

## Design and Development of Animal Drawn Ground Metered Axle Mechanism Boom Sprayer

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### ABSTRACT

A spraying technology was developed for use by rural farmers in Northern Nigeria. The farming systems in these areas are put into consideration and in keeping with appropriate technology initiative. The technology was designed to offer the farmers an equitable sprayer that shall be drawn by animal farm power and that is effective and affordable.

The equipment was constructed using the parameters obtained from design and tested at a farmland within the University premises of Ahmadu Bello University, Zaria, in Nigeria. The equipment consists of a boom with multiple Controlled Droplet Applicator (CDA) atomizer nozzles, a gear pump, a chemical tank, and chair for an operator; all attached to a framework bolted to a rear axle. It was observed that the Dynamic Wheel Load assuming even distribution of load was found to be 1575N and a net pull of 820N. The net pull offers convenient task and shall easily swallow energy requirement for spraying uphill terrains.

**KEY WORDS:** spray technology, pesticide sprayer, animal traction, tractor.

### I. INTRODUCTION

Technology development and assimilation should be run along the sides of the socio-economic and cultural enlightenment of the intended users of the technology individually and collectively. This is so since sustainable technology must have the properties for easy transfer from generation to generation. The utility value of the tractor is tremendous. Notwithstanding, its usage, application, adaptability, and assimilation in this part of the world has become almost impossible. It simply does not match the people and their social and economic environment. In the first place the equipment requires much skill to operate. Tractors, spares and implements require scarce foreign exchange and as a result their prices have risen greatly in Nigeria and in many other developing countries. This effectively makes tractor hire or ownership beyond the reach of peasant farmers (Gefu et al 2011). It is thus very difficult for tractor farming to be wholesomely employed and assimilated in our areas of concern.

On the other hand, animal traction is advantageous due to its low cost, its availability (as the crop farmers also engage in animal husbandry); its low skill requirement, adaptability and cultural acceptance. Despite these advantages, very limited use is made of animal traction and mostly for tillage

operations and transportations only. The craze for high technology without proper evaluation of the benefits leads many into tractor farming. Few successes are recorded. Most soon find the demands of tractor running beyond their means and then fall back to hoe farming with the resultant poor capacity and yield. The cost of Tractor boom sprayers is outrageous and the maintenance cost very high. This leaves our farmers no other choice other than to rely on human powered knapsack sprayers which have their own attendant drudgery and low coverage, making spraying a very difficult task. The need for increased employment of affordable farm power for spraying cannot be overemphasized and informs the desire of this work to create an affordable high coverage pesticide sprayer to be drawn by farm animals for use mainly in the North of the country where animal traction is common practice.

Weeds are the second most significant agricultural problem, second only to soil erosion. The fact is that growers must control weeds or they will suffer crop loss. There are over 30,000 weed species throughout the world and over 4,800 of these cause significant economic losses in production of food, feed, and fiber (Howard 2009). Other pests also take their turn leaving the farmer with little gain for all his toil. Chemical application has been very successful in pest

control but must be applied in rationed proportions and spray characteristics. Specialized equipment is thus essential. In fact chemical application is the only fully mechanized farming operation. Machines hitherto developed for chemical application include the knapsack sprayers, the ultra-low volume sprayers and tractor boom sprayers.

The knapsack sprayers and the Ultra-Low Volume (ULV) sprayers though successful have their limitations. Apart from the human fatigue which leads to unsteady walking steps, their field capacities are small. They barely cover about 0.2 hectare per hour. Their small swath implies that a sizeable farm would take several days to cover. Weather changes are erratic and often it is desired to spray a large farm within hours or few days for even effect, uniformity and to avoid adverse weather interference. It is also often required that a large farm be covered within a short period to avoid re-emergence of weeds before crop emergence. Deployment of many human powered knapsack operators to large farms has not been successful. Large farm spraying require boom equipment with larger swath. Reduced error in swath overlaps and spraying within the shortest possible time are then assured.

