



DEVELOPMENT OF A TRACTOR POWERED SOLID MANURE SPREADER

BY

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B.ENG. (ABU) 2015
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ZARIA, NIGERIA**

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**A DISSERTATION SUBMITTED TO THE SCHOOL OF POSTGRADUATE
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**DEPARTMENT OF AGRICULTURAL AND BIO-RESOURCES ENGINEERING,
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NOVEMBER, 2021

DECLARATION

I Zakari SHEHU, hereby declare that this dissertation entitled “DEVELOPMENT OF A TRACTOR POWERED SOLID MANURE SPREADER” has been carried out by me in the Department of Agricultural and Bio-resources Engineering. The information derived from the literature has been duly acknowledged in the text and list of references provided. No part of this dissertation was previously presented for another degree at this or any other Institution.

Zakari Shehu

Name of Student

Signature

Date

CERTIFICATION

This dissertation entitled “DEVELOPMENT OF A TRACTOR POWERED SOLID MANURE SPREADER” by Zakari, SHEHU meets the regulations governing the award of the degree of Master of Science (M.Sc.) of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

I dedicate this report to my wife and son; Hauwa Zakari and Jarumi Danasabe Zakari . Without your patience, advice and support this programme wouldn't have become a possible one.

ABSTRACT.

This project reports the “Development of a Tractor Powered Solid Manure Spreader” used for application of solid manure to Agricultural field prior to field cultivation to improve spread distribution and reduce manual spreading problem. The developed machine basically consists of a frame made up of angle iron, a hopper, screen, agitator with 3 spikes each at the top and bottom of the screen, spreading disc with 8 fins of different lengths and a gear box with a connecting shaft. During application of manure the hopper is first filled with manure which is in the form of cow dung and allowed to drop on the surface of a rotating disc which through its centrifugal action spread the manure along the swath. The evaluation of the manure spreader was carried out using Cow Dung as collected at 11.17% moisture content, at variable disc speed (150 to 450 rpm), three different flow height of (15 to 45 cm) with a steady tractor forward speed of 8.2 km/hr. The evaluation parameters were effective field capacity, spread distribution, swath width, flow rate, application rate and field efficiency of the spreader. The experiment was laid in completely randomized design (CRD) and Analysis of Variance was used to analyse the data obtained from the evaluation, the Duncan Multiple Range Test (DMRT) was adopted for the ranking

The effective field capacity, effective width, field efficiency of the spreader and flow rate ranges from 4.4 - 9.8 ha/h, 7.5 – 10.4 m, 60.8 - 89.4 %, 1070 - 3938.1 kg/h respectively. Manure application rate ranges from 3011.3 - 4082.1 kg/ha. The best performance of the developed machine was found at the combination of a disc speed of 450 rpm and 45 cm flow height rate mechanism and a tractor forward speed of 8.2 km/hr, with this combination the machine efficiency, effective field capacity, spread capacity and swath width were 89.4 %, 9.8 ha/h, 3938.1 kg/h and 9.0 m respectively.

Comparing the developed spreader and imported spreader under the same conditions, the developed spreader recorded the highest application rate of 4082.1 kg/ha to that of the imported spreader with 1875.3 kg/ha while the swath width was 9.0 metres compared to 9.5 metres of the imported.

Graphically the developed manure spreader produced a better spread manure distribution pattern and is cheaper with a cost of ₦165,440, resulting in a cost reduction of 83.56 %, compared to the imported manure spreader with a cost of ₦1,006,500

From the evaluation of the developed manure spreading machine, disc speed and flow height mechanism were found to be the major determining factor influencing field capacity, application rate and swath width of the machine. The machine is recommended for both cooperatives and commercial farming.

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ABBREVIATION, UNIT AND SYMBOLS

ANOVA	Analysis of Variance
ABU	Ahmadu Bello University Zaria
DMRT	Duncan Multiple Range Test
SAS	Statistical Analysis Software
DM	Dry Matter
CRD	Completely Randomised Design
FYM	Farm Yard Manure
IAR	Institute of Agricultural Research
Kg	Kilogram
g	grams
Kw	Kilowatt
m	Meters
ha/h	Hectare per hour
h	Hour
ha	Hectare
m ³	Meter cube
rpm	Revolution per minute
N/m ²	Newton per meter square
mm	Milimeter
m ³ /s	Meter cube per second
°	Theeta, degree
%	Percentage
ω	Omega, angular velocity
θ	Theta, Angle of repose
ρ	Rho, Density

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Plants need a well balanced diet, for better growth and yield. Manures are the substances which provide nutrients for proper growth of plants. Manure is mostly plant residue and animal droppings added to the soil to increase its fertility and enhancing for plant growth (Boller and Hani, 2004). Manure is not just the urine and faeces from livestock, but also the bedding, runoff, spilled feed and parlor wash. Manure contributes to soil fertility. In addition to nutrients, manure provides nitrogen and other constituents that improve soil humus content, biological activity, and soil physical structure (Wagner and George, 2004). Manures contribute to the fertility of the soil due to addition of organic matter and nutrients, such as nitrogen that is trapped by bacteria in the soil (Haynes *et al.*, 2003).

Fertilizers may be divided into two classes: organic and inorganic fertilizer. Organic fertilizer commonly known as organic manure are derived from decaying material of plant or animal origin. Organic fertilizer often provide more than one of the many substances needed by plants for their growth. (Boller and Hani, 2004).

In Nigeria, the application of manure by small scale farmers is done by a pick-up truck and rake to spread manure on the farm. A tractor with a pull-type spreader is recommended for land application over larger areas. (Ojeniyi, 2000). This ensures that the manure is applied in a thin and relatively uniform layer on the soil.

Better accounting of manure nutrients helps save commercial fertilizer costs and helps establish the value of manure assigned to neighboring crop farmers. Federal and state regulations require reporting of manure applications to cropland, and imply that

calibration of equipment must be carried out to some (unspecified) level of accuracy, Frunk (2002). Furthermore, there are areas within many fields where application of manure is not allowed at all; automatic shutoff of equipment when entering those setback areas is needed. Most liquid slurry tank spreaders have a simple gate valve on the discharge pipe to the applicator, and the gate valve is opened fully while spreading manure in the field. Those spreaders do not have any method for varying the flow rate of manure coming out of the tank; therefore the only way to change the application rate per acre is to vary the ground speed of the vehicle. Frunk (2002)

Uneven distribution of manure can also reduce crop yields. Research indicates that when one area of the field is over-applied and another is under applied, the total yield typically will be less than if the correct amount of manure were spread evenly over the entire field. The reason for these findings is due to the law of diminishing returns. The law of diminishing returns states that there will be a decreasing return for each additional increment of fertilizer applied. (Jain *et al.*, 2015)

Calibrating the manure spreader is important to gauge how much manure is being spread. It is done similarly to calibrating a fertilizer spreader, planter, or sprayer. Several references are available on calibrating (Athena, 2008).

1.2 Statement of the Problem

The use of inorganic fertilizer has its own disadvantages under intensive agriculture because it is often associated with increase in soil acidity and nutrients imbalance (Kang and Juo, 1980; Ojeniyi, 2000). Furthermore, the extent to which farmers can depend on this input is constrained by unavailability of the right type of inorganic fertilizers at the right time, high cost, lack of technical know-how and lack of access to credit (Chude, 1999). This has encouraged scientists towards making use of organic materials (both

organic fertilizer as well as organic wastes) for improving the physical properties of soils that allow profitable crop production (Somani and Totawat, 1996).

In some parts of the world today, most peasant farmers apply manure using manual broadcasting method and bullock - carts /tractor trailers (Singh and Singh., 2014). This method is labour intensive and relatively time consuming with low productivity, the application rate per unit area usually results in spreading problem. In this method of manual broadcasting, solid stack piled manure losses about 21% of its nitrogen to the atmosphere (Lague *et al.*, 1994).

In attempt to reduce manual spreading problem and improve productivity, imported manure spreaders were purchased by IAR and the subsistence farmers find it difficult to afford or operate due to their high cost, complexity in design and higher weight which require tractors with a higher horse power to operate them.

1.3 Aim and Objectives of the Study

Aim

The aim is to develop a tractor powered solid manure spreader capable of efficiently applying farmyard manure.

Objectives of this study are;

- i. To conduct preliminary evaluation of an existing tractor mounted manure spreader.
- ii. To modify the existing and develop a tractor mounted prototype manure spreader.
- iii. To evaluate the performance of the developed machine and compare it with an existing manure spreader.

1.4 Justification of the Study

We witnessed a change from organic to inorganic agriculture and now, thinking a move towards organic again (Sathyanarayana *et al.*, 2002). Manure application by most Nigerian farmers was made with hand labour, this method, beside being labourious, is also time consuming (Ojeniyi, 2000). Even now that mechanical application of manure is possible, the high cost associated with applicable equipment is above what most farmers can afford. Hence, simple and relatively inexpensive equipment is more welcome until farmers holdings can economically justify the use of more sophisticated and therefore more efficient machinery.

Organic manure plays important role in improving soil productivity. It is a good source of nitrogen, phosphorus and excellent source of calcium and potash. (Suthakar *et al.*, 2008). The cost of organic manure with respect to availability would be far less compared to inorganic manure, organic manure is more effective with time also than inorganic manure as noted by Olieslagers; Ramon; de Baerdemaeker, J. (1996).

Damiyal *et al.* (2017), indicated there is need to supplement mineral fertilizer with organic manure due to the high cost of inorganic fertilizer and continuous decline in soil fertility that results to low crop yield. Also in a study by Belay *et al.* (2001) and Enujeke (2013), it has been made clear that the application of animal manures to agricultural fields as a widely used method of increasing soil organic matter, fertility and microbial properties.

Application costs of organic manure are high when using labour and slow in comparison to mechanical means in flat conditions or wherever it is accessible to tractors (Simard, 1998), proper spreading and incorporation of manure in the soil reduces nitrogen loss by 5% (Lague *et al.*, 1994).

When the tractor mounted manure spreader is developed at lower cost. The following advantages would be derived.

- i. Production of the machine would be accomplished much easier and faster by the industry
- ii. The improved version would be more affordable than the existing one
- iii. Higher Spreading uniformity should be achieved
- iv. It will use locally available materials thereby reduce maintenance cost

Therefore, a simple design and relatively inexpensive tractor mounted spreader is required in mechanized agriculture. This will facilitate manure spreading operation, reduced human drudgery, cost and poor application uniformity..

