and 50% in maize**.** *Striga specie* caused total crop losses on over 15,000 ha and was present on about 20,000 ha of fallow land, parasitizing wild hosts in Benin. According to the study, only in newly opened land is weed infestation limited and one weeding is enough to get a good yield. Weed problems have been aggravated and have become particularly acute as a result of population pressure, of shortening or eliminating fallow periods, of scarcity of labour, and of the collapse of commodity prices. Thus weed problems need to be understood in the context of both the biophysical (soil, crops) and the socio-economic and political environment.

Steiner and Twomlow, (2003) reported that manual weed control is labour intensive and therefore limits the production area. It further posits that in many rural African communities it has become increasingly difficult to hire labour for weeding and other farming activities, due to a swindling labour force as consequence of out-migration of the male population into urban activities like commercial motorcycle businesses and that as a result farm operation are often delayed and labour costs have increased. Vissoh *et al.,* (2004) called for labour saving farming practices, or alternative methods to address weed control. It also posits that the drudgery associated with weed control is due to hand weeding, which is the method used by the majority of farmers and that family labour is seriously stretched on large farms and has to be deployed continuously for weeding, as the first weeded plots are re-infested by the time

the last plots are cleaned and as such farmers have no rest and sometimes have to give priority to other farm (and non-farm) activities based on opportunity cost.

Koch, (1992) stateed that weed control is one of the major labour consuming operations in traditional crop production, amounting from <30 up to about 70% of the total labour input and that there is need to drastically cut the labour input to enhance development in traditional societies. Hence, the introduction of less labour consuming technologies, e.g., herbicides, requires the proper adaptation of legislation and its control, education and training, extension, and agricultural trade. If appropriate training and access to herbicides are provided; chemical weed control is a real option for farmers in developing countries. Increasing labour shortage and costs of labour makes chemical weed control an attractive alternative for farmers in many regions (Steiner and Twomlow, 2003).

2.2 Herbicide Control

In reality, crop fields are seldom adequately weeded by hand; weeding is tedious and time consuming. Laborers are not always available when needed. Weeding is often done late, causing drastic losses in yield. The use of herbicides has gained impetus from the general rise in farm wages as a consequence of overall economic growth and growth in non-farm employment opportunities, particularly in Asia. Adequate nonchemical controls for weeds are not available, and herbicide use is increasing dramatically as a result of rising opportunity costs of labor across the developing world. The use of herbicides is increasing in worldwide crop production, as herbicides are being rapidly adopted in developing countries that face shortages of hand weeding labour and the need to raise crop yields (Gianessi, 2009).

The greatest advances in chemical weed management were made during the period 1941–1968. This was when the world went to war. A major reason for the significant growth of agriculture was the need to compensate for the devastation of food production in areas of the world ravaged by war. The discovery of the herbicidal properties of 2,4-D (2,4-dichlorophenoxy-acetic acid was a major breakthrough. Scientists researching 2,4-D and related plant growth hormone analogues were convinced that these chemicals had great potential in agriculture, Though there were herbicides before 2,4-D; none were as cheap, as effective, or as selective. Since then, the international chemical industry has produced a range of increasingly sophisticated herbicides which have been enthusiastically adopted worldwide, especially in industrialized nations (Lovett and Knights, 1996).

Effective weed control is an essential management task in farm productivity. Much of the current weed control strategies rely on the use of available herbicides. However, given community concern regarding the use of herbicides, investigation of alternative weed control methods was undertaken by George a nd Brannan (2002). The study tested the ability and cost-effectiveness of mechanical (hand weeding and inter-row slashing), mulching (sawdust over newsprint, woodchips and jute), cover crops and herbicide applications for weed control in establishing eucalypt plantations and concluded that herbicides remain the most cost-effective weed control option available to commercial growers of eucalypt plantations. The aim of herbicide application is to use the right herbicide at the right dose, applied using the right method, at the right time and delivered by the right operator in an economical and safe way with minimal impacts on the environment. The way in which herbicide is applied and the dose used are as important to the success of control as the selection of the herbicide itself.

The two conventional herbicide application technologies namely: Hand–held Knapsack and the Self-propelled and Tractor mounted boom sprayers are discussed hereunder.

2.3 Conventional Sprayers in Nigeria

There are basically two sprayers used to administer herbicide in Nigeria namely: 1). Hand-held knapsack sprayer and 2). Self-propelled and tractor mounted boom sprayer.

2.3.1 Hand-held knapsack sprayers

A manually operated knapsack sprayer is shown in Plate 2.1 and Figure 2.1. It consists of a tank, 10 to 20-liter capacity, which is carried on the back by two adjustable shoulder straps. An operating lever positioned either over the shoulder or under the arm, drives a piston or diaphragm pump. The under-arm lever can often be adjusted for use with the right or left arm, and the over the shoulder lever can be operated with either arm. A waist strap is sometimes used to provide support, hold the tank firmly in place, and ensure that the operator's pumping energy is more efficiently transferred from the lever to the pump.



Plate 2.1: Knapsack sprayer

(Source: https://rsragro.com/products/knapsack-sprayers/)

The pump is most commonly fitted on the inside of the tank to prevent damage, but is also found fitted on the outside of the tank, which allows for easy maintenance. Constant pumping is required to operate a knapsack sprayer, and the decision to use a piston or diaphragm pump should be based on the type of application to be made. Piston pumps are preferred for applying insecticides and fungicides because they are able to achieve pressures of 2.0 bar or greater with relative ease (McAuliffe and Gray, 2002).

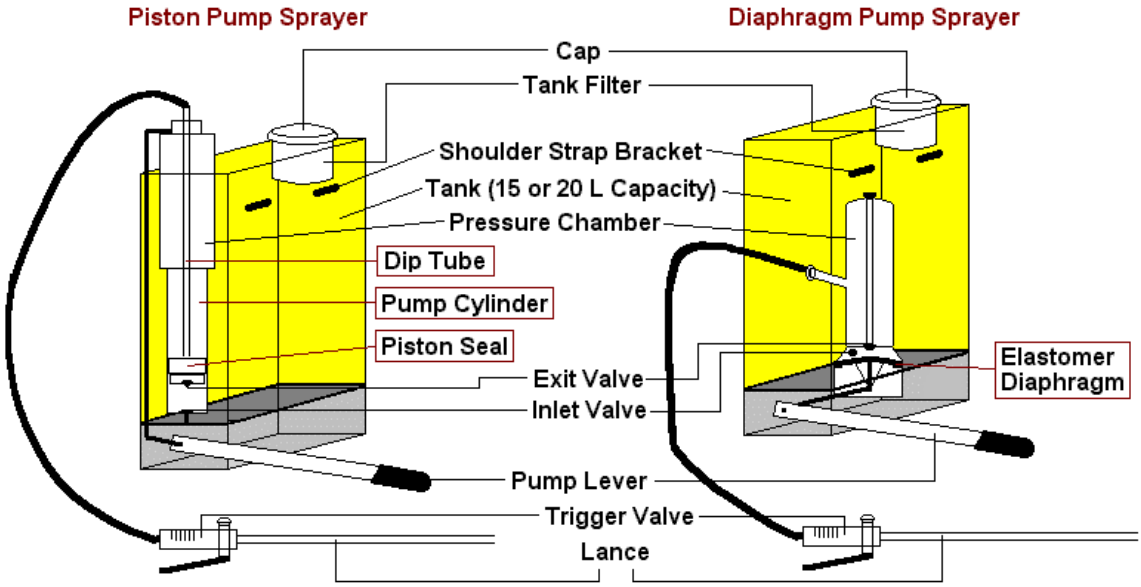


Figure 2.1: Schematic diagram of a Knapsack Sprayer
(Source: McAuliffe and Gray, 2002).

In this system, liquid is drawn from the tank through a valve into the pump chamber by the upward movement of the piston. On the reverse stroke of the lever, the spray solution passes through a second valve into an air or pressure chamber. Air is trapped in part of the pressure chamber and compressed as liquid is forced into it. Subsequently, as pressure in the air chamber increases, liquid is directed through a dip tube and hose, past a trigger valve, and through a lance to the nozzle. The lever-operated knapsack is the most common type of spray equipment used for crop protection in Nigeria and other developing countries of the

world. However, accurate and consistent pesticide applications are difficult to manage because this type of spray equipment has little or no pressure regulation. As a result, crop protection chemicals are often misapplied, leading to poor biological results, unnecessary chemical exposure to the applicator and the environment, the exacerbation of resistance to pesticides, and added expense of already cash limited farmers (McAuliffe and Gray, 2002).

2.3.2 Self-propelled and tractor mounted boom sprayers

Boom sprayers are common agricultural application equipment suited for sized farms. The sprayer has a power-driven pump which delivers spray mixture under pressure to a set of nozzles. The nozzles are usually arranged along a boom at regular intervals (e.g., 50 cm), or spaced according to crop row spacing. Conventional boom sprayers are mounted on a tractor or trailer. Spray tank capacity can be as large as 4,000 liters with boom lengths reaching 24 meters or more. Pumps are usually driven by the tractor PTO (power take off) but may have a dedicated diesel or petrol engine. Figure 2.2 is a schematic diagram of a tractor or trailer mounted boom sprayer.

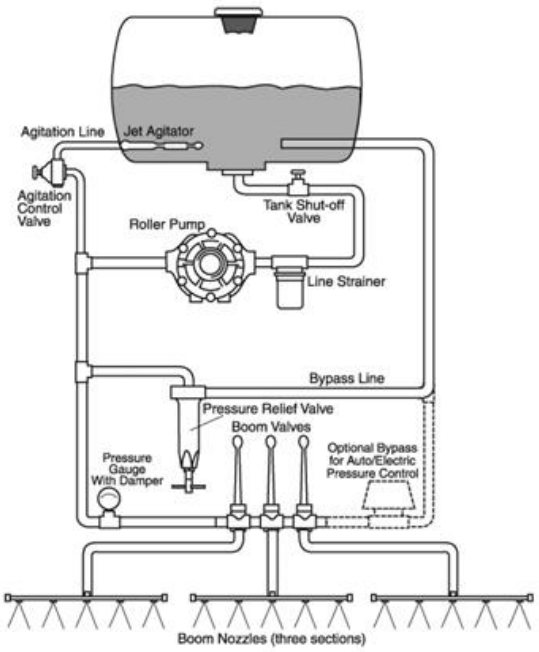


Figure 2.2: Schematic diagram of Agricultural boom sprayer
(Source: Valco and Sauls, 2017)

The pump takes fluid from underneath the tank and pumps it to the boom nozzles. Pressure relief valve and pressure gauges are installed in the line to ensure working pressure is not exceeded. Agitation of the herbicide is maintained through a control valve and piping that takes fluid in a jet into the tank.

The important components of a sprayer are: Pump, Power source, Tank, Agitator, Distribution system, Pressure gauge and Pressure regulator or relief valve (Malik *et al.*, 2012). Conventional boom herbicide applicators are the tractor mounted and tractor drawn boom sprayers together with the Self-propelled boom sprayers. These machines cover four, six, or eight rows. The length of the boom depends on row spacing and is usually not more than 8.5 m. The boom is usually equipped with fan nozzles, spaced 20 inches (50 cm) apart, that deliver 5 to 30 gpa (47 to 282 l/ha) when the sprayer is operated at a speed of 4 to 5 mph (6.4 – 8,04 km/hr) and a pressure of 30 to 40 psi (207 – 275 kPa). The boom is usually

strongly built to avoid bending or dangling. When a boom is longer than 30 feet (9 m), it should be supported by outrigger wheels and tie rods. These help to keep the boom at a uniform height, particularly on rough or rolling land (Anderson *et al.*, 2012). Plate 2.2 depicts a tractor mounted boom sprayer while Massey Ferguson's MF 9130 Self-propelled Boom Sprayer is shown in Plates 2.3.

At speeds of between 5 km/hr and 8 km/hr with boom of 8.5 m and above; conventional Self-Propelled Sprayers achieve field capacities above 4.25 ha/hr. But these are gigantic equipment suitable for very large farms. Tractor ground speed of (1.6, 2.8, 3.5 and 4.0 km/hr) for spraying is reported by Jayashree and Krishnan, (2012).



Plate 2.2: Tractor Mounted Boom Sprayer
(Source: https://www.indiamart.com/proddetail/tractor-mounted-boom-sprayer-**20957953573.html)**



Plate 2.3: Massey Ferguson's MF 9130 Plus self-propelled sprayer
(Source: https://news.agcocorp.com/news/releases-20180219-6674623)

Correlating, Ahrens (1990), reports tractor spraying speed of 16, 3.2, and 4.8 km/hr) and states that 3.2 km/hr is about the maximum speed that can be maintained in small farms especially on rough grounds. But Romanelli and Milan (2012) reports that a standard single rear axle tractor carrying a row crop boom of 10.7m with equipment and herbicide weighing 632 kg and moving at a speed of 5.4 km/hr (1.5 m /s) recorded an Effective Field Capacity (EFC) of 3.85 ha/hr with 8.2 litre/hr fuel consumption while spraying herbicide on a maize field. Similarly, Bhooshan *et al.,* (2016) explains that tractor mounted boom sprayer essentially consists of a tank which is made of fibre glass or plastic, pump assembly, suction pipe with strainer, pressure gauges pressure regulators, air chamber, delivery pipe, spray boom fitted with nozzles. These are hydraulic energy sprayers. They utilize PTO power of the tractor to operate the pump of the sprayer. The specifications for the conventional tractor mounted boom sprayer are given in Table 2.1.

Table 2.1: Conventional Tractor Mounted Boom Sprayer Specifications

Parameter	Specifications
No. of nozzle	21
Spray swath	10.2 m
Nozzle spacing	460 mm
Tank capacity	400 litre
Weight	150 kg
Adjustment range of boom height	300-1260 mm
Field capacity	1.34 ha/hr
Power requirement (kW)	35/26.25

(Source: Bhooshan *et al.,* 2016)

Studies further shows that apart from conventional self-propelled boom sprayers there are specialized herbicide boom sprayers. For instance, a large high-clearance self-propelled sprayer with ground clearance of 200 cm was reported by Chen *et al.,* (2020) for protection of very tall crops during application. It consists of a cab, an engine, a hydraulic oil tank, wheel track adjustment cylinders, a frame, a hydraulic line, front and rear wheels, front and rear suspensions incorporating a guide column, air reservoir, spring height sensor, air spring, vertical shaft as well as other related components. In addition to the high-stalk crop planting mode and agronomic demand, the main structural parameters such as ground clearance, wheel track, and the wheelbase of the chassis are determined to maximize the adaptability of the sprayer and reduce the damage of the mechanical structure to the crop during operations.

Also, a motorized farm buggy was developed and equipped with smart variable rate sprayer (SVRS) accessories. The SVRS was designed, developed, and tested using deep learning (DL) for VA application of agrochemicals. The buggy had 0.91 m of ground clearance (based on maximum potato plant height) with 0.30 m adjustability to accommodate variations of potato plant height at different growth stages. It was 0.89 m wide with tires spaced as per row

spacing of potato crop. The length of the buggy was kept at 1.8 m to allow adequate space for an operator, engine, and necessary hardware (Hussain *et al.,* 2020).

2.4 Major components of a Self-propelled herbicide boom sprayer

Major components of a Self-propelled pesticide boom sprayer include: i). One engine powered vehicle as prime mover ii). One chemical pump iii). One chemical tank iv). The Boom and v). Nozzles. Preliminary investigations availed important information on some of the locally available components.

2.4.1 Prime mover

Four locally available prime movers with potential for driving medium scale herbicide boom sprayer namely: Motorcycle, Passenger Tricycle, Cargo Tricycle and Mini-Truck were studied from available literature.

i. Motorcycle: A motorcycle, often called a motorbike, is a two wheeled motor vehicle. Motorcycle design varies greatly to suit a range of different purposes: long distance travel, commuting, cruising, sport including racing, and off-road riding. It is commonly called *Okada* and *Achaba* in Nigeria. *"Okada"* is a commercial motorcycle transport that operates within the communities and local vicinities in Nigeria. Some Nigerians are involved in the operation of this local transport as a last resort to survive (Abdussalam and Wahab, 2014). Picture of a common brand used in Nigeria is shown in Plate 2.4.