Tractor boom sprayer is a possible solution but it has become very difficult for farmers in these areas to easily engage tractors for the more laborious jobs of tilling to the extent that they would avoid tinkering with the thought of engaging tractor boom equipment for spraying. The cost of tractor hire is very high and beyond the reach of the average farmer. Farmers, who could afford tractors, find it difficult to access attachment boom spraying equipment. And when they possibly do, spare parts, maintenance and calibrations still pose insurmountable problems. It is also uneconomical to deploy a tractor for small farm operations. 50 hectares is the minimum farm size for economic tractor deployment. (Takeshima and Salau 2010). Thus a gap exists between the very small scale farms suited for knapsack and ULV deployment and the tractor boom spraying suitable for large scale farming. These problems shall continue until and unless this project is achieved to bridge this gap and ease spraying at all levels.

Nozzles are the most important components of sprayers because they are directly related to droplet size, distribution uniformity, and the spray volume. The spraying of pesticides is usually made with the help of hydraulic nozzles, although this type of nozzle produces droplets of variable size. On the other hand, new technologies which use smaller spray volumes and nozzles with the centrifugal energy are introduced. These are nozzles capable to deliver more uniformly sized droplets with a better coverage of the plant and thus better results. A few studies have already indicated that the centrifugal energy nozzles are more efficient in producing more

uniformly sized droplets. The centrifugal energy nozzles are part of the so called CDA (Controlled Droplet Applications) systems. According to Combellack and Harris, (1978), CDA enables the production and application of droplets of adequate sizes with small variation in their size, independently of the equipment and application volume. (Costa et al 2013). Controlled Droplet Application (CDA) equipment uses spinning disk to atomize chemical and offers better control in the production of spray droplets which sizes emerge uniformly more than those of hydraulic energy sprayers. The advantages of CDA are incorporated in this project to give a better deposition of more uniformly sized droplets

It is contrived that when multiple CDA nozzles are arranged on a boom and drawn by work animals, even as they are actuated by the animal traction through the axle, the coverage becomes tremendous with better even spraying occasioned by the employment of CDA atomizers. This is conspicuously a very appropriate crop protection machine for Nigerian farmers especially in the North where animal utilization for farming operations is common.

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:

- (a) **Power Source:** Animal traction is a predominant farming culture in this part of the country. It is extensively employed for tillage and transportation operations. Development and utilization of animal drawn sprayer maximizes the use of the animals.
- (b) **Solution Provided:** Farming in our mandate areas is currently on the low and medium scales. Tractor boom sprayers are for very large scale farms while human powered knapsack and ULV are for very low scale farms. Current practice where many human powered knapsack sprayers are deployed is saddled with attendant difficulties. This project is the much needed crop protection solution in Nigeria.
- (c) **Skill, Adaptability and Availability:** The skill requirement is low, making it possible for use by virtually all cadres of farmers. The adaptability is far greater than that of other spraying equipment. Availability is also assured since the technology is indigenous.
- (d) **Capacity:** The capacity weighs favourably to that of the tractor (as it can be constructed to carry as many CDA nozzles as desired to give the same swath as that of the tractor), and far greater swath than those of human powered Knapsack and ULV sprayers.
- (e) **Efficiency and Economy Of Scale:** The efficiency of boom spraying over that of single

nozzle spraying and the versatility of employing lever operated CDA applicator or hydraulic pressure oriented knapsack sprayers as desired is tremendous gain.

- (f) **Gains in Foreign Reserve:** The only alternative spraying equipment is the tractor boom sprayer which is imported at huge costs. The development of this equipment means a savings in the cost of importation of alternative machinery and of fuel and spare parts leading to great savings in foreign reserve.

## II. LITERATURE REVIEW

### 2.1. Animal Farm Power

Since the early 1970s, efforts have been mustered mainly towards tractorization. It is however evident that this has not yielded the expected results for a number of reasons including (a): Lack of skilled operators and maintenance personal (b): Lack of suitable implement and spare parts (c): Farm land fragmentations and (d): Increase in the cost of tractors and implement. (Gwani 1988).