CHAPTER TWO
LITERATURE REVIEW

2.1 Organic waste generation in Nigeria

In Nigerian cities, the average waste generation rates ranged from 0.44 to 0.66 kg/cap/day as opposed to 0.7–1.8 kg/cap/d in developed countries according to Sridhar (2012). The density of solid waste in Nigeria ranged from 250 kg/m³ to 370 kg/ m³ (Table 2. 1). Nigerian waste is rich in organic biodegradable component with organic (60 to 80 %), others such as rags, ash and etc. are minor. (Sridhar, 2012).

Table 2.1 Waste generation and density in major cities in Nigeria

City	Tons per month	Density (Kg/m³)	Volume/capita/day (m³)
Lagos	255,556	294	0.63
Kano	156,676	290	0.56
Ibadan	135,391	330	0.51
Kaduna	114, 433	320	0.58
Portharcout	117, 825	300	0.60
Makurdi	24,242	340	0.48
Onitsha	84,137	310	0.53
Nsukka	12,000	370	0.44
Abuja	14,785	280	0.66

Source: (Ogwueleka, 2009)

Many constituent states in Nigeria have faced difficulties in dealing with waste and have mountains of refuse in many locations thus making the environment very unhealthy and affecting the quality of life in those areas. This also possess a danger to

other unseen aspects of the environment such as groundwater resources (Oloruntade, 2013). Due to this there is a large available source of decompost waste which can be use as manure and help the control and management of waste in Nigeria

2.2 Manure

Most animal manure may be faeces excrement (variously called "droppings" or "crap" etc) of herbivores and poultry or plant material (often straw) which has been used as bedding for animals and thus is heavily contaminated with their faeces and urine (Whitmore and Handayanto, 2000). The Vermicompost manures may be used by mixing earthworm with soil or by adding them to compost. Cow dung is a good source of nitrogen and phosphorus. Seaweed with amino acids is an excellent source of calcium and potash (Boller and Hani, 2004). The three major classes of manure are compost, green manure and farmyard manure (FYM) (Cherry *et al.*, 2006).

2.2.1 Compost

Large quantity of fresh crop residues, on application directly to soil, causes extremely severe nitrogen immobilization and development of excessive reduced condition in the soil. To overcome such problems organic residues are piled up, moistened, turned occasionally to aerate and allowed adequate time to decompose partially and bring down the carbon nitrogen ratio to about 30. This process is called composting, (Whitmore and Handayanto 2000). Compost, is utilized for improving or maintaining soil fertility. The collected organic refuse may be of rural and urban origin and may include straw, leaves, paddy husk, ground nut husk, sugarcane trash, bagasse, cattle dung, urine, crop residues, city garbage, night soil, sewage, kitchen and vegetable wastes, hedge clippings, water hyacinth and all other residues counting organic matter. (Cherry *et al.*, 2006).

2. 2.2 Green manure

Soil productivity is an important concern for farmers. Green manuring is gaining popularity as a method that successfully improves soil productivity (Haynes *et al.*, 1989). The addition of peat moss material improves soil tilth by activities of micro organisms in the soil. At the same time, the nutrients used in plant growth are conserved and returned to the soil to enhance its fertility (Boller and Hani, 2004). Leguminous crops, such as clover, when used as green manure also fix nitrogen through rhizobium harboured in their root nodules (Whitmore and Handayato 2000). Green manure approaches to crop production may improve economic viability, while reducing the environmental impacts of agriculture (Cherry *et al.*, 2006).

2. 2.3 Farm yard manure

FYM is partially composed dung, urine, bedding and straw. Dung comes mostly as undigested material and the urine from the digested material. (Landry *et al.*, 2004). More than 50 % of the organic matter that is present in dung is in the form of complex products consists of lignin and protein which are resistant to further decomposition and therefore the nutrients present in dung are released very slowly. The nutrients from urine, becomes readily available. Dung contains about 50 % of the nitrogen, 15 % of potash and almost all of the phosphorus that is excreted by animals. Straw, saw dust or other bedding materials are used in cattle sheds to reduce the loss of urine and to increase the bulk of manure. On an average, about 3 - 5 kg bedding material per animal is used by farmers. FYM contains approximately 5 - 6 kg nitrogen, 1.2 - 2.0 kg phosphorus and 5 - 6 kg potash per tonne. The quantity and quality of FYM depend upon the type (draught, mulch) and age of the animals, the way they are feed and the care taken to collect and store the material. Though FYM is the most common organic manure in Nigeria, the farmer, in general, do not give adequate attention to the proper

conservation and efficient use of the resource. For preparing better quality FYM, the use of pit method for areas with less than 1000 mm precipitation and heap method for other places is recommended. In the pit method, the cattle shed wastes are conserved in pits of 2 m wide, 1 m deep. (Landry *et al.*, 2004).

2.3 Forms of manure

Based on the type of livestock facility, manure can be handled and stored as a liquid (less than 5 percent dry matter), slurry (5 to 10 percent dry matter) and/or solid (greater than 15 percent dry matter). (Zebarth *et al.*, 2006). Typically, beef cattle and poultry manure are handled as solid manure, whereas dairy and swine manure are stored and handled as liquid manure.

2.3.1 Solid

Solid manure, which is more than 15% solid dry matter (DM) include material from traditional covered straw yards and animal droppings. It generally contain enough bedding material, or have enough dry matter to be stacked. Typically, most solid manure is applied on the surface, often followed by incorporation. (Koroodma, 1982)

2.3.2 Liquid

Liquid manure is a mixture of animal waste and organic matter used as an agricultural fertilizer, sometimes thinned with water. It can be aged in a slurry pit to concentrate it. It normally contains a DM between 0 and 5%, (Burton and Turner, 2003).

2.3.3 Slurry

Livestock slurry contains phosphorus (P) and potassium (K), which have fertilizer values equivalent to those of mineral fertilizers, while its nitrogen (N) content has a lower and more variable fertilizer value than that of commercial fertilizers. If applied at a rate higher than plant uptake, there is a great risk of nutrient leaching and runoff that

will pollute surface- and groundwater (Burton and Turner, 2003). The density and viscosity of slurry has been correlated to the dry matter (DM) content. Landry et al. (2004) gave a thorough review in connection with their own work on concentrated slurry. Their conclusion is that, for a manure to be termed slurry it should have a DM between 5 and 10 %.

2.4 Handling and Application Methods of Spreading Manure

An effective manure handling system should take into account the farm's storage area(s), location, equipment availability, and manure utilization. Manure should be collected regularly from paddocks and stalls, this may mean daily removal depending on the type of livestock, herd count, and available grazing area (Athena, 2008). If composting the manure, the storage area can be the compost area or bins. The size and type of storage area or facility will depend on the volumes of waste generated and the length of time. (Athena, 2008).

Basically there are two available methods: manual and mechanical method of manure application:

2.4.1 Techniques of application

There are different application techniques, but all could be suitably grouped into three application methods, based on the placement of manure on or into the soil according to Huijsmans *et al.* (2003):

- i. Surface spreading (broadcasting)
- ii. Surface incorporation (banding)
- iii. Deep placement (injection)

2.4.1.1 Surface Spreading

Surface spreading is the process in which solid/liquid manure is spread, with either Truck-mounted and trailer-towed box spreaders for the solid or tanker fitted with a splash for the liquid as seen in plate 2.3. In surface spreading of solid manure the spreader mechanism (paddles, disc, flails or augers) at the side or rear of the spreader disperses manure on the ground while for the liquid manure, the manure is to be pumped through an orifice onto a splash-plate from where it was spread onto the soil, (Huijsmans *et al.*, 2003). Norman-Ham *et al.* (2008) concluded that distribution of manure across the application swath of a spreader needs to be relatively uniform to take full advantage of the fertilizer value of solid manure.

2.4.1.2 Surface Incorporation

Surface incorporation is defined as the treatment by which manure is surface spread and, subsequently, incorporated into the soil. Conventional tillage implements (cultivators with rigid tines, spring tines, discs, or harrows) are to be used to incorporate the manure into the top soil directly. (Huijsmans *et al.*, 2003)

2.4.1.3 Deep placement

Deep placement is defined as the treatment by which the manure is buried in the soil, either directly by an injector or indirectly by ploughing with a mouldboard plough directly after surface spreading. The arable land injector is equipped with spring tines, which placed the manure directly underneath the soil surface. Simultaneously the injector carried out a tilling operation by covering the manure with soil. (Huijsmans *et al.*, 2003)

2.4.2 Problems of poor spreaders pattern

Poor spreader patterns can be caused by:

- i. A malfunctioning spreader

- ii. Inexperienced operator
- iii. Incorrect swath width due to fertilizer particles
- iv. Moisture content of the material being spread
- v. Slope of the land
- vi. Incorrect ground speed synchronized with discharge rate
- vii. Driving pattern not adapted to the shape of the field
- viii. Poor conditions such as rough, uneven terrain

2.4.3 Manual method of spreading manure

Manual method is also known as cultural method of spreading manure. It employ the use of garden fork, buckets and shovels in applying manure on agricultural fields Sanchez and Miller (1986). This shows that manual labour application is still common, thus the method is suitable for small farm areas, undulating areas, areas that are ‘not conducive’, and inaccessible for tractors (Simard, 1998). However application costs are high using this method and slower compare to the mechanical method when applied under same conditions. In the event of labour availability, this is slowly becoming scarce as owners are pressured by both the shortage of labour and having to reduce application costs. (Simard, 1998).

2.4.4 Mechanical method of spreading manure

Mechanical manure spreading has been studied by many researchers in the past. Mehring and Comings (1930) found a definite relation between the kinetic angle of repose and the discharge rate, they concluded that the drillability of a fertilizer is inversely proportional to the angle of repose and that fertilizers with angles of repose greater than about 55° cannot be metered satisfactorily with the most type of equipment.

Glancey and Adams (1996) evaluated a solid manure applicator for topdressing (or side dressing) row crops with solid waste materials. The apparatus can meter and deliver

animal manures and other raw solid waste materials between rows of a growing crop without the material contacting the crop. Results from a 3-year field study clearly indicate that new poultry litter management strategies, using this litter topdressing equipment and improved soil and plant nitrogen tests, improved the agronomic and environmental efficiency of maize production.