).



Plate 2.4: *Qlink* Legend Motorcycle.
(Source: http://www.motorcyclesdetails.info/Qlink_Legend).

The cost of Motorcycles (*Okada* brands) in Nigeria in the local market in Kano as at the time of the study in 2019, range between three hundred thousand naira (₦300,000:00) to four hundred thousand naira (₦400,000:00). Lai *et al., (*2003) identified three main modes to analyze the motions of the motorcycle. They are:

a. Wobble mode of high frequency vibration motion;

b. Weave mode of low frequency vibration motion;

c. Capsize mode of non-vibration motion.

Subsequent experimental conclusions presented a consistent phenomenon that the stability of the motorcycle will become unstable at low speed, stable even under 'hands free' control (control without applying steer torque) at moderate speed, and oscillatory unstable at high speed (Lai *et al.* 2003). Specifications for *Qlink* Legend reported at the manufacturer's website; gives Power: 18 hp (13.4 kW), Ground Clearance: 134.62 mm (5.3 inches) and Front tire size 110/90-16, Back tire 130/90-15; (http://www.motorcyclesdetails.info/Qlink_Legend

ii. Passenger Tricycle: (*Keke Napep*): A tricycle is a three-wheeled vehicle that is a bit different from a motorcycle. It is a smaller version of a car but with three wheels. One front wheel and two back wheels. It is used to transport people and goods from one place to another, though it is not that suitable or recommended for long distance trips. It is designed to be used within a town or local government and it can be used to comfortably carry 3 persons at the back and the driver in the front (Saiful, 2010). Picture of the common Passenger tricycle in Nigeria is shown in Plate 2.5.



Plate 2.5: Conventional Passenger Tricycle
(Source: chinatopway.sell.everychina.com/p-94344358-bajaj-type-tricycle)

Specifications for the popular *Bajaj* Passenger tricycle reported at the producer's website; gives Rear Wheel Track (mm): 1120 mm; Power: 6.5 hp (4.9 kW) and Min Ground Clearance (mm): 200 mm (7.4 inches), Tire Front: 4.00 -8 6 PR, Tire Rear: 4.00 -8 6 PR amongst others (https://www.globalbajaj.com/global/english/brands/intracity/re/re-4s/specifications). As at 2019, a marketing website (https://jiji.ng/30-tricycles/cargo) gives cost of Cargo Tricycle in Nigeria from ₦250,000:00 -₦400,000:00.

iii. Cargo Tricycle: Cargo tricycle is tricycle specifically built for carrying loads. It was introduced into the Nigerian market shortly after the introduction of the Passenger Tricycle. A typical Cargo Tricycle is shown in Plate 2.6. *Jiangsu Linzhi Shanyang* Group Co. Ltd, a China based producer's specifications for their Cargo tricycle reported at marketing website; (*Alibaba.com*); gives Rear Wheel Track (mm): 1040 mm; Power: 12.6 hp (9.5 kW) and Min Ground Clearance (mm): 200 mm (7.9 inches), Tire size: 5.00-12 and Payload 800kg, amongst others (https://lzsy.en.alibaba.com). A marketing website (https://jiji.ng/30-tricycles/cargo) gives cost of Cargo Tricycle in Nigeria from ₦550,000:00 -₦800,000:00 in 2019.



Plate 2.6: Cargo Tricycle
(Source: https://lzsy.en.alibaba.com).

iv. Mini Truck: Common mini-trucks which are readily available in Nigeria are the *Suzuki Honda, Mitsubishi* and *Daihatsu* 350 pay load models. The most commonly used is *Daihatsu Hijet* mini-truck shown in Plate 2.7.



Plate 2.7: *Daihatsu Hijet* mini truck
(Source: https://japancardirect.com/mini-trucks-and-kei-turbo-cars/mini-kei-trucks/spec-comparison-tables).

A dealer's website gives *Daihatsu Hijet* mini truck specifications as follows: Power: 43 hp (32.25 kW) and Min Ground Clearance (mm): 160 mm (6.2 inches), Payload 350 kg, amongst others(https://japancardirect.com/mini-trucks-and-kei-turbo-cars/mini-kei-trucks/spec-comparison-tables). The wheel track was measured- 1245 mm (49 inches). As at 2019, the local market in Kano, Nigeria, gave the cost of the mini truck from ₦650,000:00 to ₦750,000:00.

The payload of *Qlink* motorcycle, *Jiangsu* cargo tricycle and *Daihatsu Hijet* mini truck are: 350kg, 800kg, and 350kg respectively. The payload of *Bajaj* Tricycle estimated from the mass of four passengers is 300 kg. Average mass of man is 75 kg (Sims and O'Neil, 2002). The cost of *Olink* motorcycle and *Bajaj* tricycle are close at ₦300,000:- and ₦350,000:= respectively. Similarly the cost of *Jiangsu* cargo tricycle and *Daihatsu Hijet* mini truck are close at ₦650,000:= and ₦700,000:=.

2.4.2 Chemical pump

Portable pumps in Nigeria that can be used for herbicide application include domestic water pumps (centrifugal and piston), hydraulic pumps (roller and gear), car electric fuel pumps (roller and centrifugal) and car washing pumps (mostly piston types). The typical features of some of these pumps as inferred from experience and from MULTIQUIP (2011), are given in Table 2.2.

Table 2.2: Pump Brand Comparison

Pump Brands/Type		**Parameters**				
		Power/ Capacity	Pressure	Water Friendly	Cost	Quantity
Domestic water pump (External, mostly centrifugal, engine and AC powered)		Good/ Good	Low	Good	Good	One
Car electric fuel pump (DC powered Immersion and centrifugal)		Good/ Low	Good	**NA	Good	Three or four units.
Submersible pumps (AC powered, immersion and centrifugal)		*NS/ Good	Good	Good	High	One
Industrial water pump (External, piston or centrifugal Engine and electric powered)		Good/ Good	Good	Good	Good	One
Hydraulic Pump (DC powered, Roller, gear and piston)		Good/ Good	Good	**NA	High	One

*NS-not suitable ** NA-no available information.

Major factors to be considered in selecting pumps for herbicide sprayers are capacity, pressure and resistance to corrosion, wear (Sumner, 2012) and cost effectiveness. It is the recommendation of the Food and Agricultural Organization (FAO) that an herbicide spray pump should have the capacity to supply the maximum recommended number of nozzles, at a flow rate equivalent to 25% above the highest recommended rate (FAO, 2001). This is to make room for pressure losses at flow junctions and the pipes. Hence a suitable pump should deliver at least 1.25 of the calculated pump outputs with high operating pressure.

2.4.3 Nozzles

A hydraulic Spray Nozzle generally consists of the spray tip which regulates the flow and pattern, the strainer which filters particles alongside the nozzle body and nozzle cap which hold the spray tip and strainer together when locked. The spray tip differentiates different types of nozzles. Hydraulic nozzles used to deliver pesticides to target areas carry a significant role in achieving the desired biological efficacy. Spray characteristics such as the droplet size, deposit density, and spray coverage significantly affect the performance of pesticides. These characteristics vary from nozzle to nozzle, even from the same nozzle operated under different spray pressures and discharge heights. Efficient and effective pest control is dependent on the best nozzle selection with the optimum operation settings (Guler *et al.*, 2012).

The most common type of nozzle used in agriculture is the fan nozzle. A fan nozzle is widely used for spraying pesticides—both banding (over and between rows) and broadcast applications. These nozzles produce a tapered-edge, flat-fan spray pattern. On boom sprayers

for broadcast applications, nozzles are positioned so that their output overlaps (Grisso *et al.*, 2013). For tractor mounted broadcast boom applications, fan-type 8003 or 8004 nozzles spaced at 20 inches or TK-2 nozzles spaced at 40 inches are effective in hauling water to the field (Ahrens, 1986). The standard flat fan nozzle with 110º fan angles and hollow cone nozzles are widely used in the conventional field sprayers. The standard flat fan nozzles are suitable for herbicide applications and they are also used for insecticide and fungicide applications. Hollow cone nozzles were designed to increase the spray coverage. The operating pressure for all hydraulic nozzles ranged from 200 kPa to 400 kPa. The flow rates of the nozzles were 0.83, 0.87, 0.90 and 0.90 L min-1 for the standard flat fan nozzle, hollow cone nozzle, air induction nozzle and twin jet nozzle, respectively (Sayinci and Bastaban, 2011).

Another type of nozzle popularly employed for herbicide application is the impact nozzle; also known as deflector or anvil nozzles (Figure 2.3). This type of nozzle consists of a circular orifice, through which the liquid jet passes to bounce off a deflecting surface, resulting in a wide-angle fan spray with a narrow rectangular spray pattern. Rated at 100 kPa pressure, these nozzles produce a relatively even distribution. The impact nozzle is widely used with a knapsack sprayer for application of herbicides. A low operating pressure of 1 bar tends to produce coarse droplets which are less prone to drift, reducing off-target contamination. When the operating pressure is raised to 1.5–2.0 bar, these nozzles will tend to produce a medium quality spray (Jones 2006).

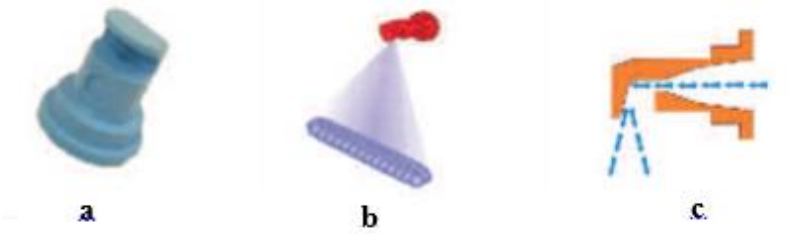


Figure 2.3: a). Impact nozzle, b). Spray pattern and c). Liquid flow.
(Source: Jones, 2006)

2.5 Field operation related literature

2.5.1 Majority farm holding in Nigeria

More than 80% of farmers in Nigeria are small holder farmers. They produce about 98 % of the food consumed in Nigeria with the exception of wheat (Mgbenka and Mbah, 2016). Oiganji (2018) correlates that smallholder farmers in Nigeria are responsible for 90% of produce yearly, and informs that smallholder farms form the backbone of the Nigerian agricultural sector and that they hold the key to agriculture's comeback. Mgbenka and Mbah, (2016) also reports that the characteristic feature of the agricultural production system in Nigeria is that a disproportionately large fraction of the agricultural output is in the hands of these smallholder farmers whose average holding is about 1.0-3.0 hectares. It further states that smallholder farmers are farmers whose production capacity falls between 0.1 and 4.99 hectares holding. Also Takeshima and Salau, (2010) classifies small scale farms as farms that are ≤ 5 ha, while medium scale farms are farms between 5 and 49 hectares. It classifies large scale farm as farms that are ≥ 50 ha.

2.5.2 Spraying time

Common crops like maize, millet, sorghum have varying germination times. Ekeleme *et al.,* (2008) carried out experimental investigations on weed control using chemicals and recommends the application of pre-emergence herbicides variously on maize, sorghum, cowpea, and soybean; within two to three days after sowing.

2.5.3 Row spacing

International Sorghum and Millet Collaborative Research Support Program frowns at broadcasting practice for Sorghum and Pearl Millet cultivation and recommends row to row spacing of 60 – 90 cm between rows and 15 – 30 cm in the row (Kimberley, 2006). Both cowpea and groundnut can be grown in flat beds or on ridges, depending on the field conditions. 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 (Ousmane and Ajeigbe, 2009). Also for high grain yield, maize should be sown in well prepared ridges 75 cm apart (Kamara *et al.*, 2020).

2.5.4 Spraying speed

Tractor ground speed of 1.6, 2.8, 3.5 and 4.0 km/hr for spraying is reported by Jayashree and Krishnan, (2012). But Romanelli and Milan (2012) reports that a standard single rear axle tractor carrying a row crop boom of 10.7 m with equipment and herbicide weighing 632 kg and moving at a speed of 5.4 km/hr (1.5 m /s) recorded an Effective Field Capacity (EFC) of 3.85 ha/hr with 8.2 litre/hr fuel consumption while spraying herbicide on a maize field (Romanelli and Milan, 2012). But tractor spraying speeds of 6 km/h to 10 km/h is recommended by Oduma *et al.*, (2019).

2.5.5 Herbicide spraying pressure

ASABE S572.1 standard uses eight droplet classification categories which include coarse sprays as droplet range (341-403 µm VMD) and very coarse sprays as droplet range (404-502 µm VMD). The standard also assigns their deployment for systemic herbicides and soil herbicides respectively (McGinty *et al.,* 2014). It is stated that low pressures of 15 psi (100 kPa) to 40 psi (267 kPa) may be sufficient for spraying most herbicides or fertilizer, but high pressures up to 400 psi (2,670 kPa) or more may be needed for spraying insecticides or fungicides (Hofman, 2018). Impact nozzles are reported to possess the characteristics of producing coarse droplets suitable for herbicide application at low pressures. The nozzle yields relatively even distribution at the rated pressure of 1 bar (Jones 2006).

2.5.6 Vehicle clearance for post-emergence application

Tann *et al.* (2011) reports that during the critical period of weed competition (CPWC) for rice, the height of the crop varieties ranged from 20-24 cm (7-10 in). Also the height of various varieties of cowpea generally ranges from 14.3 – 30cm (5 -12 in) from 3-11 weeks after transplanting (Agbogidi and Egho, 2012). (Monsanto Company, 2013) also reports that about the Critical Period of Weed Competition (CPWC), the height of corn is about 20.32-30.48 cm (8-12 in).

2.5.7 Motion resistance for steel wheels

The rolling resistance of a wheel is in general terms, the force opposing the motion of the wheel as it rolls on a surface. This force arises from the energy losses that occur due to:s

i. The elastic but non-ideal deformation of the wheel

ii. The inelastic and non-recoverable (plastic) deformation of the surface

iii. Friction in the wheel bearings (usually assumed to be negligible)

From this it will be clear that the rolling resistance of a wheel will be a function of the strength–deformation properties of the surface and the size and deformation characteristics of the wheel. For wheels with tires, the secondary factors include the air pressure, the structure of the tire carcass (radial or bias ply) and the tread pattern. For speeds used with agricultural tractors, rolling resistance is relatively independent of the speed of deformation of the soil and the tire and hence of the travel speed (Macmillan, 2002).

Wong, (2001) explains that the motion of a vehicle moving on a road is resisted by aerodynamic forces or air resistance, and road resistance which collectively make up the rolling resistance. For low speed vehicles, the air resistance is usually very small and negligible. The value of the road resistance depends on the nature of the terrain. When a tyre is rolling, the carcass is deflected in the area of ground contact. As a result of tyre distortion, the normal pressure in the leading half of the contact path is higher than that in the trailing half. The center of normal pressure is shifted in the direction of rolling. This shift produces a moment about the axis of rotation of the tyre, which is the rolling resistance moment. In a free-rolling wheel, the applied wheel torque is zero; therefore, a horizontal force at the tire-ground contact path must exist to maintain equilibrium. This resultant horizontal force is generally known as the rolling resistance. The ratio of the rolling resistance to the vertical load on the tyre is defined as the coefficient of rolling resistance. Based on experimental results many empirical formulas have been proposed for calculating the coefficient of rolling

resistance of tyres on hard surfaces. For radial-ply passenger car tyres under rated loads and inflation pressure on smooth roads, the relationship between the coefficient of rolling resistance CRR and speed V (up to 150km/hr); is given by:

$CRR = 0.0136+0.40 \times 10^{-7}V^2$ (Wong, 2001) (2.1)

And for bias-ply passenger car tires

$CRR = 0.0169+0.19 \times 10^{-6}V^2$ (Wong, 2001) (2.2)

Another empirical formula for bias-ply tires representing the worst-case scenario is given as:

$CRR = 0.01\ [1 + v/147]$ (Subbarao, 2014) (2.3).

Where CRR = Coefficient of rolling resistance
v = Speed.