The minimum and maximum animal speeds of 2.4km/hr (0.67m/s) and 4km/hr (1.1m/s) or average animal speed of 0.7m/s; and draft of 500-600N for one cow are generally accepted. (Sims and O'neil 2002; Goe & Mcdowell 1980).

The immediate alternative to tractorization is animal power. This source of power supplied by work oxen, donkeys and sometimes horses, has been very important in the northern parts of Nigeria which is free of tsetse fly and has light soils. The use of animal draft force was first demonstrated in Nigeria in Daura in the present Kastina State of Nigeria in 1922, (Gwani 1988); and since then has been the dominant farm power source next to human labour employed for farming in Northern Nigeria.

In the early 1960s, an ox-drawn ground wheel-driven piston pump sprayer was developed at the Gatooma Research station in Zimbabwe. Limited numbers were manufactured in Zimbabwe and also in South Africa, by one Henry Plenn of Nogel district. The sprayer however proved cumbersome and unmanageable in wet weather and was discarded. Instead a scotch cart was arranged to carry a human powered knapsack sprayer. Simultaneously and also in Zimbabwe, Taurus spraying systems of Harari developed an Animal – drawn Ground wheel powered boom sprayer called Pedze Nhuma. (Fowler 2000).

Chouldhury, et al (1981) developed a Ground-metered shrouded disc herbicide applicator (GMSD), which is a CDA spinning disc manually operated herbicide sprayer based on very low volume (VLV) spraying system. Essentially it consists of a spray head, which is a spinning disc shrouded at an angle of  $180^{\circ}$ , mounted on a stand such that its position above

the ground is adjustable. The spinning disc is driven by a 12V electric motor governed to rotate the disc at 1800-2000rpm. The tank is connected to the spray head by delivery tubes passing through a peristaltic pump operated by the ground wheel. As the operator pulls the machine behind him, a roller presses the flexible spray delivery tube against the fixed pump wheel and liquid is forced through the tube to the spinning disc which atomizes it into droplets. The rate of pumping of spray liquid to the centre of the disc is directly proportional to the walking speed of the operator. The work attempted to improve the spray volume distribution pattern of a conventional CDA herbicide applicator and application rate by employing the principles of disc shrouding and the use of peristaltic pump. (Shani et al 2006)

There was an attempt by Bitrus (1985) to improve the efficiency and capacity of existing manual CDA herbicide applicator technique. The sprayer has a boom of two Micron Herbi (sprayer) spinning shrouded discs of a speed of 1800rpm at 95cm apart and positioned 60cm above the ground. The results obtained based on the laboratory and field investigations gave a coefficient of variation of spray distribution of 34.6% at disc spacing and spinning height of 95cm and 60cm respectively. Imam (1981) also in an attempt to improve the GMSD sprayers obtained a similar result with a swath width of 2.9m and field capacity of 0.84ha/hr. Also Abdul-fatai (1997) developed an animal drawn controlled droplet application ground metered shrouded disc (CDA-GMSD) herbicide sprayer based on very low volume (VLV) system. The sprayer consists of the main frame, ground wheel, peristaltic pump, an 85 liters single tank feeding, 4 spinning discs on a boom length 4.8m, two 6V acid electrolyte batteries to power the discs which rotate at about 1900rpm and atomize the liquid from the tank into droplets. He obtained from laboratory test, an even spray volume distribution with coefficient of variation of 16.9% at nozzle spacing of 120cm and at vertical height of 45cm above the target. Droplet spectrum-volume and number median diameters were 250 $\mu$ m and 225 $\mu$ m respectively with low dispersion ratio of 1:1. Droplet density of 16droplets/cm<sup>2</sup> and calibrated application rate of 4.35L/ha while field performance test gave an application rate of 4.8L/ha with maximum swath of 5.82m at nozzle spacing of 120cm and boom height of 45cm above the target. Field capacity and efficiency were 1.03 ha/hr and 89.6% respectively with slippage of 1.13%. (Shani et al 2006).