Davis and Meyer (1998) designed a new trailer manure spreader. That could be quickly converted to capacious trailer. It had 4000 kg capacity with a body 3 m long by 2 m wide and sides approximately 0.8 m high. It spread finely for it was designed primarily as a power driven spreader. The rotor runs at a peripheral speed exceeding 36.58 km/hr to deliver over 25,000 cuts of load per minute.

Ling and Wilhoit (1999) evaluated the power requirements for the spinner type spreaders for broad-casting solid waste. The spinner power was evaluated by measuring the hydraulic pressure drop across the two spinner motors while the conveyor power was calculated based on formula developed for a typical spinner type spreader. The maximum power requirements for spreading poultry litter and ash at a material flow rate of 1.52 m²/min. and spinner speed of 830 rpm was close to 19 kW.

In the same way results of Sharabasy *et al.*, (2007) shows that, the increasing of the gate opening area leads to increase in the application rate (kg/h), but the increase in machine forward speed leads to decrease in the application rate (kg/fed)

Suthakar *et al.* (2008) evaluated the field performance of a tractor PTO operated manure spreading attachment to a two wheel trailer and compared it with the traditional method of spreading manure. When it comes to the forward speed of the machine over application rate he observed that the application rate of the manure was significantly decreased when increasing the forward speed. The reason was that when the forward speed was increased, application of manure over the field must be reduced. But, the speed of the spreader drum did not influence the application rate of the manure. The

desired application rate of the manure (12.202 tonnes/ha) was observed for the forward speed of 2.31 km/hr and the chain conveyor speed of 1.51 m/min with the effective width of 1.20 m and a time saving of 50-60 % when compared to the conventional method. The spread pattern obtained was a flat top profile, which is acceptable for uniform spreading. It can also be used as a trailer by just shifting a door whenever the trailer is required for transportation.

Suthakar *et al.*, (2008) also measured the spread pattern for the all the treatments. Where they were plotted using values averaged over three replications with tray position in X-axis and amount of manure collected in tray is in Y-axis. The application in tones per hectare decreased with increase in speed of the tractor and increase with decrease in the linear speed of the chain conveyor. In all the treatments spread pattern obtained was a flat top profile, which was acceptable form from the point of achieving uniform spreading. It is very much evident that the forward speed and chain conveyor speeds had a significant effect on the uniformity of application.

It was recorded by (Hanna and Richard, 2008) that the varying spreader swath interval affects application rate and uniformity. In general, a narrower swath interval increases application uniformity, but increases overall application

Similarly Sapkale *et al.*, (2010) and Thakur *et al.*, (2015) also recorded that the forward speed and conveyor speed had a significant effect on co-efficient of uniformity in manure application.

Singh and Singh (2014) developed an animal drawn spreader from an existing bullock carts which is used for transport of manure to the field. It is modified for farm yard manure (FYM) spreading operation. Keeping all facts in mind an animal drawn FYM spreader is developed for uniform spreading of manure and eliminates the human drudgery involved in spreading of manure in the field. The developed farmyard manure spreader of 480 kg capacity and gave manure application rate of 5 to 10 t/ha for the

manure delivery rate of 0.38 to 0.74 kg/s at the operational speed of 2.4 km/h, respectively.

Similarly, Reddy *et al.*, (2013) have developed a animal drawn manure spreader. Sliding plate is mainly used for adjustment of opening area in the manure box. Sliding plate is made from MS sheet and has on the bottom of platform below the agitator to control the manure delivery rate two handles were provided to the sliding plate, which helps the push or pull (forward and backward direction) the sliding plate inside the manure box. Thus by increasing or decreasing the opening width, the manure delivery rate is controlled. The sliding plate controls the opening for dropping the manure. The agitator assembly is fixed below the manure box for agitating the manure during working position. A manure spreading agitator is fixed at middle portion of main frame of rectangular chassis. The main function of agitator is to agitate the manure from manure box.

Other results were observed by Thakur *et al.*, (2015) according to them increase in engine rpm and forward speed will increase field capacity but it will decrease application rate.

The investigation of Shen *et al.*, (2011) to know the causes for differences in compost application rate in a field using two types of manure spreaders and clarifying it by measuring the travel tracks of the manure spreaders using a RTK-GPS system showed the differences in compost application rate are due to the changes in travel speeds and track distances.

In another research of Batta *et al.*, (2015) the effective field capacity of the manure spreader increased with increase in forward speed and engine rpm. As the forward speed of the tractor was increased, engine rpm the effective length over which the manure was spreaded also increased. Thus it leads to increase in effective area over which the manure was applied resulting in decrease in manure application rate per unit

area. Generally application rate of fertilizer spreader vary with the size of opening and forward speed.

The similar result was observed by the (Jain and Lawrence, 2015). The manure delivery rate varied with variation in size of opening and ranged between 0.38 to 0.83 kg per second with the increase in opening area.

The research of (Patil and Munde, 2017) showed that the application rate of manure during manure spreader operation varies from 2.46 to 10.06 t/ha for different opening areas of cover from 0.04 m² to 0.16 m², respectively. The developed manure spreader cum cart has desired manure application rate of 9-10 t/ha for 0.16 m² opening area of cover at the operational speed of 2.63 km/hr. The increase in manure delivery rate with increase in opening area of delivery slot was due to availability of more area, allowing increased quantity of manure to pass through

2.4.5 Solid manure application systems

The dry matter content of manure applied with a solid manure spreading device should be at least 15%. A common disadvantage of different solid manure spreaders is their relatively low capacity due to quite narrow spreading width. Accurate dosing of solid manure is difficult due to its uneven consistency. (Allan *et al.*, 2012). Below are examples of solid manure spreaders commonly used:

a) **Rotaspreaders** - a rotaspreader as seen in plate 2.1 is a sidedischarge spreader which features a cylindrical body and a power take-off-driven shaft fitted with flails running along the centre of the cylinder. As the rotor spins, the flails throw the solid manure out to the side.



Plate 2.1: Rotaspreader

Source: Integrated pollution prevention and control (IPPC), (2010)

b) **Rear discharge spreaders** - the spreader as seen in Plate 2.2 has a trailer body fitted with a moving floor or other mechanism which delivers solid manure to the rear of the spreader. The spreading mechanism can have two or four either vertical or horizontal beaters. The modern spreaders of this type which allow exact dosing have spinning discs as well.



Plate 2.2: Rear discharge spreader

Source: IPPC, (2010).

2.4.6 Liquid manure injector

The advantages of liquid manure application are high capacity (spreading width can be 8-24 m, depending on the machine), less intensive trafficking of soil, especially if tramlines are established in the field, and precision dosing. (Allan *et al*, 2012). An example of a liquid manure broadcaster is seen in plate 2.3



Plate 2.3: Broadcast spreader with a splash plate

Source: IPPC (2010)

a) **Broadcast spreaders** - these combine a tractor and a tanker with a liquid manure spreading device at the rear. The liquid manure is forced under pressure through a discharge nozzle, onto an inclined splash plate to increase the sideways spread. Problems in application to growing plants, especially grasslands – it is not possible to prepare a high quality silage (hay) from plants polluted with manure, and the intake of such herbage is reduced in grazing or as a green fodder. (Allan *et al.*, 2012)

b) **Band or trailing hose spreaders** - band spreaders as seen in plate 2.4 consist of a liquid manure tank and hose system, a series of hanging or trailing pipes attached to a boom. The width of a band spreader is typically 12 m, with about 30 cm between bands. Band spreaders discharge liquid manure just above ground level and rapid contact with the soil significantly reduces ammonia emissions. (Allan *et al.*, 2012)



Plate 2.4: Band or trailing hose spreader

Source: IPPC (2010)

2.5 Effect of Speed Levels on Spreaders

Different levels of shaft revolutions affect the performance of mono-disk rotary and pendulum manure fertiliser spreaders widely. Tests have been conducted on a mono-disk rotary spreader manufactured by the Italian company AGREX, and on a pendulum spreader manufactured by the Slovenian company CREINA from Kranj. The impact of different revolution levels on the transverse spread - dispersion, spread width and flow of a fertiliser, have been established, both types of spreaders have been submitted to testing at different rpm levels of the tractor drive shaft: at 150 rpm, 300 rpm, and 450 rpm. It has been established that the swath width on both spreaders is statistically significant ($P < 0.05$) as it increases with increase in the rpm's speed. The manure flow is statistically significant ($P < 0.05$) and changes only on the pendulum spreaders, whereas on rotary spreaders it has been found out that the manure flow does not depend on the rpm's (Bogomir and Tone, 2000).

Similarly Sapkale *et al.*, (2010) and Thakur *et al.*, (2015) also recorded that the forward speed and conveyor speed had a significant effect on co-efficient of uniformity in manure application.

2.6 Factors Affecting Spread Pattern and Swath

Suthakar *et al.*, (2008) measured the spread pattern for the treatments; combination of rpm disc speed and flow heightrate. Where they were plotted using values averaged over three replications with tray position in X axis and amount of manure collected in tray is in Y-axis. The application in tones per hectare decreased with increase in speed of the tractor and increase with decrease in the linear speed of the chain conveyor. In all the treatments spread pattern obtained was a flat top profile, which was acceptable form from the point of achieving uniform spreading. It is very much evident that the forward speed and chain conveyor speeds had a significant effect on the uniformity of

application. It was recorded by Hanna and Richard (2008) that the varying spreader swath interval affects application rate and uniformity. In general, a narrower swath interval increases application uniformity, but increases overall application rate.

(Singh and Singh, 2014) have recorded that the increase in manure application rate will decrease the coefficient of variation, which in turn increases the coefficient of uniformity. (Jain and Lawrence, 2015) also have showed that the coefficient of uniformity of the manure spreader also varied with variation in manure delivery rate. The coefficient of variation decreased from 23.42 per cent to 15.62 per cent with increase in manure delivery rate from 0.38 kg to 0.83 kg/s.