In preliminary performance calculation, the effect of speed may be ignored and average value of CRR for a particular operating condition may be used. The average values of CRR for various types of tire over different surfaces are given in Table 2.3 (Versonnen, 2011). The rolling resistance is proportional to the normal load and given as:

$$RR \propto Mg$$

Putting the Coefficient of Rolling resistance as the proportionality constant yields:

$RR = CRR \times Mg$ (Kelly, 2002) (2.4)

Accordingly, the power to overcome the rolling resistance of a vehicle is given as:

$PRR = [9.81/3600] \times CRR \times M \times V$ (Subbarao, 2014) (2.5)

$PRR = [2.72 \times 10^{-3}] \times CRR \times M \times V$ (Subbarao, 2014) (2.6)

Where, PRR = power (kW)

CRR = coefficient of rolling resistance

M = mass (kg)

V = velocity (km/hr.)

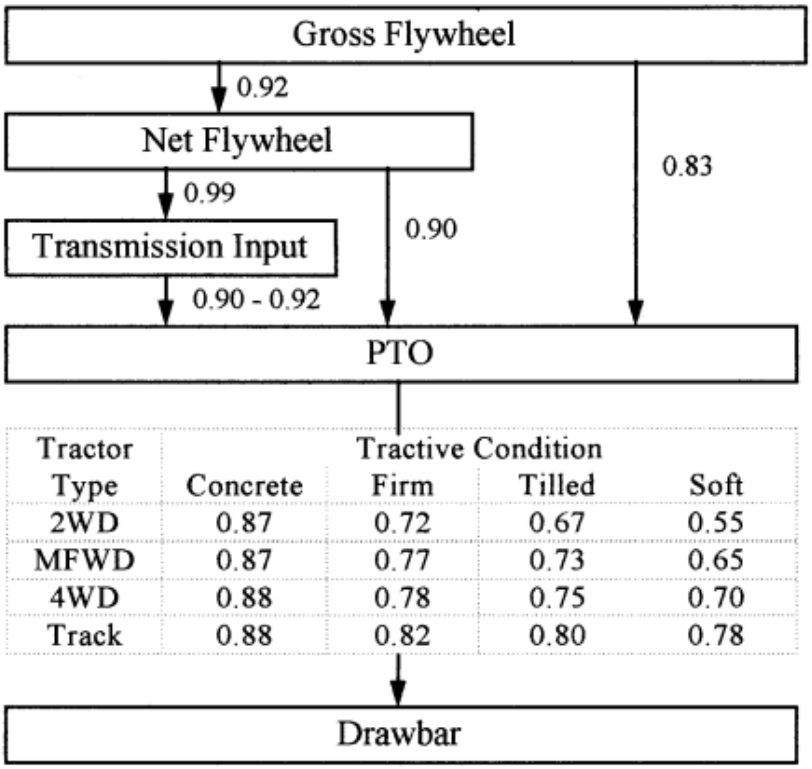
Table 2.3: Coefficient of Rolling Resistance

Road surface	Rolling resistance coefficient
Pneumatic tire of a car rolls	
on a coarse stone road surface	0.015
on a fine stone road surface	0.015
on a rolled asphalt mixed aggregate road surface	0.015
on an impacted coarse gravel road surface	0.012
on a mixed bituminous macadam road surface	0.025
on a soil road surface	0.05
on a field road surface	0.1-0.35
Pneumatic truck tire rolls on an asphalt mixed aggregate road surface	0.006-0.01
Steel wheel rolls on a field road surface	0.14-0.24
Steel wheel on a railroad surface	0.001-0.002

(Source: Versonnen, 2011).

2.5.8 Power relationships for Agricultural Vehicles

ASAE Standards (2003) states the power relationships for Agricultural Vehicles as depicted in Figure 2. 4. Power at a given location in the drive train can be used to estimate power at another location. PTO power for instance, can be estimated from net flywheel power by multiplying the net flywheel power by the transmission efficiency of 0.90. Similarly, the drawbar power can be estimated by choosing the tractor type and the tractive condition to determine the ratio. For Self-propelled sprayers the power of interest is the PTO power when spraying a tilled or soft land.



Tractor Type	Tractive Condition			
	Concrete	Firm	Tilled	Soft
2WD	0.87	0.72	0.67	0.55
MFWD	0.87	0.77	0.73	0.65
4WD	0.88	0.78	0.75	0.70
Track	0.88	0.82	0.80	0.78

Figure 2.4: Power Relationships for Agricultural Vehicles
(Source: ASAE Standards, 2003)

2.6 Capacities, cost estimate and shortcomings of some herbicide boom sprayers

Table 2.4 depicts the capacities, cost estimates and shortcomings of small and medium scale boom sprayers while those of large scale technologies are shown in Table 2.5.

Table 2.4: Small and medium scale pesticide boom sprayers, capacities, cost estimates and shortcomings as at the dates of the cited works.

Sr/No.	Works	Capacity /Cost Estimate (ha/hr) (N: k)	Shortcomings
1.	Design, Fabrication and Evaluation of Wheel Operated Sprayer (Singh *et al.,* 2020).	0.075/ 15,000.00	Drudgery/ Exposure to poisonous chemical.
2.	Development of an Animal Drawn Hydraulic Boom Sprayer. (Anibude, *et al.,* 2016).	1.04/ *NA	Scarcity of draft Animals
3.	Modification of Boom for a Lever Operated Knapsack Sprayer (Rabbani,*et al.,* 2020).	0.145/ 11,178.00	Drudgery/ Exposure to poisonous chemical
4.	Performance Evaluation of Modified Self-Leveling Boom	3.47/ *NA	Too large

	Sprayer (Ejaz *et al.*, 2004).		
5.	Development of low cost tri-cycle garden boom sprayer for fruit trees in Bangladesh (Hossain *et al.*, 2017).	0.3/*NA	Cannot move in-between ridges for post-emergence application
6.	Development and performance evaluation of single wheel driven boom sprayer (Kumar, 2015).	0.072/ *NA	Drudgery/low swath.
7.	Performance of Battery Operated Knapsack Sprayer (Dobariya and Vaja, 2016).	0.0812/ 15,000.00	Low coverage/ Exposure to poisonous chemical
8.	Fabrication and Performance Evaluation of Ground Wheel Operated Boom Sprayer (Mulatu, 2018).	0.83/*NA	Drudgery/ Exposure to poisonous chemical
9..	Development of a Push-Type Liquid Fertilizer and Pesticide Sprayer (Busari *et al.*, 2021).	1.13/*NA	Drudgery/ Exposure to poisonous chemical
10.	Design and Development of a Boom for a Lever Operated Knapsack Sprayer (Rahman, 2010)	0.195/10,000.00 (Knapsack) 0.201/12,000.00 (Knapsack with boom)	Drudgery/ Exposure to poisonous chemical.
11.	Development and Performance Evaluation of Cycle Mounted Battery-Operated Boom Sprayer. (Gururaj, *et al.*, 2020)	0.61/32,000.00	Drudgery/ Exposure to poisonous chemical.

*NA- Not available

Table 2.5: Large scale pesticide boom sprayers, capacities, cost estimates and shortcomings as at the dates of the cited works.

Sr/No.	Works	Capacity /Cost Estimate (ha/hr) (N: k)	Shortcomings
1.	John Deere 4030 Self-Propelled Pesticide Boom Sprayers (Equipment Technology, 2018).	53/ 142,000,000.00	Costly/ Too large
2.	Field Evaluation of a Tractor Mounted Boom Sprayer (Ford Tractor 4610). (Sanchavat *et al.*, 2017)	2.08 / 11,000,000.00	Costly/Too large
3.	Performance Evaluation of a Tractor Operated Trailed Type Boom Sprayer (Jassowal, 2016).	4.23/55,000,000.00	Costly/Too large

4.	Performance Evaluation of High Clearance Tractor Sprayer for Cotton Crop (Babu *et al.*, 2019)	0.24 / *NA	Too large
5.	Performance evaluation of self-propelled boom sprayer (Karale *et al.*, 2014)	1.28 and 1.69 / *NA	Too large
6.	Self-propelled Sprayer R.O.I: Part I: Pull-type vs. self- propelled sprayer:-Five things you need to know before you buy, (Equipment Technology, 2013).APACHE AS1230 Self-propelled	53/ 150,343,500.00	Costly/Too large
7.	Self-propelled sprayer (Apache ET Sprayers, 2018).JOHN DEERE R4045. Self-propelled	53/ 191,442,233.00	Costly/Too large
8.	Self-propelled Sprayer R.O.I: Part I: Pull-type vs. self- propelled sprayer:-Five things you need to know before you buy, (Equipment Technology, 2013).CASE PATRIOT 4440. Self-propelled	53/ 166,425,150.00	Costly/Too large
9.	Self-propelled Sprayer R.O.I: Part I: Pull-type vs. self- propelled sprayer:-Five things you need to know before you buy, (Equipment Technology, 2013).APACHE AS730. Pull behind	31/ 107,813,000.00	Costly/Too large
10.	Self-propelled Sprayer R.O.I: Part I: Pull-type vs. self- propelled sprayer:-Five things you need to know before you buy, (Equipment Technology, 2013).APACHE AS1030. Pull behind	31/ 139,714,940.98	Costly/Too large

*NA- Not available

2.7 Findings from Literature Review

Herbicide application though cheaper and more efficient than manual weeding, lacks matching application equipment for small and medium scale farm holdings in Nigeria. Self-propelled and tractor mounted Boom sprayers though very efficient with large coverage are very expensive beyond the financial capability of the average Nigeria farmer. Its capacity is also far above the small and medium scale farm holdings in Nigeria. Knapsack sprayers are

fragile and unsteady with variable pressures leading to under-dozing and over-dozing as the case may be. The coverage is very low. Also the operator is continuously exposed to herbicides contact which acute and chronic effects can be lethal. There is therefore a need to offer small and medium scale farmers in Nigeria, an appropriate Self-propelled herbicide boom sprayer to be deployed for improved herbicide application leading to enhanced food productivity in the country.

Literature review also reports that majority farm holdings in Nigeria who constitute more than 80% of farmers in Nigeria cultivate between 0.1 to 5 hectares each. It also informed that land holding in Nigeria is fragmented and further explained that small scale farms are farms that are ≤ 5 ha, medium scale are farms from 5 ha to 49 ha while large scale farms are farms that are ≥ 50 ha. The literature review also explains that rows spacing used by Nigerian farmers vary from 60-90 cm between rows and predominantly ridges at 75 cm apart. It also offers us the heights of common crops at about the critical period of weed completion. These information are handy for adjustments on the prime mover to equitable ground clearance and track for easy movement on cultivated soil. The literature review also enabled the appreciation of the main features of the four prime movers to be considered along power capacity, stability, track and ground clearance which formed the basis for choice of *Daihatsu Hijet* mini-truck as the prime mover. The literature on spray pumps and nozzles offered a guide to pump and nozzle selection. Equations for power to overcome rolling resistance as well as the coefficient of rolling resistance for steel wheel on various soils were also explained in the literature review.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

3.1.1 Prime mover

The prime mover is a *Daihatsu Hijet* mini truck. *Daihatsu Hijet* mini-truck dealer's website gives *Daihatsu Hijet* specifications as follows: Engine power: 43 hp (32.25 kW) and Min Ground Clearance (mm): 160 mm (6.2 inches), Payload 350 kg, Engine Rpm: 3500-5500 amongst others (https://japancardirect.com/mini-trucks-and-kei-turbo-cars/mini-kei-trucks/spec-comparison-tables).

3.1.2 Spray pump

The study employed locally available Agrimate industrial water pump (1.5 kW) commonly used in commercial car wash stations for its large pressure range and large discharge volume ranges. The specification plate reads: i). RPM 300-1000, ii). Working Pressure 20- 40 kg/cm^2 (19.6 -39.2 bar) and iii). Discharge Volume-6-18 liter/min.

3.1.3 Nozzles

Five impact nozzle were employed based on their characteristics of depositing uniform herbicide droplets at low pressures as reported by Jones, (2006)

3.1.4 Gear reducer

A gear reducer of 25:1 ratio weighing 17.4 kg with input and output shafts' diameter = 50mm was employed to reduce the original road speeds of the vehicle to equitable farm spraying speed.

3.1.5 Intermediate gearbox

One *Mitsubishi* bus gearbox was employed as an intermediate gear box between the *Daihatsu Hijet* mini truck gearbox and the spray pump. The gear actuating lever of the *Mitsubishi* bus gearbox serves to actuate and disengage the herbicide spray pump.

3.1.6: Hoses and strainers

About three meter length of 20 mm plastic suction hose, three meter of 15 mm plastic hose, four meter of 10 mm plastic hose and strainers were employed to connect the nozzles, and tank to the spray pump.

3.2 Methods

3.2.1 Design Considerations

Foremost in the considerations were the prime mover to be deployed, the pump and nozzles to achieve required herbicide droplet spectrum on soil and foliage alongside the filed terrain, target farm size, spraying time, spraying speed and spraying pressure. Vehicle ground clearance for post emergence application as well as boom stability were also considered.

3.2.1.1 Prime Mover

Four locally available, cost effective prime movers:

i. Qlink Motorcycle,

ii. Jiangsu Cargo Tricycle,

iii. Bajaj passenger tricycle and

iv. Daihatsu Hijet mini-truck, were compared for effective power, ground clearance and track for ease of adaptability as vehicle for the boom sprayer. Table 3.1 is the comparison table.

Table 3.1: Parametric Comparison of Prime Movers

Sr./No.	Parameters	*Qlink* Motorcycle	*Bajaj* Passenger Tricycle	*Jiangsu* Cargo Tricycle	*Daihatsu Hijet* Mini Truck
1.	Eng. Power kW	13.4	8.1	9.5	32.25
	(hp)	18	10.9	12.7	43
2.	+Eff. Power (kW)	6.12	3.7	4.4	14.7
	(hp)	8.2	4.96	5.9	20
3.	Ground Clearance (mm)	134	200	200	203
4.	Tire Dia. (mm)	615	421	559	595
5.	Track (mm)		1120	1040	1245
6.	Net Mass (kg); Gross (kg)	164;350 (514)	337;300 (637)	360;800 (1160)	750;350 (1100)
7.	++Av. Cost (₦)	300,000:00	350,000:00	650,000:00	700,000:00

+Eff = effective; ++ Average cost at the local market in Kano, Nigeria in 2019.

Using motorcycle or *Bajaj* tricycle would be most cost effective but the front central front wheel will not permit wheel adjustments to give desired ground clearance and permit movement in between ridges. The front forks of both the Motorcycle and the tricycles pose serious inhibition to the wheel diameter modification. However, *Daihatsu Hijet* mini truck is amenable to the track and wheel width modifications as well as the wheel diameter adjustments. Reduced exposure to chemical and operator comfort further support the choice

of *Daihatsu Hijet* Mini truck. Greater effective power of the Daihatsu Hijet mini-truck and equal front and back track that can be modified to move in between ridges makes it the prime mover of choice.

3.2.1.2 Farm size: The report by Mgbenka and Mbah, (2016) that majority farm holding in Nigeria who constitute more than 80% of Nigerian farmers and who produce about 98% of the food produced in the country farm between 0.1 and 4.99 hectares is adopted alongside Takeshima and Salau, (2010) classification of small scale farms as farms ≤ 5 ha and medium scale farms as between 5 and 49 hectares while farms ≥ 50 ha is large scale farms are upon to choose 10 hectares as the design target size to address small and medium scale herbicide application in Nigeria.

3.2.1.3 Spraying time

The recommendation by Ekeleme *et al.,* (2008) that herbicide application on farms should be concluded within three days of planting is accepted. 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 for pre-emergence after planting.

3.2.1.4 Spraying speed

Tractor ground speed for spraying as reported by Jayashree and Krishnan, (2012), Romanelli and Milan (2012) and Oduma et al., (2019) ranging from 1.6 km/h and 10 km/hr (0.4 m/s – 2.78 m/s) are accepted. The Daihatsu Hijet mini-truck dealer's website gives Daihatsu Hijet specifications as follows: Power: 43 hp (32.25 kW) and Min Ground Clearance (mm): 160

mm (6.2 inches), Payload 350 kg, Engine Rpm: 3500-5500 amongst others (https://japancardirect.com/mini-trucks-and-kei-turbo-cars/mini-kei-trucks/spec-comparison-tables). Gearbox reduction ratios and rear axle reduction ratio were ascertained manually through turning the input shaft and noting the number of revolutions at input to give one revolution of the output shaft at the various gears.