Further attempts to develop an animal drawn Ground Metered Shrouded Disc Applicator were fostered by Shani et al (2006) at the *Institute for Agriculture Research (IAR), Ahnadu Bello University, Zaria*. A prototype sprayer was fabricated and tested. Evaluation showed that the set back to the development and proliferation of the equipment is the

difficulty in sourcing suitable peristaltic tube for the construction of the pump. Hence this renewed attempt at evolving a mechanism for ground metering of pesticide.

### III. MATERIALS AND METHOD

The methodology consisted of requisite research by way of review of existing efforts in the sector before the conception which preceded the design. The design was three pronged (a): Spray parameter determination (b): Animal draft estimation and (c): Mobility parameters determination. The equipment was consequently constructed and tested at a farmland within the University premises of Ahmadu Bello University Zaria, on the 6<sup>th</sup> of August, 2014.

### 3.1 Equipment Description

The equipment consists of a boom with multiple Controlled Droplet Applicator (CDA) atomizer nozzles, a gear pump, a chemical tank, and chair for an operator; all attached to a framework bolted to a rear axle. (Fig.1 and Plate 1). The wheels are spaced at 1.5m to pass in-between a specified number of ridges. The boom carrying several CDA atomizers is attached at the rear side of the framework. An attachment for the animal harness is installed at the front of the framework.

The tire motion is transmitted and multiplied by the gear ratio of the differential axle and outputted from the pinion shaft of the differential. An intermediate shaft is installed to accept motion from the pinion flange and drive the gear pump. The pump discharge is divided equally using flow joints and meters flow into the CDA atomizer nozzles.