2.7 Effect of Flow Rate on Spreaders

Present day metering devices have a positive action in dispensing part of flow but also depend partly upon gravity. Stationary opening arrangements depend largely upon gravity. Auger feeds, conveyor feed units are positive displacement devices. Discharge rates from metering devices that are not positive acting are materially affected by the type and condition of the manure and by operating conditions, the extent of the effects being related to the degree of dependence upon gravity flow. One of the important factors affecting discharge rates is the drillability of manure. Drillability or ease of flowing is affected by such factors as the hygroscopicity of the manure, relative humidity at which it is stored, the size and shape of particles, presence of lumps, the bulk density and the compaction characteristics of the material (Kepner *et al.*, 1987). (Mehring and Comings, 1930) found a definite relation between the kinetic angle of repose and the discharge rate, they concluded that the drillability of a fertilizer is inversely proportional to the angle of repose and that fertilizers with angles of repose greater than about 55° cannot be metered satisfactorily with the most type of equipment. (Singh and Singh, 2014) concluded that the farmyard manure is heterogeneous material and moisture content of it changes with the depth of the storage pit. Hence angle of

friction is more important for sliding the manure over a sheet as compared to angle of repose. They also observed the variation of manure deliver rate at different levels of manure filled in the manure box. Meanwhile it is also evident by the research of Malgeryd and Wetterberg, (1996) the bulk density of solid manure affects spreading properties such as the flow of manure and the working width.

2.8 Cost of Manure Spreaders

Most spreaders in the market are expensive and unavailable in most developing countries and local markets (Karszes, 2012) as seen in table 2.2. the IAR imported spreader (Vicon) as listed in number 7 cost more than 1,000,000 naira with the list expensive to be Vintage Antique with a cost of more than 300,000 naira

Table 2.2 Brand, Capacity and Online Market Value of Common Manure Spreaders

S/N	Brand	Model	Attachement/Weight	Capacity (kg/hr)	Cost (Shipping inclusive)	
					\$	₦
1	Newer Spreader	Model 225	Tractor Drawn (Light)	235	1,900	579,500
2	Newer Spreader	Model 200	Animal Drawn (Light)	220	1,800	549,000
3	Country Manufacturing	Model 600	Animal Drawn (Light)	300	1,490	454,450
4	Bush Bug	MS250G	PTO (Heavy)	1150	3,450	1,052,250
5	Vintage Antique	Horse Drawn	Animal Drawn (Heavy)	620	1,164	355,020
6	Khun	Easy Spread 1212	PTO (Heavy equipment)	2320	7,500	2,287,500
7	Vicon	Rota Flow Model	PTO (Heavy equipment)	1230	3,300	1,006,500

Source: Amazon and eBay (October 2019)

2.9 Distribution Pattern

The uniformity of a field pattern depends upon the location of the spread center-line and the weight of manure distributed per unit area. The traditional method for evaluating a distribution pattern uses a series of trays placed on the ground in a line perpendicular to the direction of travel (Fig. 2.1) Larry and Allan (2012). One or more passes of the spreader in the same direction deposits material in the trays. A plot of the material weight from each tray ($0.5 \times 0.5 \times 0.2$ m³ at 0.6 m interval, versus the location of the tray gives a visual picture of the distribution pattern. Kits available for this evaluation include a set of wooden boxes. Material from the trays is weighed in kilogram and poured into nylon bags and marked at each disc speed in rpm and the flow height rate mechanism in centimetres. A graph of weight of manure is plotted against distances from the centre in a graph to assist in visualizing the spread pattern.

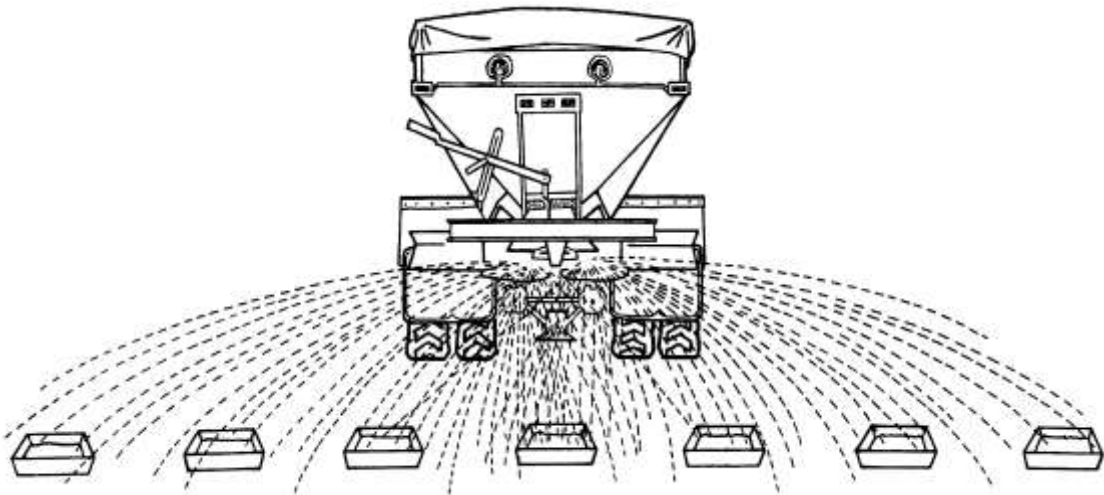


Figure. 2.1:Tray systems for evaluating spreader distribution pattern

Source: Lary and Allan, (2012)

Theoretically, the ideal distribution pattern for a broadcast spreader is shown in Figure 2.2. The visual picture is a flat-topped, trapezoidal pattern with uniform sloping sides. Since there are equal amounts of material on each side of the spreader centerline, subsequent passes of the equipment would overlap adjacent spread patterns halfway up

each respective side of the graph; 20% of the total width of spread is scientifically proven to be used when overlapping according to (Hammond *et al.*, 1994). Most broadcast spreaders actually produce a distribution pattern as shown in Figure 2.3. The oval that results produces a rather large span in the center of the pattern where the material is uniformly distributed, but this drops off at the ends of the swath. Effective coverage with this pattern is about 60 percent; that is, about 20 % of the swath width must be overlapped in subsequent passes in order to produce uniform distribution. For example, an oval pattern 12 m in width would have an effective width of 7.2 m. Overlap of 1.44 m would be required in subsequent passes (Larry, 2012).

A large number of spreaders produce the pyramid pattern shown in Figure 2.4. Although this is an acceptable pattern, the effective swath width is only about 50 percent of the theoretical swath width. For example, instead of 40-foot swath center spacing, 20 feet is the maximum possible for uniform distribution. The result is reduced field efficiency in that greater time is required per hectare (Larry and Allan, 2012).

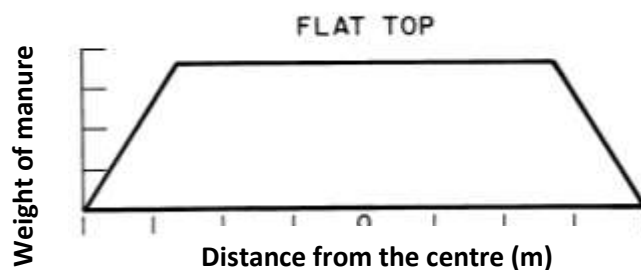


Figure 2.2: The ideal manure spread pattern.

Source: Larry and Allan (2012)

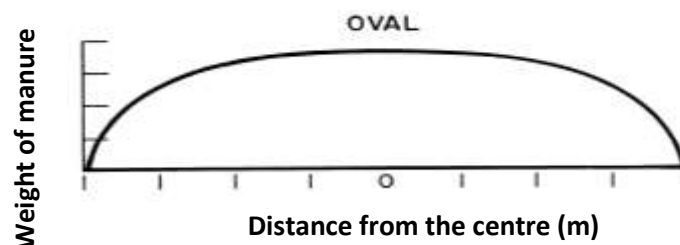


Figure 2.3: The normal spreader distribution.

Source: Larry and Allan (2012)

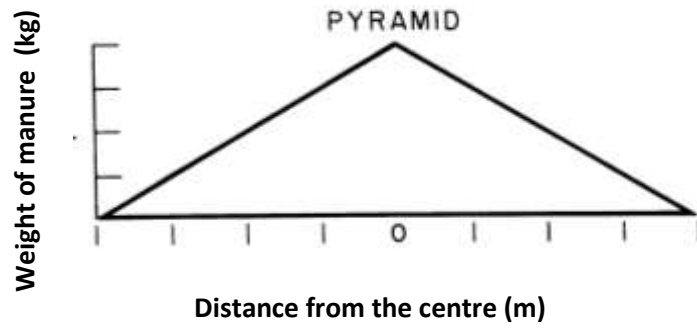


Figure 2.4. An acceptable distribution pattern.

Source: Larry and Allan (2012)

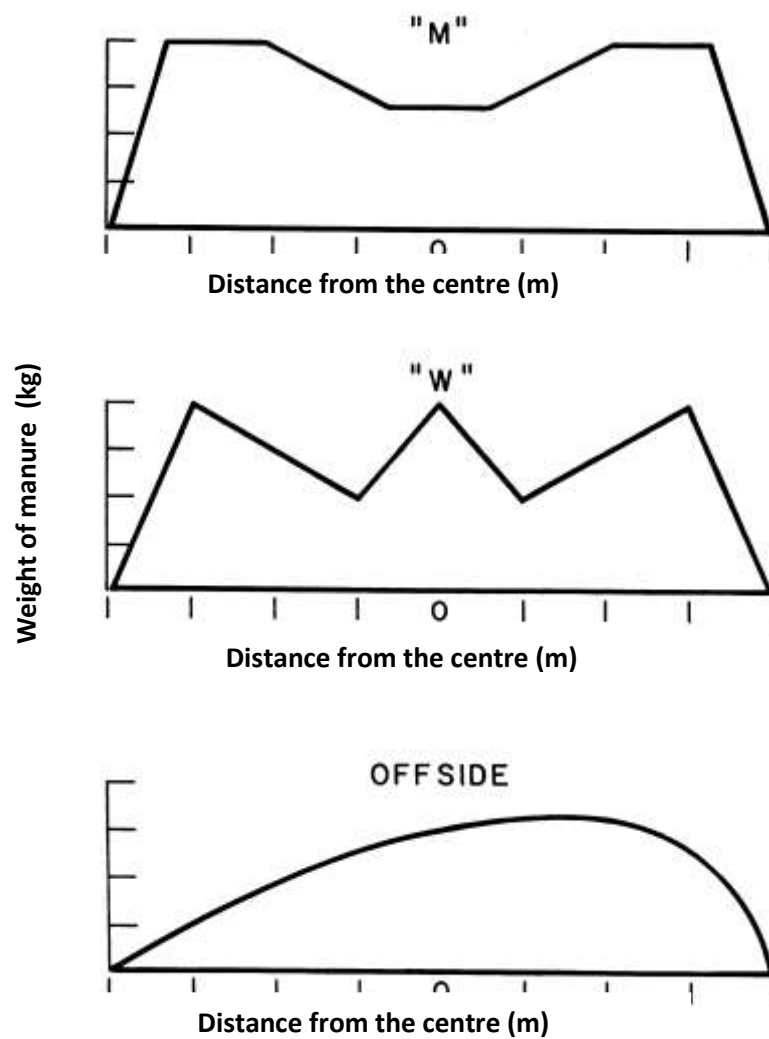


Fig 2.5: The three major problem-type spreader patterns.