Figure 3.1 depicts the mechanical transmission system of the boom sprayer. The maximum engine Rpm = 5500, minimum engine Rpm = 3500. Hence, average engine Rpm = 4500. The rear axle ratio is 3:1, while the Gearbox ratios at Gear 1, Gear 2 and Gear 3 are respectively 4:1, 2.4:1 and 1.73:1. The relationship between wheel Rpm, forward speed and angular velocity as in Khurmi and Gupta, (2002) is used to determine the extra reduction necessary to give the recommended forward speeds of 1.6 km/h and 10 km/h (0.4 m/s – 2.78 m/s) at the wheels.

$$v = wr \tag{3.1}$$

$$w = 2\pi N/60 \tag{3.2}$$

Where, v = forward speed (m/s)

r = radius of the wheel (m)

w = angular velocity (rads/s)

N= revolutions per minute.

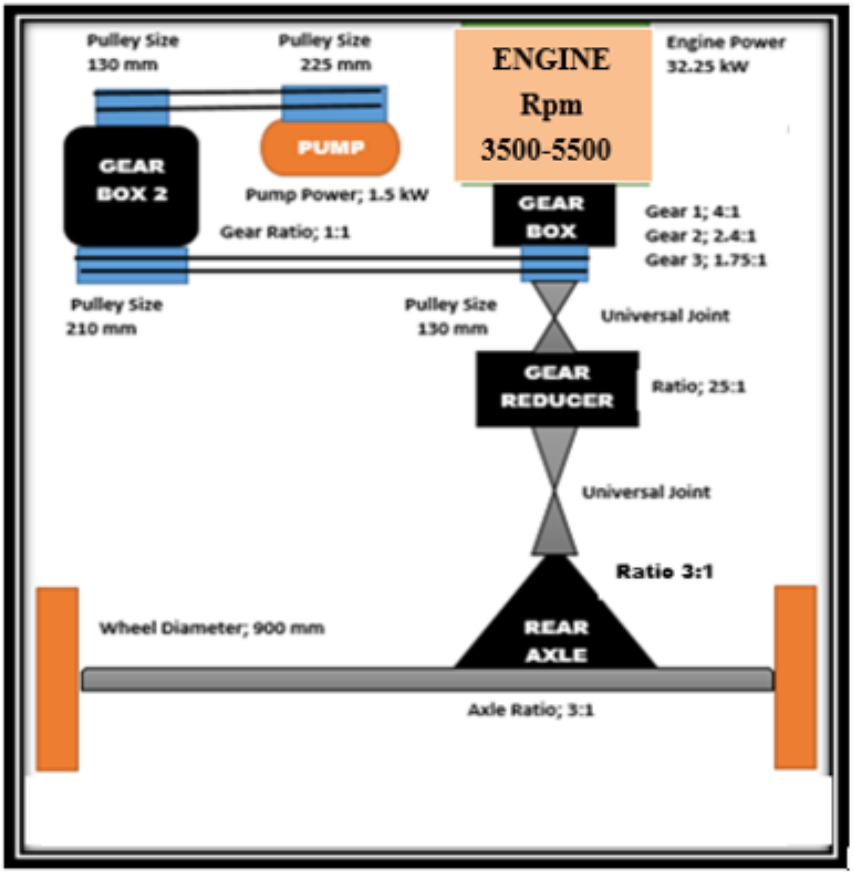


Figure 3.1: Mechanical Transmission system of the herbicide boom sprayer

Employing equations 3.1 and 3.2;

$$v = \frac{2 \, x \, \pi \, x \, N \, x \, r}{60} \tag{3.3}$$

Substituting for v_1 = 0.4 m/s, v_2 = 2.78 m/s and r = 0.45m;

The Revolution per minute (Rpm) N_1 and N_2 at the rear wheels can be obtained thus:

$$N_1 = \frac{60 \, x \, 0.4}{2 \, x \, \pi \, x \, 0.45}$$

$$= 8.5 \text{ Rpm}$$

$$N_2 = \frac{60 \, x \, 2.78}{2 \, x \, \pi \, x \, 0.45}$$

$$= 59 \text{ Rpm}$$

Reduction ratio required to reduce the average Rpm of 4500 to 8.5 Rpm and 59 Rpm are 529:1 and 76:1 respectively. Accommodating reduction ratio at Gear 1 (4:1) and rear axle reduction ratio (3:1), the extra reduction ratios are 6:1 and 44:1 respectively. Hence average reduction ratio required is (6+44)/2 = 25. A gear reducer of 25:1 ratio was installed between the mini-truck gearbox and the rear axle to achieve forward speeds of 3.2 km/h, 6.12 km/h and 7.24 km/h when the gear selector is in Gear 1, Gear 2 and Gear 3 respectively. Plate 3.1 depicts the underneath of the mini-truck with 25:1 ratio gear reducer in between the vehicle gearbox and axle.

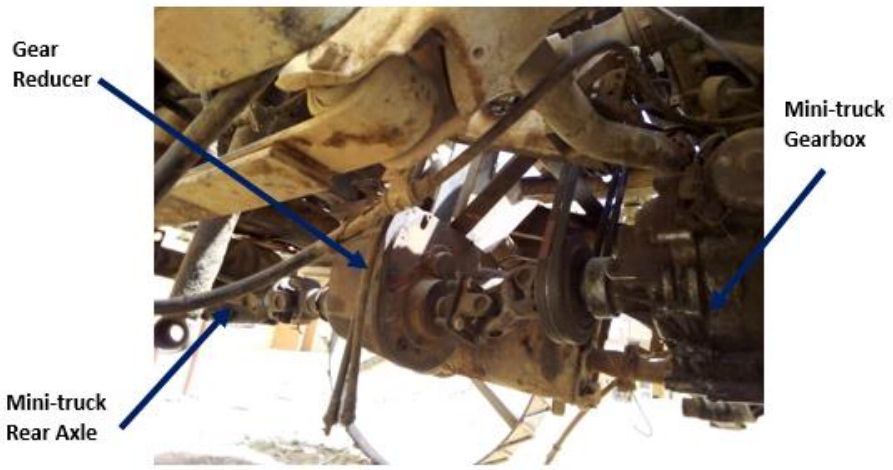


Plate 3.1: A 25:1 Gear Reducer installed between the vehicle gear box and rear axle

3.2.1.5 Vehicle Ground Clearance for post emergence application

This study adopted the reports of (Monsanto Company, 2013), Tann *et al.,* (2011) and Agbogidi and Egho, (2012) that heights of common crops about the critical period of weed competition (CPWC) range from 24 cm – 30cm. Plate 3.2 shows the four steel wheels (90 cm diameter each) with lugs employed to increase the vehicle ground clearance from 20.3 cm to 35.56 cm, and ease movement on farm soil without interfering with crops during post emergence application.

3.2.1.6 Row Spacing

The common row spacing of 75 cm apart recommended by Kimberley, (2006), Ousmane and Ajeigbe, (2009) and Kamara *et al.*, (2020); as planting requirements for common crops is adopted. Plate 3.2 depicts the hub (127 mm width) of the steel wheels employed to extend the vehicle track from 1245 mm to 1500 mm to allow movement between two rows 75 cm apart.

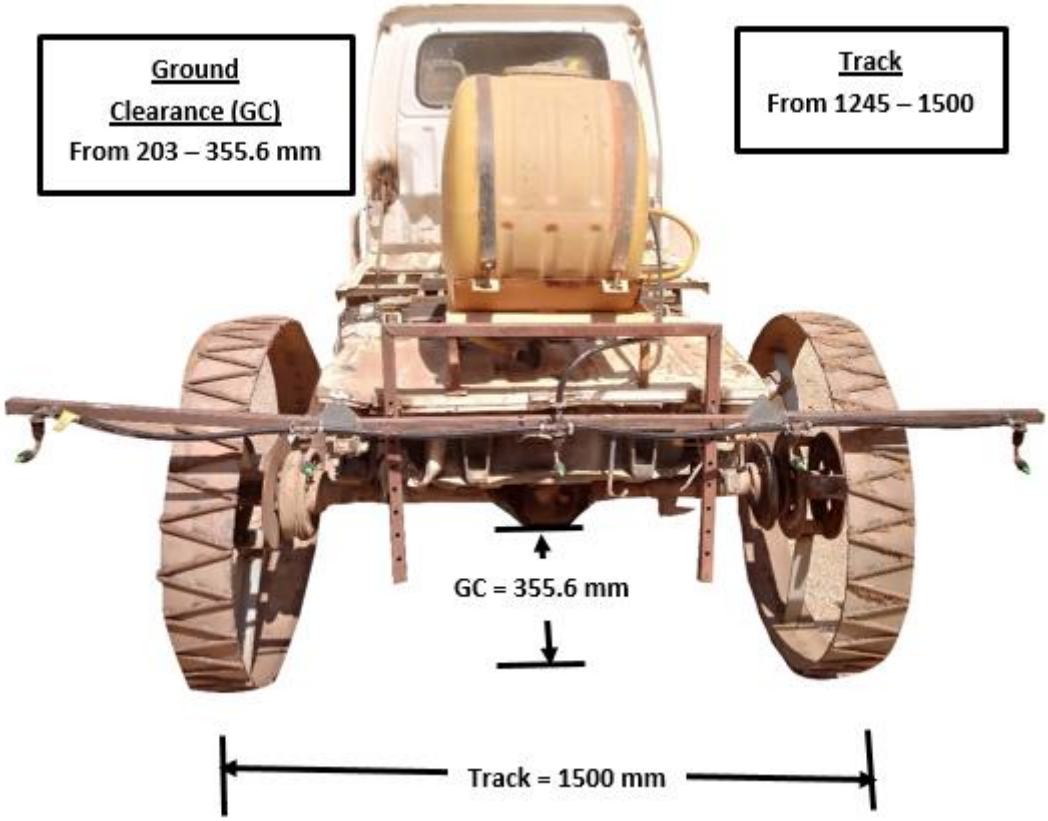


Plate 3.2: Track and ground clearance of the Self-propelled herbicide boom sprayer

3.2.1.7 Spraying Pressure

Holfman (2018) reports that coarse droplets for herbicide application are produced at low pressures of 100 kPa to 267 kPa. Impact nozzle is reported by Jones (2006); as very effective in depositing uniform droplets at such low pressures. Hipkins and Grisso (2014) and *Beyaz et al.*, (2017) recommend the application of coarse herbicide droplets on soil and foliage to ensure effectiveness. Above recommendations informed the employment of impact nozzles in

the development of the sprayer. Similarly, the study also employed locally available Agrimate industrial water pump (1.5 kW), for its large pressure range and large discharge volume ranges. The specification plate reads: i). RPM 300-1000, ii). Working Pressure 20- 40 kg/cm^2 (19.6 -39.2 bar) and iii). Discharge Volume-6-18 liter/min. Also the motion transmission to the spray pump is such that at Gear 1 (3.2 km/h), Gear 2 (6.12 km/h) and Gear 3 (7.24 km/h), the pump pressure is 100 kPa, 200 kPa and 300 kPa respectively.

3.3 Calculation of Sprayer Boom width, Pump Output, Nozzle throughput and number of nozzles

3.3.1 Boom Width

The Boom width is calculated as in Matthews (1979) using the 10-hectare design farm size, within eighteen hours spraying time or three days after planting and the forward speeds generated following the installation of the 25:1 gear reducer; namely: 3.2 km/h, 6.12 km/h and 7.24 km/h when the gear selector is in Gear 1, Gear 2 and Gear 3 respectively.

$$W = \frac{A}{TS}\ m \qquad (3.4)$$

Where,

W = Boom width or swath (m);

A = Area requiring treatment (m^2);

T = Time Available (h);

S = Vehicle Speed (m/h).

$W_1 = \frac{10\ x\ 10000}{18\ x\ 3200}\ m \quad = 1.736\ \approx 2\ m;$ for Gear 1

$W_2 = \frac{10\ x\ 10000}{18\ x\ 6120}\ m \quad = 0.9 \approx 1\ m;$ for Gear 2

$W_3 = \frac{10\ x\ 10000}{18\ x\ 7240}\ m \quad = 0.767 \approx 1m;\ \text{for Gear3}$

The highest boom width of 2 m is adopted.

3.3.2 Pump output

The pump output is calculated as in Matthews, (1979), using Application Rate of conventional tractor Boom sprayers of 47 to 282 l/ha (164.5 l/ha average); as reported by Anderson *et al.,* (2012). The calculated boom width of 2m and the 3.2 km/h speed at the chosen width alongside the nozzle spacing of 50cm employed on conventional boom sprayers as reported by Anderson *et al.,* (2012), Sumner (2012) and Noyes *et al.,* (2007), are adopted in the computation for pump output and nozzle throughput.

$$\text{Pump Output: } P = \frac{WArS}{600}\ L/\min \tag{3.5}$$

Where, W = Boom width or swath (m);

Ar = Application rate (L/ha);

S = Vehicle Speed (m/h).

Hence, $P = \frac{2 \text{ x } 282 \text{ x } 3.2}{600} = 3\ L/min$

3.3.3 Nozzle throughput

The nozzle throughput is given by Matthews (1979) as:

$$N_{th} = P\ (L/min) \text{ x } \frac{ns\ (m)}{W\ (m)} \tag{3.6}$$

$$N_{TH} = 3 \text{ x } (0.5/1.73) = 0.87 \text{ l/min}$$

3.3.4 Number of nozzles

$$\text{Number of nozzles} = \frac{P\ (L/min)}{Nth} \quad (3.7)$$

Where, N_{th} = Nozzle Throughput (L/min);

P = Pump Output (L/min);

n =Number of nozzles;

ns =Nozzle spacing (m);

Number of Nozzles = 1.75/0.5 = 3.5 ≈ 4 + a center nozzle
= 5 nozzles

3.4 Design of Components

3.4.1 Boom design

Volume 2 of the guidelines on minimum requirements for agricultural pesticide application equipment for vehicle-mounted and trailed sprayers by FAO (2001), guided the design of the boom. Pertinent stipulations guiding the design states that booms should be rigidly constructed so that all nozzles along a boom are supported at the same height and that the sprayer should be fitted with a mechanism to lock the boom sections securely in the transport position while ensuring the protection of the nozzles from damage from contact with the ground. The boom length is 2 m as calculated. The work of the boom is to carry the nozzles and hose connections measured as 1.32 kg firmly and stable as the vehicle moves. Punmia *et al.,* (2008) states that when a beam is loaded, it deflects. The amount of maximum deflection depends on the span, the moment of inertia of the section, the distribution of the load, the modulus of elasticity and the support conditions. It further posits that generally the deflection should not exceed 1/325 of the span of the beam. For uniformly distributed load as in the boom whose weight and nozzles are evenly located:

Deflection $D = 0.013 \times L_t X^3 / EI$ (Punmia *et al.,* 2008 (3.8)

Where, D = Deflection

L_t = total load (kN)

X = effective span (mm)

E = Modulus of Elasticity (N/mm^2)

I = Moment of Inertia (mm^4)

AustubeMills, (2013) gives the moment of inertia for hollow square pipe 25 mm x 25 mm x 2mm as 0.0148 x 10^4 mm4. (Kut and Stachowicz, 2020) gives the Modulus of Elasticity of 2.5 cm x 2.5 cm x 2 mm mild steel square pipe as 199 GPa.

Putting L_t = 0.0001295 kN; L = 2000 mm; E = 199000 N/mm^2 and I = 0.0148 x 10^4

$$D = 4.57 \times 10^{-5}$$

But allowable deflection D_A = 1/325 x 2000 = 6 mm.

It is acceptable to use the available 25 mm x 25 mm x 2mm square pipe for the construction as the allowable deflection is far above the value of the deflection which the loading can induce in the member. The orthographic drawing of the spray boom and attachment bracket assembly is shown in figure 3.2. The study employed mild steel 2.5 cm x 2.5 cm x 2 mm square pipe for the construction of the spray boom and bracket after determining its suitability.