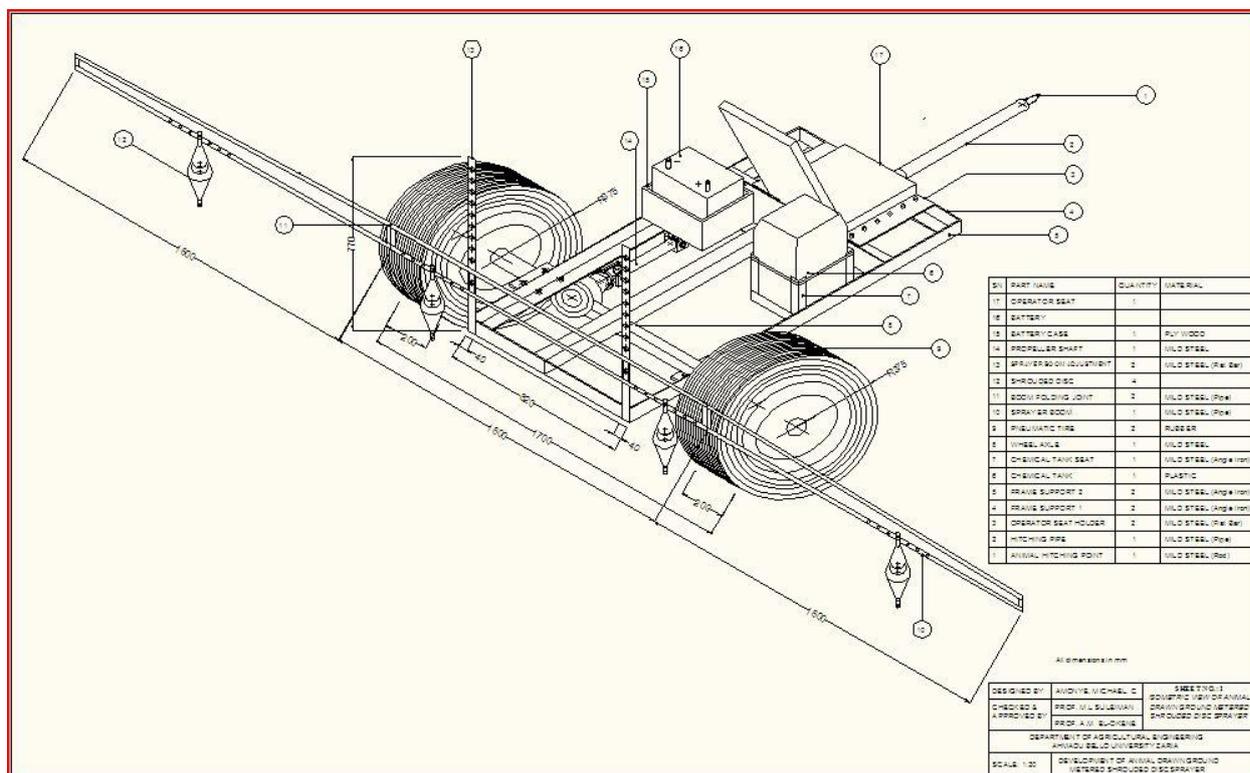


Fig.1 Schematic drawing of the sprayer

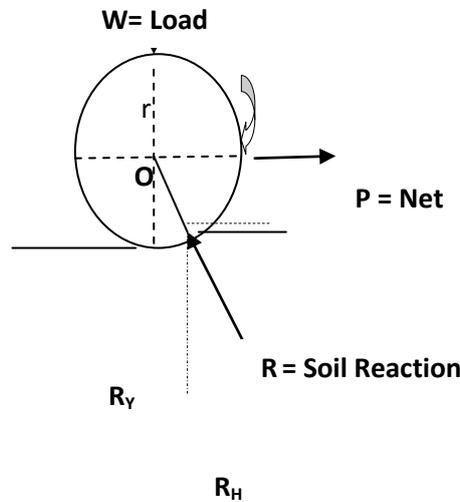
### 3.2 Design procedure

The equipment is constructed as a trailing vehicle on two tires. The weight of the framework, the multiple knapsack sprayers and accessories shall be distributed between the two tires. Equations have been developed to predict the tractive performance of bias ply tires operating on cohesive-frictional soil.

There are two basic types of tire construction, bias ply and radial ply. Bias ply tires are constructed of overlapping crossed layers of cord material and are typically made with nylon, polyester and other materials. The crossed piles run on a diagonal from tire bead to tire bead and comprise a generally stiff sidewall area. Radial ply tires are made with the cord material running in a radial or direct line from bead (at 90 degrees to the centerline of the tire) and are typically made with one steel body ply or multiple plies of other materials. The radial sidewall area is generally less stiff than the bias ply sidewall, though the tread area is normally much stiffer. The bias plies are cheap but of poor traction characteristics than radial ply tires. Prediction of tractive performance for bias ply tires is the worst case scenario. Hence equations developed for bias ply tires shall

conveniently hold true if not improved by the employment of radial ply tires. Given a wheel driven through the soil as shown in **Fig. 2**.

The torque applied to the wheel ( $Q$ ) can be assumed equal to the gross thrust ( $Q/r$ ) acting at an effective moment arm ( $r$ ). Part of the gross thrust is required to overcome motion resistance to the movement of the wheel through the soil. The remainder is equal to the net pull. (**Brixtus 1987**).



**Fig. 2:** Free Body Diagram of a Rolling Wheel

### 3.2.1 Gross Thrust

$$\text{Gross Thrust} = Q/r = \text{Motion Resistance (M)} + \text{Net Pull (P)} \text{ ----- (7.1)}$$

By dividing through by the weight on the wheel ( $W$ ), the following dimensionless equations result:

$$Q/rW = M/W + P/W \text{ ----- (7.2)}$$

Where

$Q/rW$  = Torque Ratio

$M/W$  = Motion Resistance Ratio.