Source: Larry and Allan, (2012)

The most common problem is the offside pattern with excessive material placed on one side of the centerline. Another problem is the “W” pattern with three areas of high material concentration. The “M” pattern produces too little fertilizer or lime directly behind the applicator machine. The “W” and “M” patterns are usually associated with twin-spinner spreaders. Many times the “W” and “M” are also offside, which complicates correction of the problem. Such patterns must be corrected before continuing to apply fertilizer or manure. Overlapping on “W” or “M” patterns only doubles the material where too much as already been spread. In order to correct spread patterns, refer to Figure 2.6. Adjusting the point of fertilizer delivery, blade pitch, or spinner spreader may be necessary to correct the pattern (Larry and Allan, 2012).

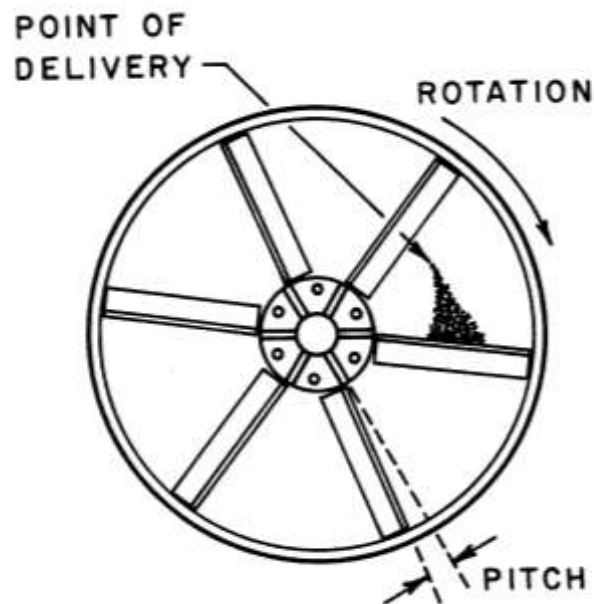


Fig 2.6: Adjustment of point of fertilizer delivery, blade pitch or spinner speed may be necessary for uniform distribution

Source: Lary and Allan, (2012)

For example, if the right half of the pattern (as viewed from behind and above the spinner) from a clockwise-rotating, single-spinner is heavier than the left half, any of the following adjustments will delay the release of manure from the spinner and correct the pattern:

1. Move the chute to shift the point of delivery in a clockwise direction.
2. Move the point of delivery closer to the center of the spinner.
3. Move blade tips forward in the direction of the spinner rotation.
4. Decrease the spinner speed.

If the left half of the pattern is heavier, make the adjustment in a direction opposite to those indicated. With twin-spinner distributors, the counter-rotating spinners must start unloading at the proper time to provide uniform coverage directly behind the machine. If application directly behind the spreader is too light, such as with the “M” pattern, earlier release of fertilizer from the spinners will correct the pattern. To do this, make at least one of the following adjustments:

1. Move the chute to shift the points of delivery in a direction opposite to the direction of the individual spinner rotation.
2. Shift the points of delivery closer to the periphery of the spinners.
3. Move blade tips back in a direction opposite to the direction of individual spinner rotation.
4. Increase the spinner speed.

If the pattern is offside on a twin-spinner, the flow divider must be positioned to deliver equal amounts of material to each spinner. Spinner spreaders work best when the hopper discharge chute extends down near the spinner. Even with proper adjustment, not all dry blends of fertilizer materials can be uniformly distributed across the swath. For uniform distribution without segregation of the ingredient materials, it is important that particle size and density of materials be closely matched. Because the distributor action is conducive to segregation, this precaution should be observed regardless of whether the materials are blended by a stationary bulk blender or a compartmented blending truck (Larry and Allan, 2012).

2.11 Deductions from Literature Review

The following deductions were made from literature

- i. Literature has shown no tractor mounted manure spreading machine have been developed in Nigeria, all the ones available are imported.
- ii. Most spreaders in the market are expensive and unavailable in our national and local markets as stated by Karszes and Howland (2012). This is also indicated in table 2.2. Therefore there is need to develop affordable manure spreader suitable for wider acceptability.
- iii. The IAR imported manure spreader produces large clods due to ineffective agitation during preliminary analysis. Therefore it is suggested that future work should consider developing a spreader with an effective agitator.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Machine Description

The rotating disc manure spreader (Figure 3.1) consists of the following components; hopper, agitator, spreading disc, flow rate control mechanism, frame, power transmission unit, screen and gear box

Hopper: is a trapezoidal container attached to topmost part of the spreader, used temporarily for holding the material to be spread prior to and during the spreading operations. It is made of mild steel sheets and selected base on availability. Its views and dimensions are shown by an AutoCAD on Sheets 8 and 9 in appendix G .

Agitator: This is a stirring device made from steel metal rod of 210 mm length and 21 mm in diameter three spike of metal rod was attached to sides of agitator at both the top of the shaft and discharge opening of the hopper, the number of spikes was adopted from the IAR imported spreader. A detail view is presented in Sheet 19.

Spreading disc: This is a circular disc of 340 mm diameter of steel material that is mounted at the bottom of the hopper just below the aperture openings of the twin pyramidal frustum. The spreading disc has eight equally spaced fins in which six of the fins (major) are of 490 mm length, and two of the fins (minor) are of shorter length of 257 mm. All its views and dimensions are shown on sheet 13

Flow rate control mechanism: A flow rate control mechanism with locking device is provided at the tail end of the hopper opening to control the flow of manure through the aperture to the spinning discs. The mechanism is controlled by a hand lever from the tail end of the hopper. Its views and dimensions are shown on Sheets 10, 11 and 12

Frame: The frame was fabricated using two inches angle iron and galvanized steel pipes. The frame was firmly welded against pressure unevenness and to maintain stability and rigidity. The frame is presented in sheet 5, 6 and 7

Power transmission unit: The unit comprises of the PTO which transmits power to the spreading mechanism by the means of connecting shaft from the PTO to the gear box. The agitator which is fixed to the spreader disc rotates in the same direction as the spreader disc.

Screen: This is located within the hopper at the middle of the agitator. It helps to separate unwanted materials such as large stones, bottles and pieces of metals. It also helps in trapping large clods of manure which can be broken into smaller pieces. Its view and dimensions are shown on Sheet 20.

Gear Box: This consists of a pair of bevel gears of transmission ratio 1:1. The input shaft takes power from the PTO shaft while the output shaft drives the spreader disc and the agitator. the gear box is shown in sheet 14,15,16 and 17

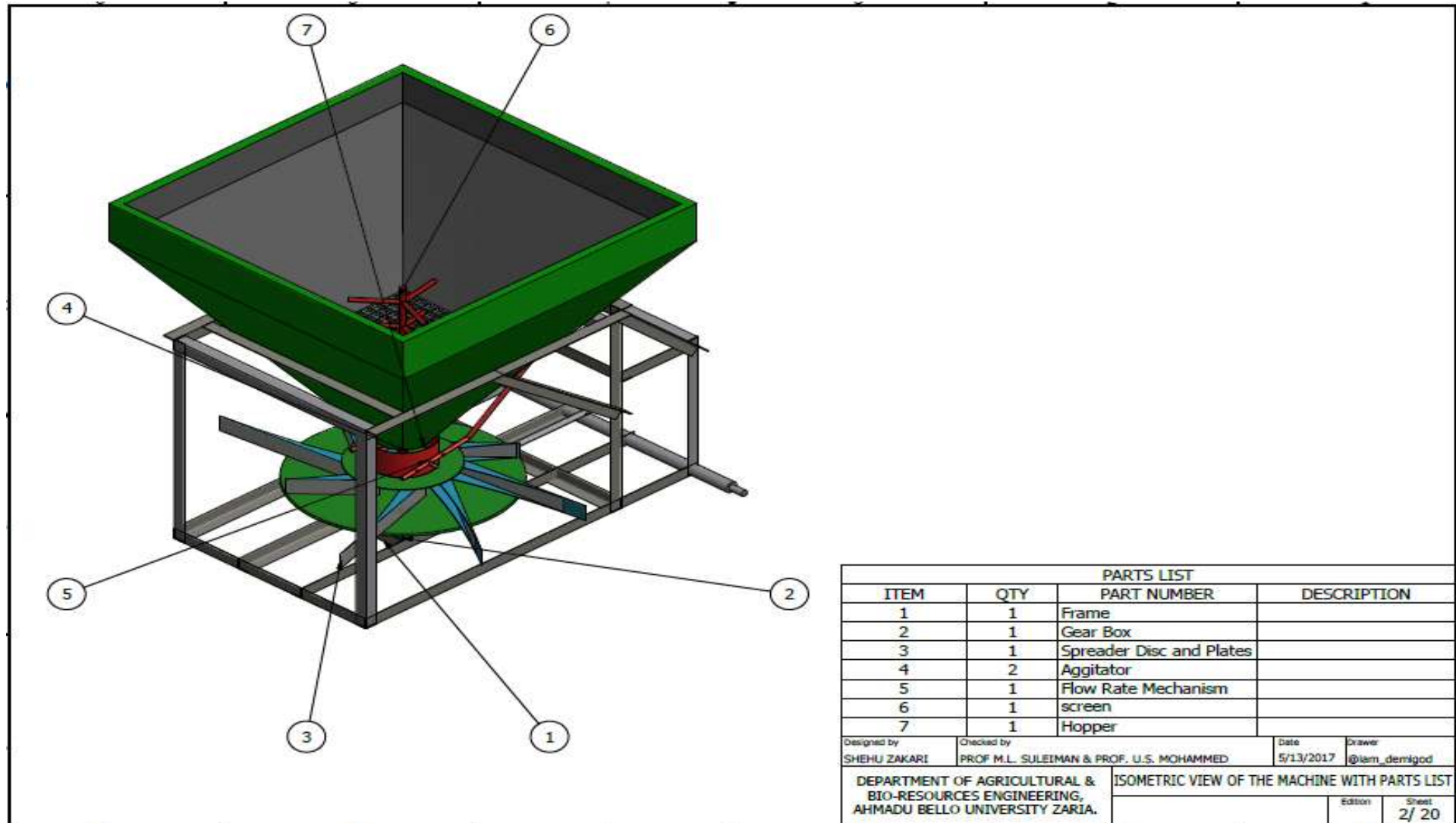


Fig. 3.1: Isometric View of the Manure Spreader

3.2 Design Considerations

The factors that were considered in the design of the manure spreader include

- i. The spreader is of horizontal rotating disc type
- ii. Capacity of the hopper is 0.56 m³ (Based on the IAR imported spreader)
- iii. The spreader is to handle solid manure only.
- iv. The rate of application should be proportional to the spreader forward speed.
- v. Ease of passage/metering of the manure to the spreader disc
- vi. Ease of disassembly of the spreader for cleaning and maintenance
- vii. The spreader is to be mounted and powered by a tractor.
- viii. The speed for the spreading disc is considered to be from 150 to 450 rpm and determined using a tachometer (Pequea Machine operational manual, 2005)
- ix. Corrosion resistant materials (Copper) are selected for the spreader disc.
- x. The spreader components are designed based on durability, strength and cost.
- xi. The forward speed of the machine selected was 8 km/h (Measured)