The bracket is welded to the rear frame while the boom is bolted onto the bracket at positions to give desired nozzles height above target. The nozzles are attached on the boom at 50 cm spacing. The reports by Sumner (2012), Noyes *et al.* (2007) and Anderson *et al.*, (2012), that pesticide nozzles are usually spaced 20 inches (50 cm) apart on the boom at a height of about 15-24 inches (38 cm – 61 cm) were adopted in designing the boom with nozzles at 50 cm

apart and height of nozzles above target from 30 cm to 60 cm. The boom width is 2 m, as calculated.

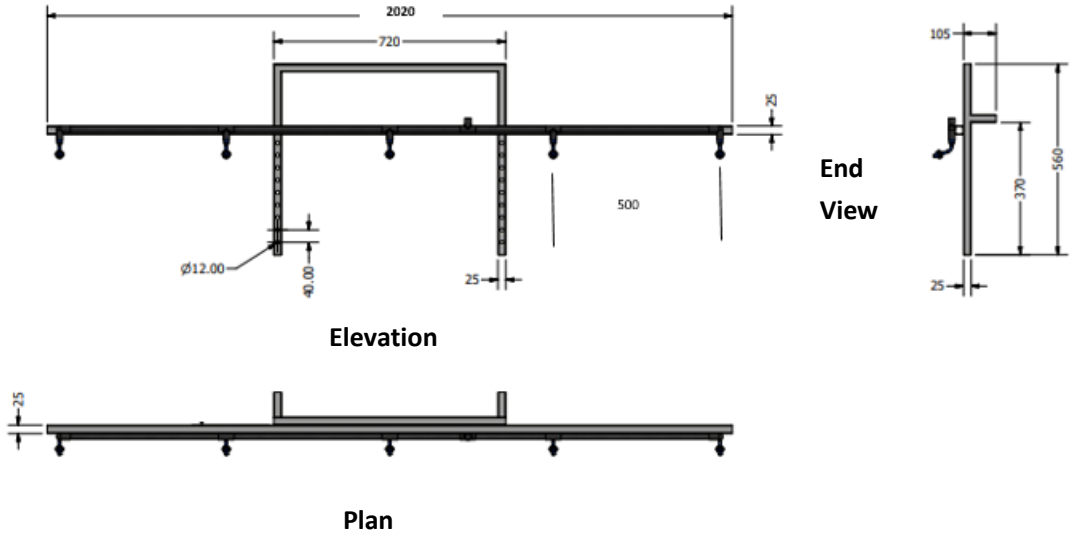


Figure 3.2: Orthographic views of the spray boom and attachment bracket

3.4.2 Design of Steel wheels

The sprayer shall be deployed both for pre-emergence and post-emergence herbicide application. It is needed to raise the ground clearance of the *Daihatsu Hijet* mini truck originally at 20.3 cm to 35 cm and above to be clear of growing crops at about the critical period of weed completion. The radius of the *Daihatsu Hijet* mini truck rear axle is 10 cm and together with the original ground clearance gives 30 cm. The ground clearance required extra addition of at least 15 cm for the radius of a matching wheel to be achieved. A wheel of 45 cm radius is required to achieve the ground clearance of 35 cm. The size of the wheel is not available as rubber tyres. Steel rings of varying diameters are available at the local Head

bridge market in Onitsha, Anambra state. A steel wheel of 90 cm diameter and 5 mm thickness was procured after bending endurance analysis indicated its suitability for the work. The gross weight comprising the vehicle net weight and permissible payload is 1100 kg. It is assumed that the loading load on the mini truck would be uniform and that load on each wheel is 2697.75 N. The design determined the bending stress using the maximum dynamic radial load as given by Ganesh and Periyasamy, 2014):

$$Fr = kF \quad (3.9)$$

Where

Fr = Radial load in N

F = the maximum load coming on to the tyre in N

k = Radial coefficient according to the industrial standards

According to standards, k = 2.25,

Hence, radial load on each wheel = 6070 N.

The bending moment is calculated as in Ganesh and Periyasamy, 2014):

$$M_b = ((\mu r) + d) \times F \times c \quad (3.10)$$

Where

M_b = Bending moment in 'Nm'

μ = Friction Coefficient between the wheel and the road surface (no units)

r = Radius of the wheel in 'm'

d = Offset of the wheel in 'm'

F = Maximum load acting on the wheel in 'N'

c = Bending coefficient specified according to the standards.

According to the industrial standards: $\mu = 0.7$, d = 37 mm, c = 1.5 (Ganesh and Periyasamy, 2014). Bending moment $M = ((\mu r) + d) \times F \times c$

$$= ((0.7 \times 0.45) + 0.037) \times 6070 \times 1.5$$

$$= 3205 \text{ Nm}$$

Bending stress as given by (Punmia et al., 2008) $BS = My/I$ (3.11)

Where

M = Bending moment

I = Moment of inertia

y = Distance in (m), from the base of steel plate to its neutral axis.

The moment of inertia is calculated as in Wilson, (2015):

I = Mass x radius /2 (3.12)

$$= 148.8 \times 0.45/2$$

$$= 33.48.$$

Hence bending stress $BS = 3205 \times 0.0025/33.48$

$$= 0.239 \text{ N/m}^2$$

$$= 0.000239 \text{ kPa.}$$

Employing 388 MPa, yield strength of steel as in (Kut and Stachowicz, 2020) and permissible bending stress of 0.66 x yield stress as in Punmia et al., (2008); permissible stress is:

$$0.66 \times 388 = 256 \text{ MPa.}$$

The bending stress occasioned on each wheel is in fractions of kilo paschal while the permissible stress is in mega paschal. Thus, it is safe to employ the steel wheels.

The motion of all wheels on any surface is enhanced by a certain amount of friction. Wherefore excessive friction may consume power or make it impossible for a wheel to roll on the ground, some friction is important for movement to occur. Threads are put on rubber tyres while cleats are put on the steel wheels to improve rolling motion without slipping. According to Hewitt, (1919) cleats increase the soil wheel interaction insofar as the soil resists shearing; that is, the cleat carries a section of the top soil and slides it against the soil below the edge of the cleat. This implies that while cleats can improve on most farm soils, it may not do well in water logged soils which does not resist shear. Hewitt, (1999) further posits that experiments indicated that efficient movement on soil was practically independent of the depth of the cleat, but depended solely on the shearing strength of the soil at the depth of the cleat edge. It also informed that in some cases the shallower cleat pulled more than the deeper cleat because the roots in the sod were not cut off and advantage was taken of their shearing strength. 12 mm rods were welded -diagonally on the wheels to enhance the wheel movement on soil.

3.4.3 Design of herbicide tank

The tank was designed by considering the weight of an empty tank together with the weight of herbicide and water that when added to the weight of other components would not near the value of the Daihatsu Hijet mini truck payload specified as 350 kg. Computed indicated that weight of empty tank, water and herbicide below 150kg would serve. The dimensions of the tank which guided the selection from the local market were determined using the following mathematical expression as given by Anibude *et al.*, (2016):

$$C_t = \pi r^2 h \qquad (3.13)$$

Where; C_t = tank capacity (m^3), π = constant (pie), r = tank radius (m), h= tank height (m)

Available tanks in the local market in Zaria were inspected for their dimensions. The nearest plastic tank inspected had dimensions of height = diameter = 50 cm.

Therefore, employing equation 3.13; C_t= (3.142 x 0.25 x 0.5) m^3

= 0.0982 m^3

= 98.2 x 10^3 m^3 (100 liters tank capacity was chosen).

The study employed the said one 100 liter capacity plastic tank weighing 12.4 kg which was procured from the local market in Zaria as the herbicide tank.

3.4.4 Design of V-belt transmission to the spray pump

The maximum engine Rpm = 5500, minimum engine Rpm = 3500. Hence, average engine Rpm = 4500. The rear axle ratio is 3:1, while the Gearbox ratios at Gear 1, Gear 2 and Gear 3 are respectively 4:1, 2.4:1 and 1.73:1. Thus, using average speed of 4,500 Rpm, the speeds at the gears are: 1,125, 1,875 and 2600 Rpm for Gear 1, Gear 2 and Gear 3 in that order. The maximum power on the pump's name plate is 5 kW while the engine power is 32.25 kW. The speed on the pump's name plate is 800 Rpm to 1200 Rpm. The reading on the pressure gauge indicated from 0 – 10 bar (0 – 1000 kPa). Pressure needed is from 100 – 300 kPa. If motion is transmitted to the spray pump directly from the tail of the *Daihatsu Hijet* mini truck, the pump would spray continuously and cannot be stopped unless the gear is disengaged which will automatically stop the sprayer. An intermediate gear box was installed to take motion from the *Daihatsu Hijet* mini truck gear box and deliver to the spray pump. (See Figure 3.1).

Wherefore, the gear box lever of the intermediate gear box is employed as an on and off actuator to power the spray pump as needed.

The relationship between the driven pulley speed and the speed of the prime mover or drive pulley as given by Nwakairea *et al.*, (2011), was relied upon to fix four two-way v-pulleys of diameters 150 mm, 210 mm, 150 mm and 225 mm on the *Daihatsu Hijet* mini truck gear box output shaft, intermediate gear box input shaft, intermediate gear box output shaft and spray pump driven shaft respectively.

$N_1 D_1 = N_2 D_2$ Nwakairea et al., (2011) (3.14)

Where, N_1 is speed of the driver, N_2 is speed of the driven, D_1 is the diameter of the driver pulley, and D_2 is the diameter of the driven pulley. The V-belts were selected based on their rating as given in Table 3.2. The two sets of v-belts were all class "A" having been defined by the load. Acceptable speeds of 535 Rpm, 892 Rpm and 1238 Rpm were achieved at the pump pulley at Gear 1, Gear 2 and Gear 3 were and gave pumping pressures of 100 kPa, 200 kPa and 300 kPa respectively.

Table 3.2: V belts Cross Section Tag and Power Rating in kW

Cross section	Load of drive (Kw)	Recommended min. pulley pitch diam., *d* (mm)	Nominal top width, *w* (mm)	Nominal thickness, *T* (mm)	Weight per meter (kg f)
A	0.75 – 5	75	13	8	0.106
B	2-15	125	17	11	0.189
C	7.5-75	200	22	14	0.343
D	22-50	355	32	19	0.596
E	30-190	500	38	22	—

(Source: Nwakairea et al., 2011)

3.5 Wheel traction and motion resistance

The major components contributing to payload are shown in Table 3.3.

Total mass on the wheels = Mass of Daihatsu Hijet + mass of Payload Components

= 700 kg + 250.68 kg = 950.68 kg.

The power to overcome the rolling resistance (PRR) of the boom sprayer is calculated as in Subbarao (2014) and employing Coefficient of Rolling Resistance (CRR), for steel wheel on field road surface given as 0.14 – 0.24 by Versonnen, (2011). The upper value of 0.24 is employed to contain the worst case situation.

Table 3.3: Mass of Payload Components

	Component	Mass (kg)
1.	Pump	7.82
2.	Intermediate Gearbox	9.7
3.	Gear Reducer	17.4
4.	(Wheels –Tire) x 4 148.8 kg – 55.44kg	93.36
5.	Empty Chemical tank	12.4
6.	98 liters water	98
7.	1.2-liter Glyphosate [xx] Density = 1.7	2
8.	Other appurtenances (pulleys, V-belts, hoses, bolts, angle iron sections etc.	10
	Total	250.68

[xx] (Source: WHO, 1994)

PRR = [9.81/3600] x CRR x M x V (3.15)

Where : PRR = power (kW); CRR = coefficient of rolling resistance; M = mass (kg); V= velocity (km/hr.)

But total dynamic wheel load or mass:

M = 944.68

Hence,

PRR = 9.81/3600 x 0.24 x 950.68 x 3.2

= 1.99 kW = 2 kW

Net Power = Effective Power – PRR – Pump Power

= 14.7 – 2 – 5

= 7.7 kW

3.6 Engineering drawing

The isometric view, orthographic and exploded views of the sprayer are depicted in Figure 3.3, Figure 3.4 and Figure 3.5 respectively.

Figure 3.3: Isometric view of the Self-propelled boom sprayer for small and medium scale herbicide application

Figure 3.4: Orthographic view of the Self-propelled boom sprayer for small and medium scale herbicide application

Figure 3.5: Exploded view of the Self-propelled boom sprayer for small and medium scale herbicide application

3.7 Description of the Self-propelled herbicide boom sprayer+-

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, pulleys and other connection accessories such as strainers, hoses and clips. The *Daihatsu Hijet* 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-liters capacity pesticide tank and also to the nozzles at the back of the vehicle frame. The boom sprayer moves on four steel wheels each of 90 cm diameter, offering higher ground clearance to allow post-emergence application without destroying growing crops. The 12.7 cm width of the wheel hub extends the vehicle track from 124.5 of the original *Daihatsu Hijet* mini-truck to 150 cm to permit movement in between ridges of 75 cm apart.

3.8 Laboratory Evaluation of the herbicide boom sprayer

There are two factors which influence the spray parameters namely: the pumping pressure, occasioned by the vehicle forward speed and height of nozzle above target. The recommendation of McGinty et al., (2014) that coarse herbicide droplets (300 – 400 VMD) be applied for weed control alongside the report of Holfman (2018) that coarse droplets for

herbicide application are produced at low pressures of 100 kPa to 267 kPa informed varying the pressure at three levels of 100 kPa, 200 kPa and 300 kPa corresponding to vehicle forward speeds: (3.2 km/h, 6.12 km/h, 7.34 km/h) respectively. Summer (2012) reports that nozzle spacing of 50 cm and height of nozzle above from 38 cm to 60 cm are the usual practice for the common fan nozzles was adopted. This study varied the heights of nozzles above target at (30 cm, 45 cm, 60 cm); while the flow rate, droplet size and swath were determined. Also, the volumes collected by twenty two collection tubes across the patternator during each experiment were employed to determine the spray volume distribution pattern across the entire settings. Spray volume distribution pattern is a critical sprayer parameter since the essence of spraying is to evenly deposit herbicide to achieve the desired results. Irregular or variable deposition implies deposition of over and under doses which is ineffective, destructive and most times wastage of chemical and man hour. The Experimental layout drafted using the Chart of Random numbers are shown in Table 3.4.

Table 3.4: Experimental Layout

P_3H_2	P_2H_1	P_2H_3
P_2H_3	P_3H_2	P_3H_2
P_3H_3	P_2H_2	P_1H_3
P_1H_2	P_3H_1	P_1H_1
P_1H_1	P_3H_1	P_1H_2
P_2H_1	P_3H_3	P_3H_1
P_1H_2	P_3H_3	P_1H_3
P_3H_3	P_2H_2	P_1H_1
P_2H_1	P_1H_3	P_2H_2

3.8.1 Test Materials

The following test materials were used for the tests:

i. Measuring tape for measuring the swath width and experimental field.

ii. Stop watch for time recording.

iii. Polythene sacks for collection of liquid (1liter capacity)

iv. Graduated Measuring cylinder (0.3 liter capacity graduated in mm)

v. Glyphosate (Altrazine), a pre-emergence herbicide as the test fluid.

vi. Patternator Test Rig.

vii. Droplet size measuring instruments which include:

   a. Magnesium ribbon

   b. Microscope set.

   c. Porton G12 Graticule.

   d. Glass slides for droplet samples collection.

3.8.2 The Experimental Rig

The experimental test rig for the laboratory experiments is the patternator (Plate 3.3 and Plate 3.4). It consists of twenty-two slanting channels underneath the nozzle spray. Water is employed as the test fluid. Tubes for collection of water running into each channel are placed under each channel outlet. Plate 3.4 shows the Herbicide boom sprayer positioned outside the laboratory while the rear wheels are raised above the ground. This is to prevent forward motion of the Sprayer when the gears are engaged to power the spray pump for the experiments.