$P/W$  = Pull Ratio. (**Brixtus 1987**).

For a towed wheel, torque is equal to zero which implies that the wheel is not powered. A towed condition occurs when slip is less than zero. (**Brixtus 1987**) An animal drawn wagon moves at the instance and speed of the animal. Figure 2 shows effective forces on a towed wheel. Work on determination of Motion Resistance Ratio or Towed Force of a wheel has been fostered by Wismer and Luth (1974), who evolved the general equation:

$$TF/W = 12/C_n + 0.04 \text{ ----- (7.3)}$$

Where

TF = Towed force (N).

W = Dynamic Wheel Load (N).

$C_n$  = Wheel Numeric. (**Elwaleed and Yahya 1999**).

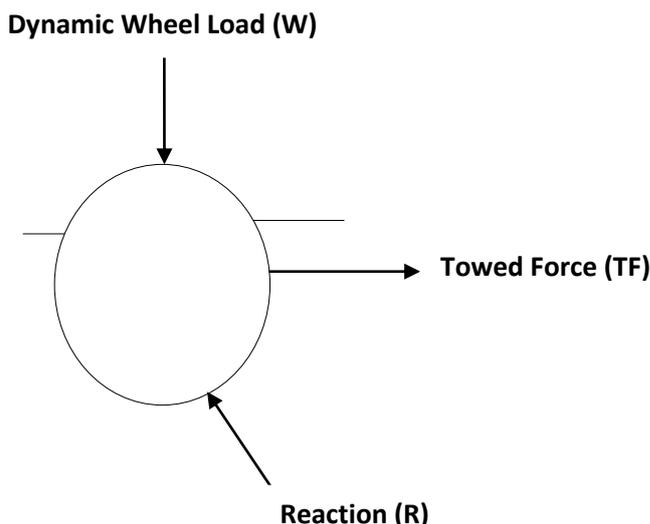


Fig. 3: A towed wheel

Following the shortcomings of the **Wismar and Luth** equation with regard to its applicability to all wheels, **Elwaleed and Yahya 1999** employed regression analysis on Bridgestone bias ply tires to determine the best prediction equation describing the motion resistance ratio. Five general forms of equations were considered in the analysis with the wheel numeric as an independent variable namely: linear, power, exponential, logarithmic and Wismar and Luth models. The logarithmic model was the best to describe the tire motion resistance ratio based on the coefficient of determination. The predicted logarithmic equations in terms of wheel numeric ( $C_n$ ); for 221KPa (32psi); 193KPa (28psi); and 166KPa (24psi) respectively are as follows:

$$TF/W = 0.0682 \ln(1/C_n) + 0.3719 \text{ ----- (7.4)}$$

$$TF/W = 0.0627 \ln(1/C_n) + 0.3443 \text{ ----- (7.5)}$$

$$TF/W = 0.0684 \ln(1/C_n) + 0.3854 \text{ ----- (7.6)}$$

(Elwaleed and Yahya 1999)

$$\text{Wheel Numeric } C_n = \frac{b \times d \times CI}{DWE} \text{ ----- (7.7)}$$

Where  $b$  is the tire width (mm),  $d$  is the tire diameter (mm) and  $CI$  is the Cone Index (MPa). (**Naderi et al 2008**). Values of Cone Index for agricultural drive tires on typical soil surfaces as given by **ASAE STANDARDS D497** are listed in table 1.

**Table 1:** Values of  $CI$  for Agricultural Drive Tires on Typical Soil Surfaces (Source: Asae Standard D497.4 Feb03).

No.	SOIL	CI (KPa)
1.	Hard	1800
2.	Firm	1200
3.	Tilled	900
4.	Soft, sandy	450

### 3.2.2 Component Mass Computation

1. Herbi-4 ----- 4kg.
2. Operator ----- 69kg.
3. Chemical Tank ----- 7.3kg.
4. Liquid Herbicide ----- 48kg.
5. Harness Attachment ----- 8.68kg.
6. Towing Attachment ----- 19.76kg.
7. Chair ----- 3.5kg.
8. Axle ----- 43.42kg.