3.3 Machine Parts Design

The machine parts design are presented

3.3.1 Determination of the hopper capacity

The hopper design was based on the volume of trapezoidal container with a square based area, dimension are determined arbitrary. The volume of the hopper was determined by estimating the volumetric and gravimetric capacity of hopper as given by (Harris and Stocker, 1998) in equation 3. 1

$$\text{Capacity of the hopper, (trapezodial) } (V_h) = \frac{l^2}{3} h + l^2 \times b \quad (3.1)$$

Where,

$V_h =$ Capacity of the hopper (m^3)

$l =$ length of the base end (1.15 m)

$h =$ Height, distance of the line segment stretching from the “point” of the pyramid to the plane of the base at perpendicular angles to both (0.811 m)

$b =$ height of the base (0.153 m)

$V_h = 0.56 m^3$

3.3.2 Hopper angle of sliding friction

The equation given by (Landry *et al.*,2004) for Hopper angle of sliding friction is presented in equation (3.1.1)

$$\theta = \tan^{-1} \left(\frac{h}{r} \right) \quad (3.1.1)$$

$\theta =$ Angle of repose, degrees,

$h =$ Height of heap, = 5 m

$r =$ Radius of heap, = 3.6 m

$\theta = 54.24^\circ$

3.3.3 Determination of manure weight in the hopper

The weight of manure in the hopper is determined by computing the mass of manure when the hopper is full to the brim using the average bulk density of manure. The weight was converted to normal force to assist in determining the force exerted on the agitator.

$$N_w = M_m g \quad (3.2)$$

Where,

$N_w =$ Normal force (weight of the manure, N)

g = acceleration due to gravity (9.8 m/s^2)

M_m = Mass of manure full to the hopper brim (kg)

$$M_m = \rho_m \times V_h$$

V_h = Capacity of the hopper (0.56 m^3) as determined in eq (3.1)

ρ_m = Bulk density of manure (kgm^{-3}), average bulk density of farmyard manure as noted by Singh and Singh (2006). $\rho_m = 230 \text{ kgm}^{-3}$

$$M_m = 128.8 \text{ kg}$$

$$N_w = 1262.24 \text{ N}$$

3.3.4 Determination of mass of the spreader disc assembly

The mass was determined by calculating the volume of each component of the spreader disc, the sum of the total volume of all the components was then computed and multiplied by the density of steel (7850kg/m^3) as giving by (Harris and Stocker, 1998)

$$M_{Ts} = \rho V \tag{3.3}$$

Where,

M_{Ts} = mass of spreader disc (kg)

ρ = density of the disc material (Steel) (7850kg/m^3)

V = total volume of disc material (m^3)

But

$$V = At = V_c + V_{lf} + V_{sf} + V_d \tag{3.4}$$

Where,

A = total area of material (m^2)

t = thickness of material (m)

V_c = Volume of circular disc material beneath the fins = 181,584.06 mm³

V_{lf} = Volume of longer fins (six in number) = 117,600 mm³

V_{sf} = Volume of shorter fins (two in number) = 61680 mm³

V_d = Volume of circular disc material above the fins = 30787.61 mm³

$V = 391651.67 \text{ mm}^3 = 3.92 \times 10^{-4} \text{ m}^3$

$M_{Ts} = \rho V$

$M_{Ts} = 3.07 \text{ kg}$

3.3.5 Determination of weight of agitator

The weight is determined by computing the total volume of the material and multiplying it by the density of material.

$$M_{Ta} = \rho_a V_a \quad (3.5)$$

Where,

M_{Ta} = total mass of agitator assembly(kg)

ρ_a = density of the agitator material (Steel) (7850kg/m³)

V_a = total volume of the material (m³)

But

$$V_a = Al \quad (3.6)$$

Where,

A = total area of material (m²)

l = total length of material including length of spikes (0.886 m)

$$A = \frac{\pi d^2}{4} = 3.46 \times 10^{-4} \text{ m}^2$$

$$V_a = 3.07 \times 10^{-4} \text{ m}^3$$

$$M_{Ta} = \rho_a V_a = 7850 \times 3.07 \times 10^{-4}$$

$$M_{Ta} = 2.41 \text{ kg}$$

3.3.6 Determination of weight of manure at a point during spreading

The mass of manure was determined by collecting manure weight available on the disc at rest, the weight collected at rest was more than the weight during spreading.

$$M_{Tm} = \text{mass of manure on spreading disc at a point during spreading} \quad (3.7)$$

$$M_{Tm} = 495 \text{ g} \cong 500 \text{ g}$$

3.3.7 Determination of weight of spreader disc, agitator and the manure on disc at point of spreading

The weight of the spreader disc and agitator was determined to estimate the amount of load being exerted on the gear by both the spreader disc and agitator. The total weight of the spreader disc assembly and the agitator is given in equation 3.8

$$W_T = M_T g \quad (3.8)$$

$$M_T = M_{Ts} + M_{Ta} + M_{Tm} \quad (3.9)$$

W_T = total weight of the spreader disc, agitator assembly and manure on disc (N)

g = acceleration due to gravity (9.8 m/s^2)

M_T = total mass of spreader disc and agitator assembly and manure on disc (kg)

therefore

$$W_T = M_T g$$

$$M_T = M_{Ts} + M_{Ta} + M_{Tm}$$

$$M_T = 5.98 \text{ kg}$$

$$W_T = 58.66 \text{ N}$$

3.3.8 Determination of the centrifugal force developed by the rotating disc agitator and manure on disc

The Centrifugal force is determined using the formula given by Khurmi and Gupta (2005) in equation 3.11. The force will be use to compute the power required to drive the agitator and spreader disc.

$$F_c = \frac{M_T \omega^2 D}{2} \quad (3.11)$$

Where,

F_c = centrifugal force (N)

M_T = total mass of spreader disc and agitator assembly and manure on disc (5.98 kg), as computed in (3.9)

ω = angular velocity of the spreader disc assembly (rad/s)

$$\text{But } \omega = \frac{2\pi N}{60} \quad (3.12)$$

Where,

N = maximum speed of the spreader disc in rpm

$\omega = 47.12$ rad/s

D = diameter of spreader disc (0.34 m) base on existing design

$F_c = 2257.15$ N

3.3.9 Determination of peripheral speed of the spreader disc

The peripheral (linear) speed of the spreader disc was related to the revolution per minute and the diameter of the spreader disc as given by equation 3.13

$$V_D = \frac{\pi N}{60} D \quad (3.13)$$

Where,

V_D = peripheral speed of the spreader disc assembly (m/s)

N = revolution per minute of the spreader disc assembly (450 rpm)

D = diameter of spreader disc (0.34 m)

$V = 8.11$ m/s

3.3.11 Agitator shaft design

In order to withstand the stress on the agitator, the diameter of the agitator has to be determined to prevent avoidable system failure against centrifugal force developed on the shaft. Kreg (1975) stated that the diameter of an agitator to withstand the stress is a function of the unit stress that acts on the agitator,.

3.3.11.1 Determination of stress on the walls of agitator per unit area

The formula for determining the stress per unit area on the wall of the agitator as established by Kreg (1975) was utilized. The value was used to select appropriate agitator material that will withstand failure.

$$\delta_b = \frac{2W_{Ta}}{\pi d_k^2} \quad (3.14)$$

Where,

δ_b = stress on the wall of the agitator material per unit area (N/m²)

d_k = diameter of the agitator shaft (m)

W_{Ta} = total weight of agitator assembly (N).

$W_{Ta} = M_{Ta} g$

Where,

M_{Ta} = total mass of agitator assembly (2.41 kg), as computed in equation (3.5)

$$W_{Ta} = 23.62 \text{ N}$$

$$\delta_b = 15.035 (d_k)^{-2} \text{N/m}^2$$

3.3.11.2 Determination of the diameter of the agitator shaft

the diameter of the agitator shaft and the maximum permissible stress of the material expressed by equation 3.15. Using ASAE (2003) code for steel which gives the steel permissible stress (δ_p),

δ_p = permissible stress of the agitator material ($42 \times 10^6 \text{ N/m}^2$)

$$d_k = \frac{\delta_b D_h}{2\delta_p} \quad (3.15)$$

Where,

d_k = diameter of the agitator shaft (m)

δ_b = stress on the wall of the agitator material per unit area ($15.035 (d_k)^{-2} \text{ N/m}^2$), as computed in equation (3.14)

δ_p = permissible stress of the agitator material ($42 \times 10^6 \text{ N/m}^2$)

D_h = diameter of hopper bottom (0.75 m)

$$d_k^3 = 1.3424 \times 10^{-7} \text{ m}$$

$$d_k = 0.00512 \text{ m} = 5.12 \text{ mm}$$

3.3. 11.3 Torque required to turn the spreader disc and the agitator

The torque required to turn the spreader disc and agitator was given by equation 3.16 by Khurmi and Gupta, (2005). This include:

i) The force required to turn the disc, agitator and amount of manure on the disc

ii) Agitation work (resistance of the manure to agitation)

$$T = (F_c + F_{rm}) \times r \quad (3.16)$$

Where,

T = torque of the spreader disc and agitator (Nm)