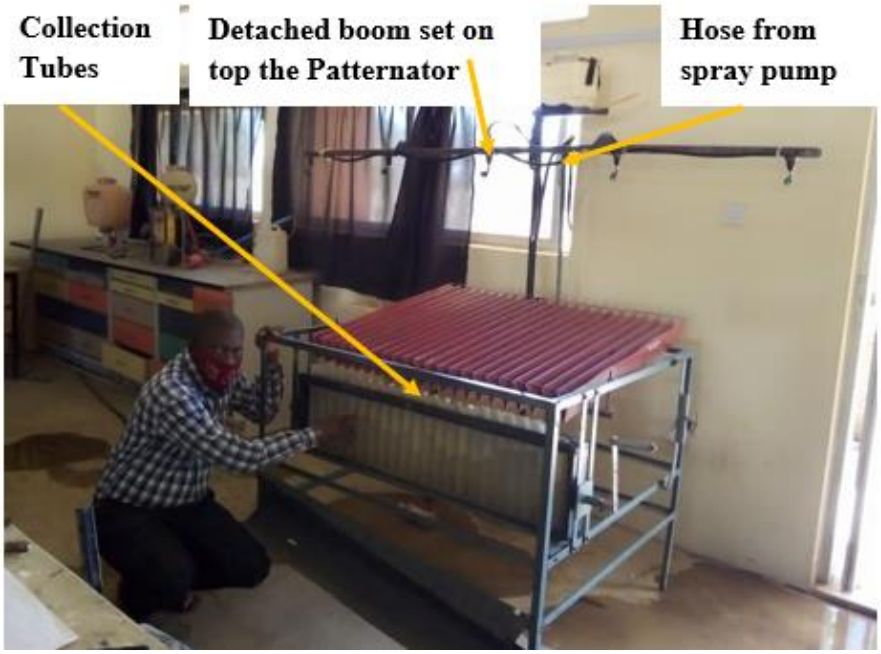


Plate 3.3: Patternator test rig inside the laboratory. The detached boom is mounted on the test rig



Plate 3.4: Machine stationed outside with a long hose connecting the spray pump to the boom mounted on the test rig

The boom of the sprayer is detached and mounted above the patternator table and connected to the pump through a long hose. The hose is indicated in Plates 3.3 and 3.4. The heights of

the nozzles above the patternator table are adjustable to enable experiments to be carried out at the various heights. A pressure gauge is placed close to the nozzles to read the pressure.

3.8.3 Laboratory procedure

The procedure for the determination of the flow rate, swath and droplet sizes are as follows:

i. Flow rate: Polythene sacks are tied to the boom such that liquid discharge from the nozzles collect in the sacks. After timed flow at the chosen pressure, the volumes are each measured using the graduated measuring cylinder. The flow rates were determined using expression given below.

$V = Q/t$ l/min (Matthews 1979) (3.16)

Where

V = Flow rate (l/min.)

Q = Average discharge in liters

T = Average time for discharge in minutes

Analysis of Variance (ANOVA) and Duncan multiple range test was carried on the results using Statistical analysis software (SAS) to determine the effects of variations in heights of nozzles above target and varying pressure settings on the flow rate of the boom sprayer. Further analysis was carried out using linear regression model.

ii. Spray volume distribution pattern: The spray pattern of single impact nozzle is tapered. To achieve uniform distribution on a boom of multiple nozzles, a degree of overlap of the spray patterns is required because spray distribution from a nozzle is generally more in the central region, reducing towards the outer edges, following a

normal distribution. The patternator test at various heights enables the determination of the height that gives the most uniform spray volume distribution. The position corresponding to minimum coefficient of variation is selected as the best placement for the nozzles on the boom at the particular height of the nozzles from the target and at the given working pressure (Khurana et al., 2007).

The nozzle spray volumes were collected in the twenty two test tubes. The averages, standard deviation and coefficient of variations of the experiments were processed using MS Excel software 2010. Evenness of the spray was ascertained from column chart, graphical presentation and histogram plots of the COVs. Analysis of Variance (ANOVA) and Duncan multiple range test were carried out on the results using Statistical analysis software (SAS) to determine the effects of variations in heights of nozzles above target and varying pressure settings on spray volume distribution pattern. The results were further subjected to linear regression analysis for a better understanding of the relationships.

iii. Droplet size: Droplet size is the diameter of an individual spray droplet and measured in microns (micrometers, μm). It is one of the most influential factors in spraying system, which affects crop coverage, biological efficacy of the applied herbicide and spray drift risk (Chethan *et al.,* 2019). To indicate a particular average droplet diameter within a spray, volume median diameter (VMD) is the diameter used. The volume median diameter is the diameter of a droplet in a representative sample of spray droplets such that when divided into two equal parts, one half contains droplets whose diameters are smaller than the VMD, while the other half of the volume

contains droplets whose diameters are larger than the VMD (Kaul and Suleiman, 1990). Spray droplets smaller than 150 microns tend to be the most prone to drift. These small droplets fall more slowly than large droplets. They do not have enough weight to overcome air resistance and are likely to float in wind currents. Droplet size smaller than 150 microns poses most serious drift hazard problems and the droplet size 200 microns and larger in size are less likely to be get drifted (Chethan *et al.*, 2019). For herbicide application, Hipkins and Grisso (2014) and Beyaz et al., (2017) recommend that coarse herbicide droplets be applied on soil and foliage. ASABE S572.1 standard states coarse sprays as droplet spectrum (341-403 µm VMD) and very coarse sprays as droplet spectrum (404-502 µm VMD) (Chethan *et al.,* 2019).

Glass slides were uniformly coated with magnesium oxide by burning two 10 cm strips of magnesium ribbon. Droplet samples were collected on the coated slides, at the various test pressures. The samples collected were then observed under a microscope fitted with a field Graticule eyepiece for precise droplet size measurement (Matthews, 1979). With the aid of mechanical stage of the microscope, the craters were lined in series on Graticule in which droplets are classified as 50 microns, 100 microns 200 microns and 400 microns. Analysis of Variance (ANOVA) and Duncan multiple range test was carried on the results using Statistical analysis software (SAS) to determine the effects of variations in heights of nozzles above target and varying pressure settings on the droplet size. The results were further subjected to linear regression analysis for a better understanding of the relationships.

iv. Swath: The spray from common agricultural nozzles including impact nozzles are cone shaped. Figure 3.6 depicts the spray pattern from overlapping multiple nozzles. The red, blue and green lines show that at any horizontal position along the Nozzle Height above target, the Spray volume distribution pattern and Swath must vary. Laboratory test is required to determine effect of variations in height on swath, thereby determine the height and swath which offers the optimum uniform deposition of herbicide. At the test height and pressure, the horizontal width covered by the spray during the three replications are measured. The average gives the swath for the particular pressure and height.

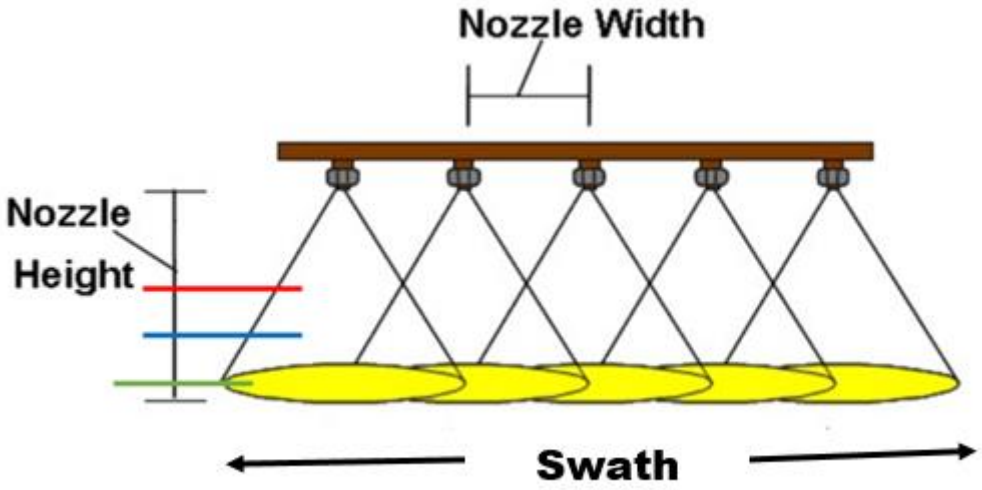


Figure 3.6: Spray pattern from multiple nozzles.

Analysis of Variance (ANOVA) and Duncan multiple range test was carried on the results using Statistical analysis software (SAS) to determine the effects of variations in heights of nozzles above target and varying pressure settings on the swath. The results were further subjected to linear regression analysis for a better understanding of the relationships.

3.9 Field Performance Evaluation

The field evaluation was carried out to determine the following parameters under field conditions. The parameters are:

i. Effective field Capacity (EFC)

ii. Application Rate (Ar)

iii. Field Efficiency (FE)

The Theoretical Field Capacity (TFC) is calculated using the following equation:

$$\text{TFC} = \frac{W\ x\ S}{10}\ ha/h \quad (\text{Udaybhaskar } et\ al., 2018) \tag{3.17}$$

The theoretical design speed of 3.2 km/h and boom width of 2 m are used to compute the Theoretical Field Capacity (TFC) Hence,

$$\text{TFC} = [2 \text{ x } 3.2]/10 = 0.64 \text{ ha/h}$$

Where,

TFC = Theoretical Field Capacity (ha/h)

W = Swath (m)

S = Vehicle Speed (km/h)

For the field tests, a 20 m x 16 m space (0.032 ha) was marked. The sprayer was deployed to the area, the time taken to cover the area was noted at the three operational speeds. Also, at each speed the quantity of water sprayed was determined using a measuring cylinder to find the quantity of water which filled the depleted tank after spraying. The data was used to evaluate the fraction of the hectare sprayed during the time recorded by the stop watch as well as the quantity of water sprayed per hectare to get the EFC and Ar. For calculating actual

field capacity, the time consumed for real work and that lost for other activities such as turning, filling of tank were taken into consideration. Actual field capacity was calculated as given by Udaybhaskar *et al.,* (2018):

$$EFC = \frac{A\ (ha)}{T\ (h)}\ (ha/h) \tag{3.18}$$

Where,

EFC = Effective field capacity (ha/h)

A = Area covered (ha)

T = Total time taken to cover the area. (h).

The application rate gives a measure of the volume of herbicide to be deposited per hectare. It helps to arrange the volume of water and chemical to be used for a farm land. The spray liquid application rate was determined using the mathematical expression as given by Anibude *et al.*, (2016).

$$\text{Ar} = \frac{Q(l)}{A\ (ha)}\ l/ha \tag{3.19}$$

Where,

Ar = Application rate

Q = Volume sprayed

A =Area covered

Field efficiency is the ratio of the effective field capacity to theoretical field capacity. Field efficiency of the sprayer was calculated as in Sanchavat *et al.,* (2017).

$$\boldsymbol{FE}\ \% = \frac{\boldsymbol{EFC}}{\boldsymbol{TFC}}\ \% \tag{3.20}$$

Where,

FC= Field efficiency (%),

EFC = Effective field capacity (ha/h)

TFC = Theoretical field capacity (ha/h)

3.10 Cost Estimation of the Sprayer Prototype

The cost of the machine is one million five hundred and three thousand two hundred naira (₦1,503,200:00) as listed in Table 3.5.

Table 3.5: Cost Estimate for Production of the Machine

Sr. No.	Name of Component	Number	Unit Cost(₦:K)	Cost (₦:K)
	Bought Materials			
1.	Impact nozzles	5	500	2,500:00
2.	Connection hoses, strainers, bolts and nuts		15,000	15,000:00
3.	Daihatsu Hijet mini-truck	1		800,000:00
4.	Pulleys	4	5,000	20,000:00
5.	Chemical tank (100 liters)	1	8,500	8,500:00
6.	Chemical (Glyphosate)	2 bottles		3,000:00
7.	Gear Reducer	1	50,000	50,000:00
8.	Pump	1	35,000	35,000:00
9.	Intermediate gearbox	1	15,000	15,000:00
10.	V-belts	4	550	2,200:00
11.	Universal joints	4	3,000	12,000:00
	Constructed Materials			
12.	Steel wheels	4	35,000	140,000.00
13.	Iron sections for frame reinforcement			15,000:00
14.	Consumable tools			25,000:00
15.	Cost of Labour			300,000.00
16.	Transportations			60,000:00
		Total		₦1,503,200:00

CHAPTER FOUR

RESULTS AND DISCUSSION

The results of this project are discussed under the following headings:

i. Presentation of the developed Self-propelled herbicide boom sprayer.
ii. Laboratory performance evaluation of the Self-propelled herbicide boom sprayer.
iii. Field performance evaluation of the Self-propelled herbicide boom sprayer.

4.1 Presentation of the developed Self-propelled herbicide boom sprayer.

The developed Self-propelled herbicide boom sprayer is shown in Plate 4.1. The *Daihatsu Hijet* mini-truck is shown modified with the rear chassis carrying the spray pump, chemical tank and other spraying appurtenances.

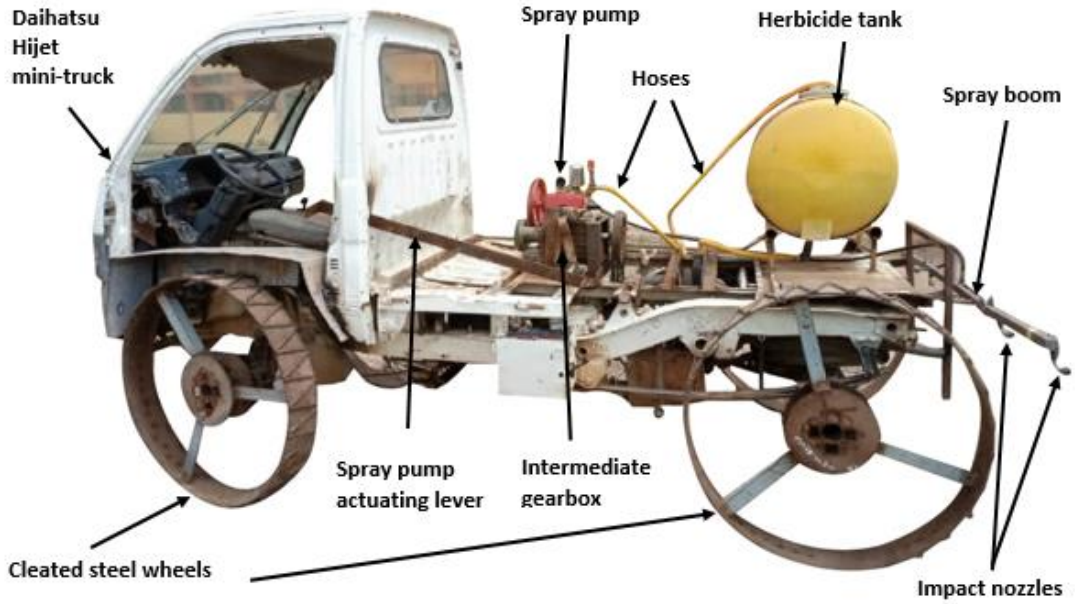


Plate 4.1: Self-propelled herbicide boom sprayer

The boom with nozzles is seen held on its attachment affixed at the rear end of the chassis. The tyres were replaced with large wheels to increase the ground clearance to enable spraying post emergence herbicide when the crops are grown. The intermediate gearbox which receives motion from the *Daihatsu Hijet* mini-truck gearbox and transmits to the spray pump

is also indicated. The machine has the spray pump actuating lever positioned into the driver's cabin to enable engaging and disengaging the spray pump with ease. The machine's pertinent specifications are given in Table 4.1.

Table 4.1: Self-propelled Herbicide Boom Sprayer Specifications

Engine power:	32.25 kW
Track	150 cm
Pump	1.5 kW
Ground clearance	35.56 cm
Transmission ratio	300:1
Wheel diameter:	90 cm
Boom width	200 cm
No. of Nozzles	5

4.2 Principles of Operation

To operate of the sprayer, the sprayer is first calibrated using water as liquid and the usual format to allow the application of the correct volume rate per hectare. The template for the calibration of the boom sprayer is attached as Appendix 5. Then the herbicide tank is filled manually with the proper mix of glyphosate herbicide or any herbicide of choice. The sprayer is designed to apply both pre-emergence and post emergence herbicides. The boom is provided with height adjustment attachment to enable the raising and lowering of the nozzles height above target variously during pre-emergence or post-emergence applications. The boom is set at the choice height above target while the gear selector is put to the speed of choice with the left foot pressing the clutch. The engine is started and the pump is actuated as the clutch is released. A hand throttle is provided to help maintain constant forward speed during spraying.