9. Frame	----- 30.63kg.
10. Pump Pulley	----- 4.68kg.
	<u>Total= 238.97kg.</u>

Add 10% contingent mass for boom, hoses, rollers and incidentals  
 Total load on tires = 302,5 ≈ 303kg.

### 3.2.3 Tires

Tire selection ordinarily is based on the load index of the tire. Load Index is an international numeric code associated with the maximum load a tire can carry at tire speed under specified conditions. The Load Index data shows that four tires of index greater than LI 24 shall conveniently carry the load at normal speed. (SOURCE: Data Book (2006), Off-the Road Tires, Bridgestone Corporation, Toyo, Japan; and Replacement Tire Selection Manual (2006), Bridgestone Firestone North American Tire.)

Available and affordable passenger vehicle tires of Load Index between 74 and 80 assuredly satisfy the load capability requirement. The tires in HUNT D 1995 in Table 5 with designations 6.00-16 and 11.00-15 fall into this group. 6.00 -16 tiers are for light loads. Where heavy wheel loads are involved, HUNT D 1995 recommends the 11.00-15tire for better traction. External diameter of 15inches and 16inches Rims in Data Book 2006 from Bridgestone Corporation are between 22inches and 31inches. Thus average tire diameter equals 26.5inches. The average weight of one whole passenger tire (mass of rim plus cover), is equal to 20lb (9.07kg). (SOURCE: ANNUAL WASTE TIRE TRANSPORT REPORT (2010), Indiana Department of Environmental Management).

Hence total dynamic wheel Load

$$\text{DWL} = 303 + 18.14$$

$$= 321.14 \approx 321\text{kg.}$$

### 7.5: Computation of Motion Resistance

Taking the 6.00-16tire as choice, important parameters are as follows:

$$\text{Width} = b = 6 \times 25.4\text{mm}$$

$$= 152.4\text{mm.}$$

$$\text{Average diameter} = d = 26.5 \times 25.4\text{mm}$$

$$= 673.1\text{mm}$$

Dynamic Wheel Load assuming even distribution of load:

$$\text{DWL} = \frac{321\text{kg} \times 9.81}{2}$$

$$= 1574.5 \approx 1575\text{N}$$

Table 1 gives Cone Index (CI) for tilled agricultural soil

$$\text{CI} = 900\text{KPa}$$

$$= 0.9\text{MPa.}$$

Wheel Numeric

$$C_n = b \times d \times \text{CI}$$

$$\text{DWL} = \frac{152.4 \times 673.1 \times 0.9}{1575}$$

$$= 58.6$$

Employing equation 7.5 for tire pressure of 193KPa (28psi).

$$\text{TF/W} = 0.0627\ln(1/C_n) + 0.3443 \text{ ----- (7.5)}$$

$$= 1575 [0.0627\ln(1/58.6) + 0.3443]$$

$$= 140\text{N}$$

Total Motion Resistance of the two tires

$$= 140 \times 2$$

$$= 280 \text{ N}$$

Net Pull = Animal Draft – Motion Resistance

From section 2.1 paragraph 2, the draft per work animal is 550N, this implies that the equipment can be conveniently pulled by two work animals.

$$\text{Net Pull} = (1100 - 280) \text{ N}$$

$$= 820\text{N}$$

The Net Pull offers convenient task and shall easily swallow energy requirement for spraying uphill terrains.



**Plate 1:** Animal Drawn Ground Metered Axle Mechanism Boom Sprayer in operation.

#### IV. CONCLUSION

The sprayer was designed and accordingly constructed at the workshop of Department of Agricultural Engineering, Ahmadu Bello University Zaria Nigeria. It was tested on a farm field in the University, 5 hectares was covered during the test and the performance was good. As the result obtained shows that all the grasses within the swat covered died within one week after spraying.

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