F_c = Force required to turn the spreader and agitator (2257.15 N), as calculated in equation (3.11)

$F_{rm} = \mu N_w$ = Resistance force of manure to agitator (N)

r = radius of the spreader disc assembly (m)

Where,

μ = Coefficient of friction, $\mu = 0.4$ average value for farmyard manure by Singh and Singh (2006)

N_w = Normal force (weight of the manure), $N_w = 1262.24$ N as computed in eq. (3.2)

$$F_{rm} = 504.89 \text{ N}$$

$$T = 469.54 \text{ Nm}$$

3.3.11.4 Torsional deflection of the shaft carrying the spreader disc and agitator

For the shaft to withstand torsional deflection, the angle of twist was calculated as follows:

$$\theta_T = \frac{584TL}{G_T d_k^4}$$

θ_T = Angle of twist in radians

G_T = Modulus of torsional shear, 80 Nm^{-2} for steel material (Khurmi and Gupta, 2005)

L = Length of agitator shaft, 0.21 m, (Arbitrary selected)

$$\theta_T = 0.014 \text{ rad}$$

3.3.11.5 Determination of shaft size carrying the disc and agitator

The required size to overcome torsional moment is computed by the equation given by Khurmi and Gupta (2005)

$$d^3 = \frac{16M_t}{\pi\tau_a} \quad (3.17)$$

Where,

d = spindle size (m)

M_t = Torsional moment (1202.07 Nm) as computed in eq. (3.16)

τ_a = Allowable shear stress of material ($42 \times 10^6 \text{ N/m}^2$). Khurmi and Gupta (2005)

$d = 52 \text{ mm}$

3.3.12 Power required to move the manure to the desired swath width

The power required to spread the manure is determined by the use of an equation (Khurmi and Gupta, 2005) is given in equation 3.18. Computing the power helps in matching the machine spreader with the right Tractor.

$$P = \frac{2\pi N_{pn} T}{60} \quad (3.18)$$

Where,

P = power required (Watt)

N_{pn} = speed of the spreader disc (450 rpm)

$P = 22126.55 \text{ W} = 22.12 \text{ kW}$

3.3.13 Determination of the rate of manure discharge

The rate of manure discharge determines the rate of spread/swath width of manure being dispersed. The rate of manure discharge and spread is determined by the equation 3.19

$$Q = v_{md} A_{md} \quad (3.19)$$

Where,

Q = Discharge rate (m^3/s)

A_{md} = Area of manure delivery hole, arbitrarily selected ($4.42 m^2$)

v_{md} = Speed at which manure is delivered and spread ($19.22 m/s$), as computed from equation (3.13)

$$Q = 0.085 m^3/s$$

3.3.14 Design of bevel gears

3.3.14.1 Introduction

In this design straight-bevel gear will be employed and design as given by (Chironis, 1967). Bevel gears transmit power most efficiently.

3.3.14.2 Pressure angle

The pressure angle in gear design depends on the number of teeth on the pinion and the gear ratio. However, straight-bevel gears have standard pressure angle of 20 degree (Chironis, 1967).

3.3.14.3 Bevel gear design consideration

The gears can be designed for surface durability and strength using the following two equations

Surface Durability

$$T_d = \frac{FK_v}{2K_m} \times \left(\frac{S_c d}{C_p}\right)^2 \quad (3.21)$$

Strength

$$T_d = \frac{FJK_v(S_t d)}{2K_s K_m P_d} \quad (3.22)$$

The smaller of the two values of T_d is to be used.

Where,

T_d = maximum allowable torque, N-m

S_c = allowable contact stress

S_t = allowable bending stress

d_d = pinion pitch diameter at larger end of tooth, (m)

P_d = diametral pitch at large end of tooth

F_d = face width, (m)

C_p = elastic coefficient

I = geometry factor (durability)

J = geometry factor (strength)

K_m = load distribution factor

K_v = dynamic factor

K_s = size factor

Computed value of T from either of the above torque equations is not less than the design pinion torque.

3.3.14.4 Bevel gear dimensions

The bevel gear dimensions needed for workshop construction as calculated in appendix A, for both the pinion and the gear, being of equal size, are summarised in table 3.1, nomenclature of the bevel gear is also presented in figure 3.4.

3.3.15 Design of flow rate control

Design was conducted arbitrarily as presented in sheet 10 and 11 with required specifications

3.3.16 Design of screen

Design was conducted arbitrarily as presented in sheet 10 and 11 with required specifications.

Table 3.1: The Bevel Gear Parts and Dimensions

S/N	Parts	Dimensions
1.	Number of pinion teeth, N_p	22
2.	Number of gear teeth, N_G	22
3.	Dimetral pitch, pd	6.56
4.	Face width, F	19 mm
5.	Working depth, h_k	8 mm
6.	Whole depth, h_t	9 mm
7.	Pressure angle, ϕ	20°
8.	Shaft angle, ϵ	90°
9.	pitch diameter, d	84 mm
10.	pitch angle, $\gamma = \gamma_1$	45°
11.	Outer cone distance, A_o	59 mm
12.	Circular Pitch, P	12 mm
13.	Addendum, $a_{op} = a_oG$	4 mm
14.	Dedendum, $b_{op} = b_oG$	4.6 mm
15.	Clearance, C	1 mm
16.	Addendum angle (face angle), $\gamma_0 = \gamma_0$	49°27'
17.	Dedendum angle, $\delta_p = \delta_G$	4°27'
18.	Root angle (base angle), $\gamma_R = \gamma_R$	40°33'
19.	Outside diameter, $d_o = D_o$	89 mm
20.	Pitch apex to crown, $X_o = x_o$	39 mm
21.	Circular thickness, $t = T$	6 mm

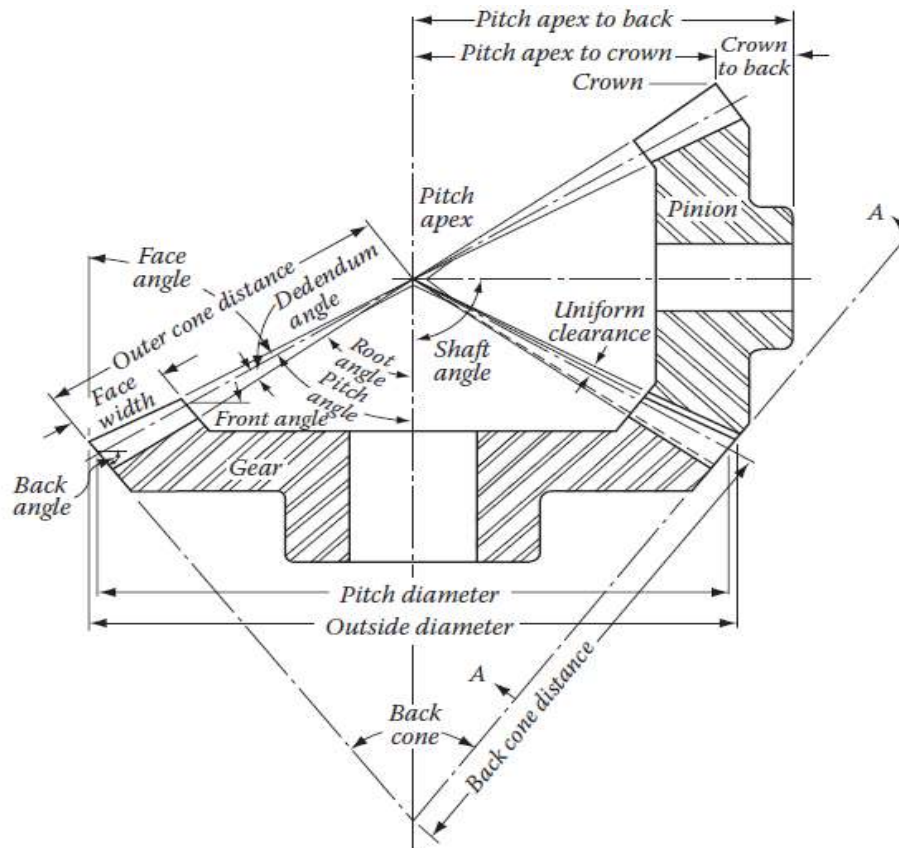


Fig. 3.4: Numenclature of the bevel gear (Chironis, 1967).

3.4 Construction Materials

The construction materials were selected based on availability locally, cost, durability, strength and resistance to corrosion. Angle iron of size 250 mm × 250 mm × 2 mm made of mild steel was chosen for the frame of the spreader, metal sheet made of mild steel was used for hopper construction and aluminium material for the spreader disc to prevent corrosion.

3.5 Operational Procedure

The solid manure was fed into the hopper manually (batch loading) at appropriate height flowrate control. The manure flowed by gravity down onto the spreading disc and with the help of an agitator, the manure clods are broken into smaller pieces. The centrifugal force aided by the rotating spreader disc eventually spreads the manure onto

the fields The two shorter fins and six longer fins helped in spreading manure to near and far distance respectively. Design length was adopted from the IAR imported spreader.