4.3 Laboratory performance evaluation of the medium scale Self-propelled herbicide boom sprayer

Table 4.2 is the laboratory experimental results. The Table depicts values of flow rate, patternator readings for the flow volume distribution pattern, droplet size and swath for each of the experiments at the three pumping pressures: (100 kPa, 2000 kPa, and 300 kPa), and at the three heights of nozzles above target: (30 cm, 45 cm, and 60 cm).

Table 4.2: Laboratory Experimental Results

No.	Height of nozzles above target (cm).	Pump pressure (kPa)	Coefficient of variation (COVs %)	Flow rate (L/min)	Swath (m)	Droplet size (µm VMD)
1	30	100	30.6708	7583	3.5	400
2	30	100	29.3663	13600	3.6	400
3	30	100	30.1172	17500	3.7	400
4	30	200	27.1254	7583	4	250
5	30	200	27.6271	13600	4.1	250
6	30	200	26.734	17500	4.2	250
7	30	300	23.8893	7583	4.4	200
8	30	300	23.8912	13600	4.5	200
9	30	300	23.7168	17500	4.6	200
10	45	100	15.2579	7582	3.6	400
11	45	100	15.4206	13601	3.7	400
12	45	100	15.2112	17501	3.9	400
13	45	200	15.6853	7584	4.4	250
14	45	200	15.94	13601	4.5	250
15	45	200	15.65	17501	4.6	250
16	45	300	15.915	7584	4.9	200
17	45	300	15.2777	13601	5.2	200
18	45	300	15.2978	17501	5.2	200
19	60	100	16.3421	7582	3.5	400
20	60	100	16.7142	13602	3.7	400
21	60	100	16.4685	17502	3.8	400
22	60	200	28.8026	7582	4	250
23	60	200	28.7281	13602	4.1	250
24	60	200	28.022	17502	4.3	250
25	60	300	30.2728	7581	4.8	200
26	60	300	30.4054	13602	5	200
27	60	300	30.4326	17502	5.1	200

The calculated averages of the volumes collected in the tubes during the twenty seven experiments as well as the standard deviation and coefficient of variation (COV %) as processed using MS excel software 2013 and presented in Appendix 1. Appendix 2 and Appendix 3 are respectively the column chart and graphical presentation of the COVs % of the spray volume distribution. Appendix 4 is the histogram of the COVs %. Analysis of variance (ANOVA) with Duncan multiple range test (DMRT) processed through Statistical analysis software (SAS), on the experimental results enabled the determination of the spray characteristics of the prototype, with regard to flow rate, spray volume distribution pattern, droplet size and swath at the various heights of nozzles above target and pumping pressure settings.

The ANOVA/DMRT printout of the flow rate, COVs of the spray volume distribution pattern, droplet size and swath are attached as Appendices 6, 7, 8 and 9 respectively. The results of these four pertinent spray perimeters determined by the laboratory evaluation namely: Flow rate, spray volume distribution pattern, droplet size range and swath, are discussed hereunder.

4.3.1 Flow Rate

The flow rates of the Prototype sprayer at three heights of nozzles above target and three pressures are presented in Table 4.3. The upper section of the table displays results for height variations, while the lower section displays the results for pressure variations. The variation of height at different levels did not produce any significant difference with respect to flow rate of the self-propelled herbicide boom sprayer. However, variations in pressure significantly affect the flow rate of the Self-propelled herbicide boom sprayer. Increase in the

pumping pressure results in increase in the flow rate. Linear regression analysis of the effect of variation in pressure on flow rate is shown in Figure 4.2.

Table 4.3: Flow Rates of the Herbicide Boom Sprayer at three Nozzle heights above target and three pressures

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.

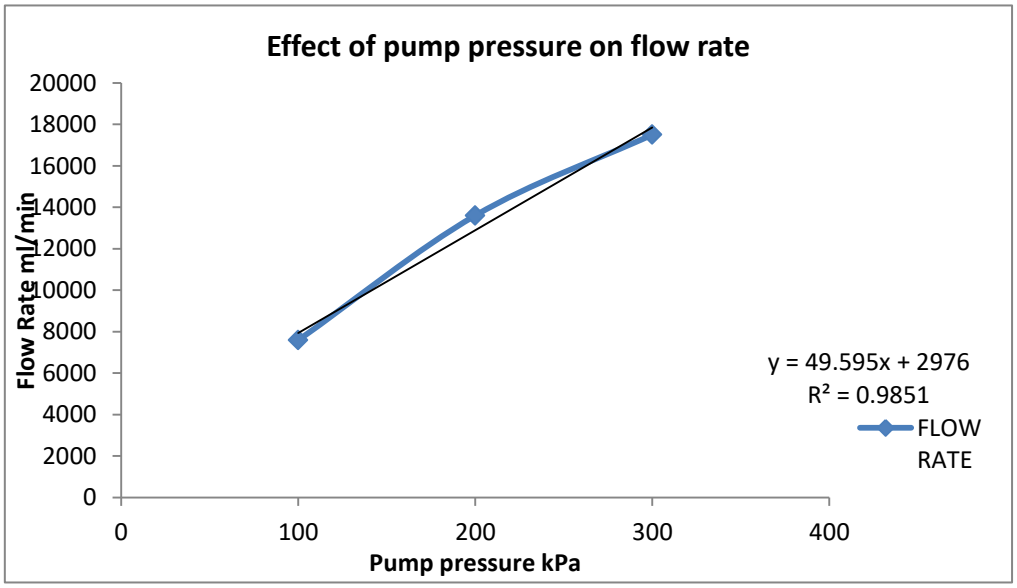


Figure 4.1: Effect of pump pressure on flow rate

Figure 4.1 shows that the effect of pump pressure on the flow rate is a near linear relationship which can be represented by a linear regression model equation. Increase in pump pressure is

proportional to increase in flow rate. Thus, at the recommended pump pressure for herbicide application small quantity of diluent would be required.

4.3.2 Spray Volume Distribution Pattern

The Coefficient of variation (COV %) for the Spray volume distribution pattern at the three heights of nozzles above target and pressures of 100 kPa, 200 kPa and 300 kPa are depicted in Tables 4.3a, 4.3b and 4.3c, respectively.

Table 4.4a: The COV % for the spray volume distribution pattern of the boom sprayer at the three heights of nozzles above target and 100 kPa pressures

Treatment	Coefficient of variation (COV %)
Pressure (kPa) /Height (cm)	
P100+H30 cm	30.05a
P100+H45 cm	15.13c
P100+H60 cm	16.49b
SE±	0.270

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

Table 4.4b: The COV % for the spray volume distribution pattern of the boom sprayer at the three heights of nozzles above target and 200 kPa pressures

Treatment	Coefficient of variation (COV %)
Pressure (kPa) /Height (cm)	
P200+H30 cm	37.33a
P200+H45 cm	15.32c
P200+H60 cm	27.14b
SE±	0.617

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

The different coefficient of variations (COVs) at the various heights show that varying the height above target at different levels on the Self-propelled herbicide boom sprayer significantly affects the spray volume distribution pattern of the self-propelled herbicide

sprayer. It can be noticed that pressure variations do not affect the spray volume distribution pattern of the prototype sprayer.

Table 4.4c: The COV % for the spray volume distribution pattern of the boom sprayer at the three heights of nozzles above target and 300 kPa pressures

Treatment	Coefficient of variation (COV %)
Pressure (kPa) /Height (cm)	
P300+H30 cm	30.39a
P300+H45 cm	15.26b
P300+H60 cm	30.39a
SE±	0.141

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

The linear regression analysis of the effect of height of nozzle above target on the spray volume distribution pattern at 100 kPa, 200 kPa and 300 kPa are depicted in Figure 4.2a, 4.2b and 4.2c respectively.

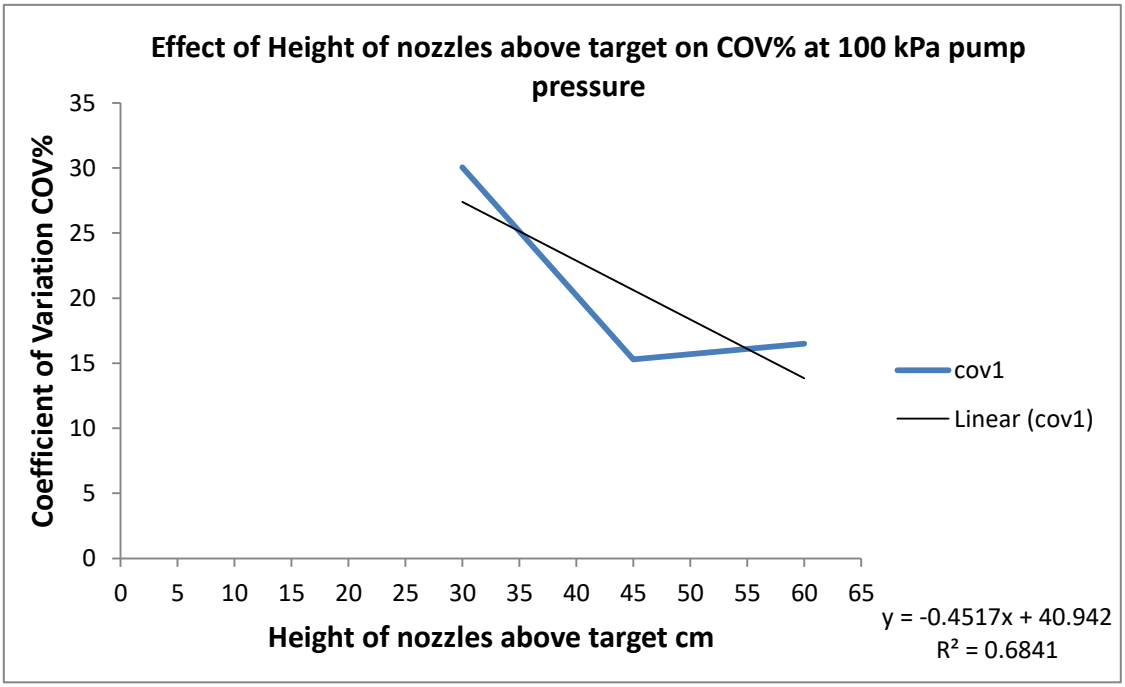


Figure 4.2a: Effect of height of nozzles above target on COV% at 100 kPa pump pressure

The height of nozzles above target play very important role in spray volume distribution of the spray boom. If the boom height is lower than the optimum height above target, uneven spray dispersion can occur. A lower boom will prevent proper overlap or even cause a complete lack of application. These cases are problematic because weeds can develop resistance to herbicides when they receive sub-lethal doses. In the area directly under the nozzle, severe over application can occur, which results in wasted product and is environmentally harmful to the crop. Also, if the height of the boom above target is higher than the optimum height, droplet drift can increase. This would result in application to areas that was not intended to be treated and under dozing of targeted areas as much herbicide would be lost to drift. Hence the need to ascertain the optimum height and pumping pressure for the most uniform spray volume distribution.

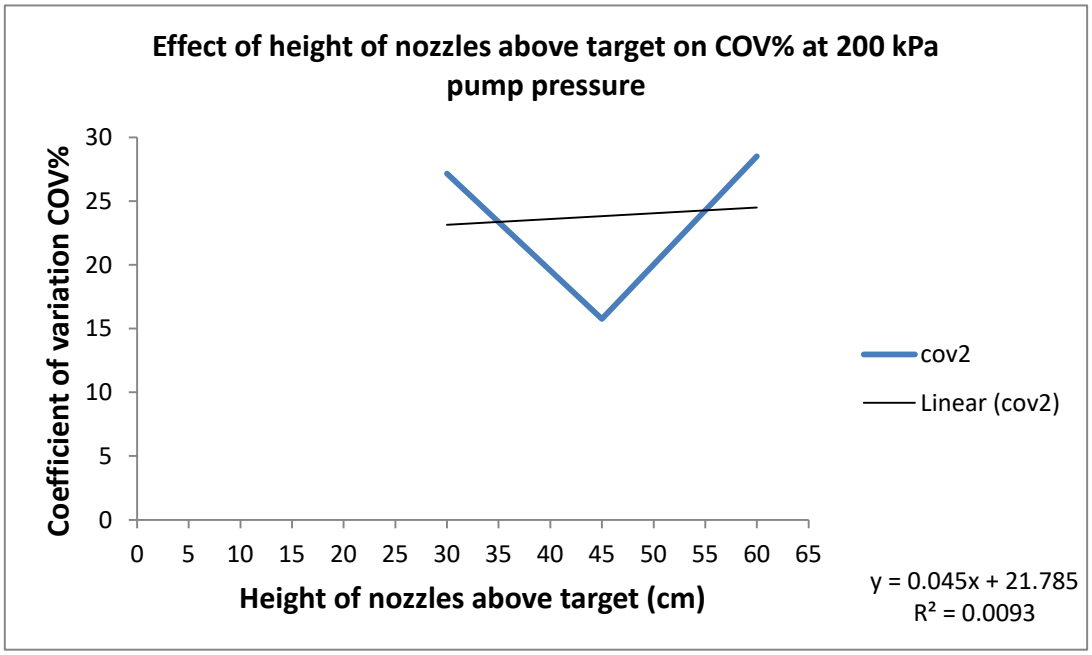


Figure 4.2b: Effect of height of nozzles above target on COV% at 200 kPa pump pressure

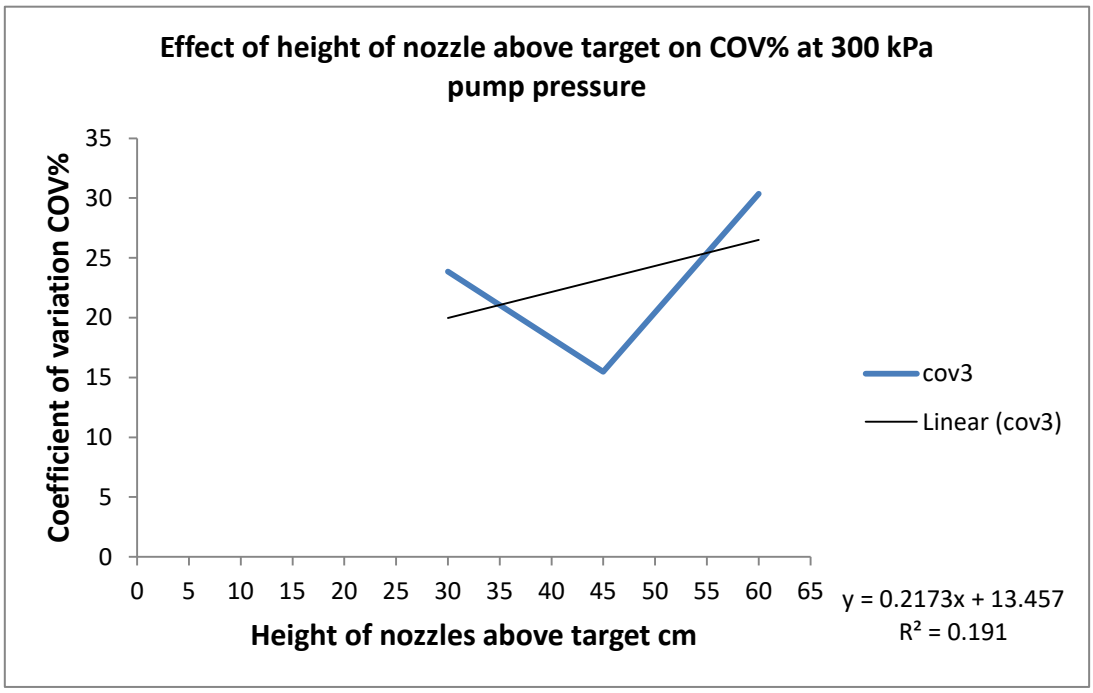


Figure 4.2c: Effect of height of nozzles above target on COV% at 300 kPa pump pressure

Tables 4.4a shows high coefficient of variation COV% at 30 cm height of nozzle above target while the COV% at heights of 45 cm and 60 cm were low meaning that application at 100 kPa pressure can be expected to be fairly uniform at heights of nozzles above target of 45 cm and 60 cm but irregular at height of nozzle above target of 30 cm. Table 4.4b at pumping pressure of 200 kPa depicts large COV% at both heights of nozzles above target of 30 cm and 60 cm. The least COV% is recorded at 45 cm height of nozzle above target. The same behaviour is depicted at Table 4.4c pumping pressure of 300k. The least COV% is recorded at height of nozzle above target of 45 cm. For the three pressures, the COV% remained close and low at height of nozzles above target of 45 cm. The least COV of 15.13 % is achieved at speed of 3.2 km/h corresponding to pressure of 100 kPa which is the rated pressure for impact nozzles (Jones 2006). Hence, spraying at forward speed of 3.2 km/h and 100 kPa pressure assuredly ensures the most uniform deposition when the height above target is 45 cm.

The linear regression analysis shown in Figure 4.2a, Figure 4.2b and Figure 4.2c confirm the above inference. Figure 4.2a shows that the point with the lowest COV% when spraying at 100 kPa is 45 cm mark. For heights below 45 cm, the COV% increases steeply while heights above 45 cm depicts gradual increase in COV%. Similarly, Figure 4.2b depicts that when spraying at 200 kPa, the effect of height of nozzle above target and COV% is not linear and that heights below and above 45 cm record higher COV% than the 45 cm height. Steep increases of COV% are marked at heights below 45 cm and heights above 45 cm. Also, when spraying at 300 kPa the 45 cm height is the height with the least COV%. The relationship is not linear and heights above 45 cm register steeper increases in COV% than heights of nozzles below 45 cm. The 45 cm height of nozzles above target is the optimum height to achieve uniform deposition of herbicide on soil and foliage.

4.3.3 Droplet Size

The mean droplet spectrum of the sprayer at three heights of nozzles above target and three pressures are presented in Table 4.5. The upper section of the table displays results for height variations, while the lower section displays the results for pressure variations. Spraying at the heights of 30 cm, 45 cm and 60 cm respectively does not show any significant difference on droplet size range 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 size range. The sprayer produces choice range for herbicide application of about 300 - 400 µm VMD; at the pressure of 100 kPa It is followed by 200 kPa while 300 kPa significantly produced the least droplet size range (200-250 µm VMD). The linear regression graph presented in Figure 4.3.

Table 4.5: Droplet spectrum of the boom sprayer at three nozzle heights above target and three pumping pressures

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.

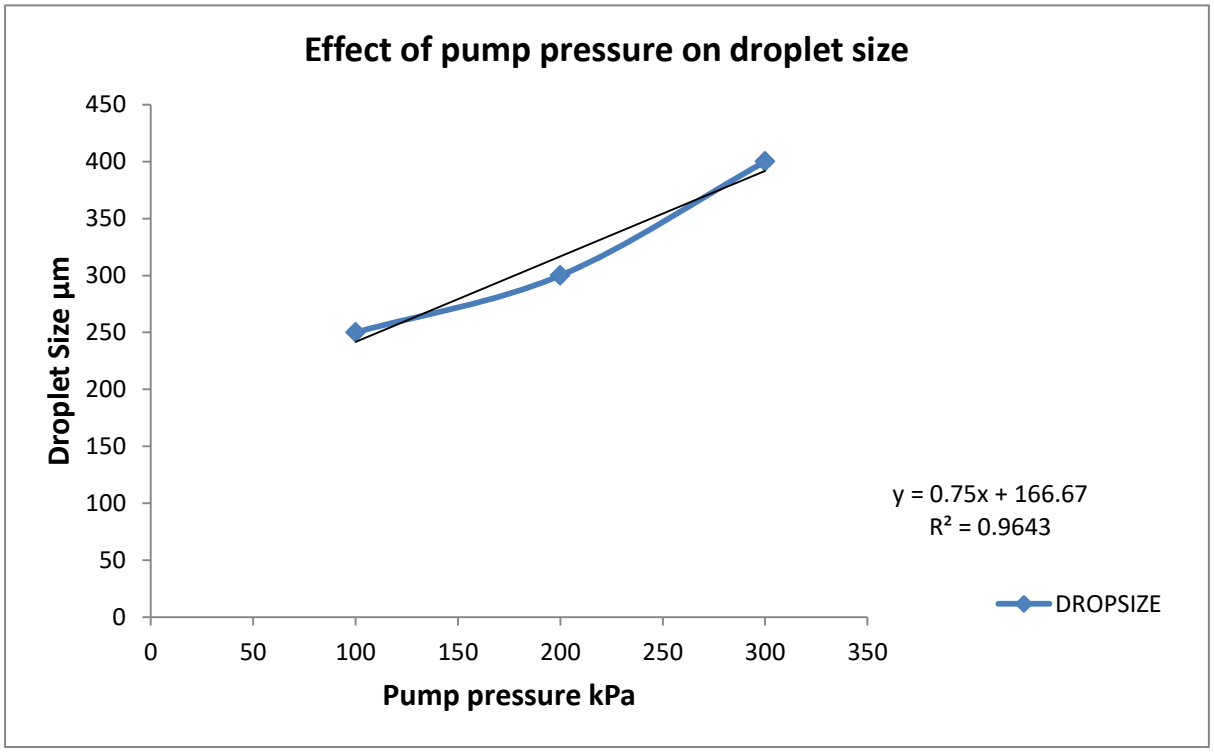


Figure 4.3: Effect of pump pressure on droplet size

The figure shows that the effect of pump pressure on droplet size is a near relationship which can be represented by a linear regression model equation. The pump pressure is directly proportional to the droplet size. The lower the pump pressure, the smaller the droplet size.

The self-propelled sprayer produces coarse droplets suitable for herbicide application at pump pressure of 100 kPa as recommended by Jones (1990) for impact nozzles.

4.3.4 Swath

Table 4.6 shows the effect of height above target and pressure on swath of self-propelled herbicide boom sprayer. 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.

Table 4.6: Swath of the boom sprayer at three nozzle heights above target and three pumping pressures

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.

Applying pressure at 300 kPa significantly produced the highest swath followed by the application rate of 200 kPa while the application of pressure at 100 kPa produced the least

swath of the self-propelled herbicide boom sprayer. 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. Figure 4.4 and figure 4.5 linear regression curves showing the Effect of pressure on swath and the effect of height of nozzles above target on swath respectively.

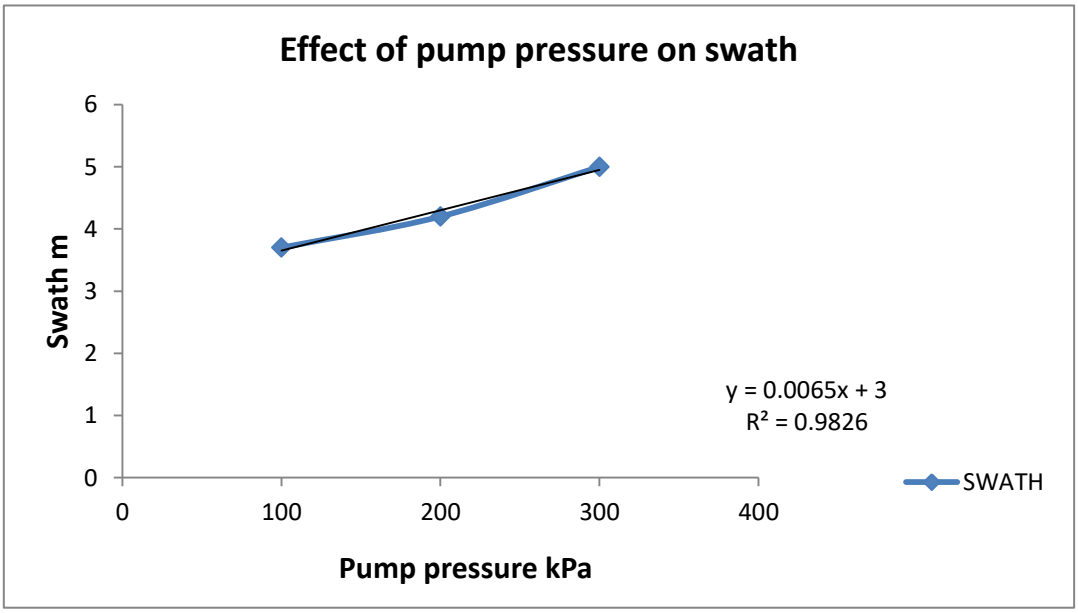


Figure 4.4: Effect of pump pressure on swath

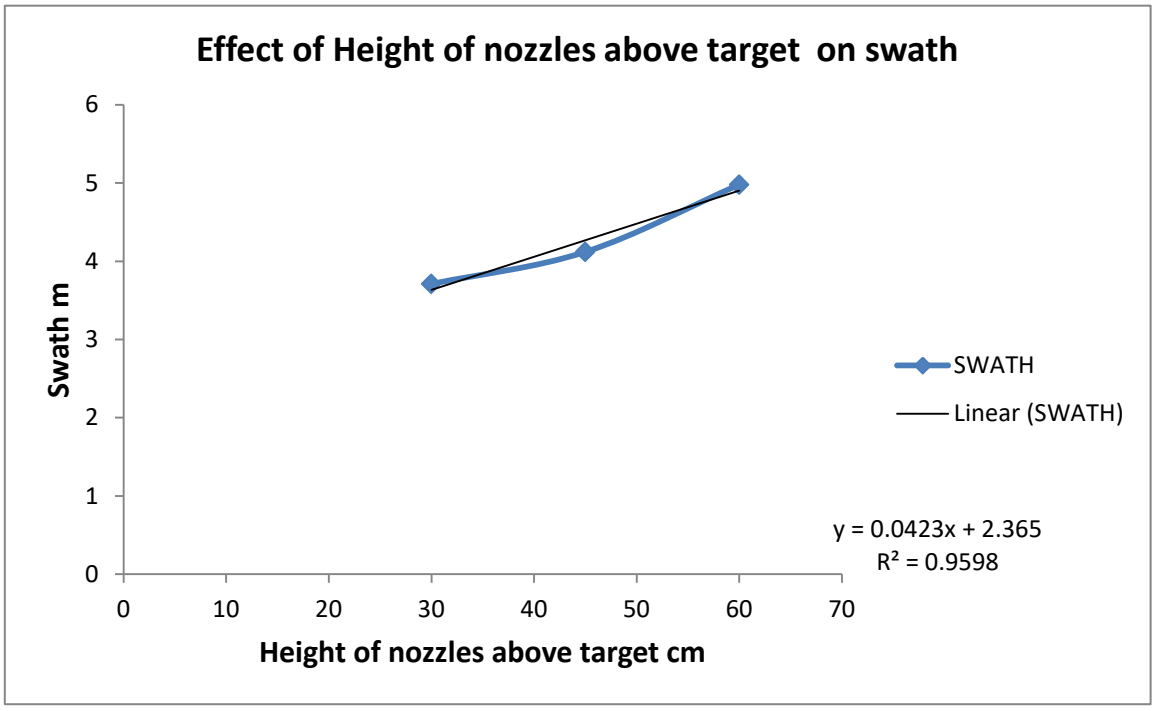


Figure 4.5: Effect of height of nozzles above target on swath

Linear regression depicts that effect of pressure on swath and effect of height of nozzles above target are both linear and can each be represented by linear regression model equations. Thus, the greater the pressure, the greater the swath. Similarly, higher height of nozzle above target will engender bigger swath and vice versa. At the optimum performance setting of 45 cm height and 100 kPa pressure, the machine achieves a swath width of 4.1 m.

4.4 Field Performance Evaluation of the Self-propelled Cost-Effective Herbicide Boom Sprayer prototype.

Field results for the Effective field capacity (EFC), Application rate (A_r) and Field efficiency (FC) of the sprayer performed at 45 cm height of nozzle above target and at the three speeds: 3.2 km/h, 6.12 km/h and 7.24 km/h, are presented in table 4.7. Effective field capacity at 100 kPa corresponding to 3.2 km/hr speed is very poor compared to the theoretical field capacity. This is as a result of the small steering turning angle of the *Daihatsu Hijet* mini truck. Much

time is spent to turn and spray fresh field when it reaches the end of the field. The turning angle should be improved before deployment.

Table 4.7: Field evaluation results at 45 cm height of nozzles above target

Speed (km/h)	Area sprayed (ha).	Mean Volume sprayed (liters)	Time (min)	Mean App. Rate (l/ha)	TFC (ha/h)	EFC (ha/h)	FE (%)
3.2	0.032	37	6.41	1,156	0.64	0.3	47
6.12	0.032	39.2	5.04	1,225	"	0.38	59
7.24	0.032	52	4.45	1,625	"	0.43	67

It can be seen that the Field Efficiencies at 3.2 km/h and 6.12 km/h; corresponding to pressures of 100 kPa and 200 kPa respectively are poor. At 7.2 km/h, which corresponds to pump pressure of 300 kPa, the Field Efficiency is better. The only flaw noticed during the field evaluation has to do with the steering. The turning angle was discovered to be small and as such delayed turning to engage fresh area each time it reached the end of the field. This resulted in poor effective field capacity.

4.5: Comparison with Tractor mounted and Self-propelled Boom Sprayers

Effective Field capacity of 3.83 ha/h is reported for herbicide application employing tractor boom sprayer in maize silage operation with a boom of length 10.7 m and at the speed of 5.4 km/hr (Romanelli and Milan, 2012). Jayashree and Krishnan, (2012) reports effective field capacity of 4.25 ha/hr at a speed of 8 km/hr with a boom of length 8.5 m of a self-propelled boom sprayer. The effective field capacities of this study with a boom of length 2 m and at speeds 3.2 km/hr, 6.12 km/hr and 7.24 km/hr are respectively: 0.3 ha/h, 0.38 ha/hr and 0.43 ha/h. The effective field capacities are clearly very small pointing to the need to improve the boom width to achieve realistic effective field capacities at the various speeds.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary

A self-propelled boom sprayer for small and medium scale herbicide application was developed. A *Daihatsu Hijet* mini truck was employed as the prime mover and housing for the machine components. Power was tapped from the *Daihatsu Hijet* mini truck engine to achieve sprayer mobility and also power the spray pump. The machine was evaluated both in the laboratory and in the field. During laboratory evaluation two factors, the height of nozzles above target and the pumping pressure which influenced spray parameters were varied at three levels each, while the spray parameters of flow rate, spray volume distribution pattern, droplet size and swath were determined. Analysis of variance (ANOVA) and DUCAN multiple range tests were performed on the results using Statistical Analysis software (SAS). Also linear regression analysis were employed to further understand the results. Laboratory analysis showed the height of nozzle above target to achieve uniform herbicide deposition is 45 cm. It also indicated the pressure of 100 kPa as the pressure to produce herbicide droplets between 300 – 400 VMD suitable for weed control on soil and foliage. Field evaluation was also carried out with the boom set at 45 cm height of nozzles above target while the Application rates and Effective field capacities at the various speeds were determined. Maximum Application Rate, Effective Field Capacity and Field Efficiency are respectively 1,625 l/ha, 0.43 ha/h and 67%. The least Application Rate, Effective Field Capacity and Field Efficiency are respectively 1,156 l/ha, 0.3 ha/h and 67%.

5.2 Conclusion

i. The components of a Self-propelled herbicide boom sprayer for small and medium scale herbicide application in Nigeria were designed, selected and procured.

ii. The machine was constructed using locally available components and materials.

iii. Laboratory and field evaluation of the machine were successfully carried out.

iv. Results of the laboratory evaluation were processed with Analysis of Variance (ANOVA) and DUNCAN multiple range test using Statistical analysis Software (SAS). Linear regression analysis on the results was also performed using MS Excel 2010.

5.3 Recommendations for future studies

i. The small steering turning angle should be improved upon to enhance the Effective field capacity.

ii. Also, the Swath and Effective Field Capacity can be enhanced by increasing the length of the boom thereby accommodating more nozzles and increasing coverage.

iii. The herbicide Sprayer can be modified for fungicide and insecticide application by changing the nozzles to cone and fan nozzles respectively. In this respect, the speed of the pump can be increased to achieve higher pump pressure required.

iv. Also a lower ratio gear reducer can be employed to increase field speed in the case fungicide and insecticide application.

v. Bigger chemical tank can be installed if the vehicle chassis is strengthened within the capacity of the engine power to counter the rolling resistance.

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