3.6 Instrumentation

The following instruments were used during the experiment

- i. **Tachometer:** This was used to determine the speed of the prime mover shaft in revolutions per minute (rpm). Description; Make; Lutron, Model: DT-2234B photo Tachometer, Resolution: 0.1 RPM < 1,000 RPM, Accuracy: +/- (0.05 % + 1 digit)
- ii. **Weighing balance:** This measured the weight of manure materials in kilogram. Description; Brand: Camry, Maximum Capacity 500 kg with 50 g increment, precision 1/3000 F.S, working current 500 mA
- iii. **Stop watch:** This was used to measure time of spreading during the experiment. Description; Make: Racer. Model: TM 3007
- iv. **Tape:** This was used to measured the width and distance covered by the manure after spreading operation. Description; Brand: Tamiya. Model: TAM87030

3.7 Performance Evaluation of the Machines

The developed machine as indicated in Plate 3.1 and the imported machine were both evaluated in the laboratory but further evaluation was done on the field for the developed machine as presented in Plate 3.3. Each of the spreader machine was mounted on the three point linkage of the tractor by the help of the hydraulic system. The attachment of the power source was also mounted, this is shown in Plate 3.2. Before the experiment began. The developed machine was evaluated based on four parameters viz: spreading distribution, effective field capacity, field efficiency ,flow

rate, application rate, swath width and of the spreader. Plate 3.1 shows the developed machine under construction and plate 3.2 shows the machine during test running and coupled to the Tractor PTO shaft and 3 point linkage, plate 3.3 shows the developed manure spreader under field operation



Plate 3. 1: The Developed Spreader



Plate 3. 2: Mounted Manure Spreader



Plate 3.3: Developed Manure Spreader Under Operation

3.7.1 Laboratory test

A preliminary test was first conducted in the laboratory to determine the machine flow rate [quantity in kilogram discharged per hour (kg/h)] at 3 levels of flow height (F1 = 15cm, F2 = 30cm and F3 = 45cm) and 3 levels of disc peripheral speed (150, 300 and 450 rpm) at a stationary position. This is where collection trays were used to determine the spread distribution pattern of manure spread. This method was used to carry out preliminary test on the imported spreader and also the developed spreader after construction

The experimental procedure began by measuring the moisture content of manure (cow dung) using gravimetric method on dry basis. Weights of 40 kg (as sold in the market)

were measured and used for each experiment. After uploading the measured manure into the hopper, the stop watch starts simultaneously as the spreading begins

Time taken: The time taken for the machine to complete spreading operation in a constant forward speeds (8 km/hr) using 40 kg of manure at every replicate of F₁, F₂ and F₃ calibrations, was recorded with a stop watch that reads both minutes and seconds. This was carried out for both IAR and developed machines

Moisture content

Moisture content for manure was determined to be 11.17 % d.b after the manure samples were oven dried and measured consistently until there is no change in weight at 105°C. the results where measured and recorded. The optimum moisture content for spreading solid manure is 15 % as cited in Sapkale (2010). The recommended formula by ASAE (1983) for estimating the mixture content on dry basis is given as in Equation (3.17):

$$M_{db} = \frac{w-w_d}{w_d} \times 100 \quad (3.17)$$

Where ;

M_{db} = Moisture content on dry basis (%)

w = Initial mass of sample (g)

w_d = Mass of dry sample (g)

$$M_{db} = \frac{150.3-135.2}{135.2} \times 100\% \quad M_{db} = 11.17\%$$

3.7.2 Field test

For the field test the same procedure was followed during the laboratory test but this time on a 100 m x 25 m field and a tractor forward speed of 8.2 Km/h . After uploading the measured manure into the hopper, the stop watch starts simultaneously as the

spreading begins, effective time, delay and total time are recorded. The swath width was also recorded and average taken.

3.7.3 Experimental design

The independent variable were disc peripheral speeds and flow heights. The tractor forward speed was taken at 8 km/h, three levels of spreader disc speed of 150, 300, and 450 rpm (as used by Bogomir and Tone (2000) along side with three levels of flow height of 15, 30 and 45 cm were considered. Manure type taken, was Cow Dung. The experiment was laid in CRD with three replications. The parameters gave 3×3 factorial experiment fitted in Completely Randomised Design (CRD). The independent variables are presented in table 3.2 and the experimental layout are presented in appendix B

Table 3. 2: The independent factors for the study

Factors	Levels
PTO Speed, <i>S rpm</i>	(<i>S</i> ₁ , <i>S</i> ₂ , and <i>S</i> ₃)
Flow height <i>cm</i>	(<i>F</i> ₁ , <i>F</i> ₂ and <i>F</i> ₃)

3.7.4 Determination of field efficiency of the spreader

The spreading efficiency of spreader was determined using Equation (3.13) and (3.14). It gave the actual time required to perform the operation. Time loss due to overlap, turning, loading and unloading the materials were duly accounted.

$$FE = \frac{T_t - T_d}{T_t} \quad (\text{Singh and Singh, 2014}) \quad (3.13)$$

$$T_t = (T_e + T_d) \quad (3.14)$$

Where:

FE = Field efficiency

T_t = Total time required to spread manure including delayed time, min

T_e = Total effective time in spreading manure, min

T_d = Total delay time required for cleaning, turning, reloading and repair, min

3.7.5 Spread distribution pattern of the spreader

According to Lawrence and Yule (2005), the ASAE 341.2 standard collection tray method of determining spreading uniformity was used by placing six collection trays at right angle to the direction of travel of the spreader. Each of the trays has a dimension 0.5 m x 0.5 m x 0.3 m. The distance between the trays was 0.6 m. The sample from each collection tray was collected in polythene bags and labelled. The samples were weighed and presented graphically.

3.7.6 Determination of effective width of the spreader

The effective width of the manure spreader was measured using a tape after manure has been spread in three randomly places and the average taken.

3.7.8 Determination of effective field capacity of the spreader

The effective field capacity of the spreader was calculated using Equation (3.16) given by ASAE (1983)

$$C_{\text{eff}} = \frac{SW}{10} \times FE, \text{ ha/h} \quad (3.16)$$

Where:

C_{eff} = Effective Field Capacity of the manure spreader, ha/h

S = Forward speed of the tractor during the operation, km/h

W = Swath width of the manure spreader, m

FE = Field efficiency

3.7.9 Determination of application rate of machine

The application rate is determined in kg/ha after a known quantity of manure is spread over a known area, all treatments and the mean was taken.

3.7.11 Determination of machine flow rate

The flow rate is determined by recording the time it takes to spread a known quantity of manure in kilogram per hour.

3.8 Statistical Analysis

Data from the performance evaluation of the developed machine and the imported machine was subjected for comparison and to Analysis of Variance (ANOVA) using SAS (V.9.0). Duncan's Multiple Range Tests (DMRT) was used to rank the significance means. Graphs were generated using Microsoft Excel

3.8 Machine Production cost

For the purpose of this machine, three costs are considered to make the work complete.

The cost analysis is therefore computed under the following groups:

- Material cost
- Labour cost
- Miscellaneous
- Total cost

Material cost: This is the cost of the materials used in the fabrication of the spreading machine. Table 3.6, Shows the cost of each material, the quantity bought and the unit price of each of the materials used in the fabrication.

Labour cost: This is the cost of workmanship which comprises cutting, welding and painting.

Miscellaneous: These are cost incurred in the cause of production. It accounts for transportation and other out of pocket expenses.

Total cost: This is the production cost of the machine consisting of material, labour and miscellaneous.

The proposed bill of Engineering material at the time of construction are summarized in Table 3.6

Table 3.6: Material and Cost

Material	Quantity	Unit cost (₦)	Total (₦)
Metal sheet	2 Sheet	8,500	17,000
Bearing	2	6,000	12,000
Electrode	2 Sachet	4000	8000
Mesh wire (45" x 71")	1/2 yards	500	500
Angle iron (250 mm × 250 mm × 2 mm)	6	3,500	19,500
Gear box(Jackton, 40HP, 30 Kw K Series motor reduction, Helical Bevel Gear Drive)	1	30,480	30,480
Shaft	3ft	12500	12500
Bolts and nuts	20	100	2,000
Coupel	2	1000	2000
Diesel	8 litres	245	1960
Total			105,440

Labour cost = ₦ 50,000

Miscellaneous = ₦ 10,000

Total production cost = ₦165 ,440

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Developed Parts of the Constructed Manure Spreader

A summary detailing the developed parts of the solid manure spreader is presented in Table 4.1

Table 4.1: Description of developed parts of the Solid Manure Spreader

Parts	Description
Hopper	Hopper capacity was increased from 0.38 m ³ to 0.56 m ³ and it's base opening from 10 to 15 cm in diameter
Agitator	The agitator was redesigned by increasing the length of spikes from 15 to 35 cm and the number of spikes on agitator were increased from 4 to 6, with 3 spikes each at the bottom and top part of the agitator(arbitrary selection), the top set of spikes can be adjustable in height.
Screen	The size of the screen was increased for the developed spreader from 2 to 5 cm to increase application rate, screen area was reduced from 115 cm to 30 cm .
Spreader disc	The number of spreader discs was reduced from 2 to 1 this also reduced the number of gear box from 2 to 1.
Frame	The frame was constructed from available local material

4.2 Spreading Capacity of IAR Imported and Developed Spreader

A preliminary test was carried out on the IAR imported manure spreader. The spreader was tested on a stationary position and a selected gear speed that runs at 8 km/h. The readings recorded were shown in Table 4.2. The highest average spread capacity was recorded at flow height mechanism setting 'U' with 2000 kg/h and swath width of 10 m, the lowest average spread capacity was 432.79 kg/h with a swath width of 8.63 m at flow rate setting 'A'. Comparing both manure spreaders from Table 4. 2. It is seen that the developed spreader spreads more manure in less time compared to the imported

spreader, 2000 kg/h was the highest recorded for the imported spreader and 4131.41 kg/h was the highest recorded for the developed spreader after using the same quantity of 40 kg of manure.

Table 4.2: Spread Capacity, Time and Swath Width of the Spreaders.

Flow rate setting	Rep	Machine Capacity (kg/h)	Swath Width (m)
IAR Imported Spreader			
A	1	430.87	8.6
	2	441.98	8.8
	3	425.53	8.5
Mean		432.79	8.63
K	1	685.71	9.6
	2	623.37	9.9
	3	661.16	9.9
Mean		659.75	9.8
U	1	1935.48	9.8
	2	1690.4	10
	3	2000	10
Mean		1875.21	10
Developed Spreader			
F1	1	2862.02	7.37
	2	3105.92	7.70
	3	3065.98	7.43
Mean		3011.31	7.50
F2	1	3634.10	8.70
	2	3587.11	9.10
	3	3897.89	9.23
Mean		3706.37	9.01
F3	1	4109.93	10.50
	2	4005.05	10.33
	3	4131.41	10.27
Mean		4082.13	10.37

4.3 Spreading Distribution Pattern of IAR Imported Spreader and Developed Spreader

Figures 4.1 and 4.2 show the pattern of flow height with respect to disc speed respectively on spread distribution for the Imported manure spreader. K and U gave normal distribution pattern (Fig 2.3). A settings gave an offset distribution (Fig 2.5)

this agrees with Lary and Allan (2012). In terms of the disc speed, spreading was more uniform on 150 rpm and 450 rpm compared to 300 rpm. Deposits of manure did not give a uniform spread distribution as the speeds increases

Visually from the figures, Figures 4.3 and 4.4 showed the pattern of disc speeds with respect to flow height on spread distribution for the developed spreader. It gave a uniform distribution pattern at disc speed of 300 rpm, followed by 150 rpm and least distribution pattern at 450 rpm as shown in Figure 4.3. The three distribution pattern agreed with the result obtained by (Lary and Allan, 2012) as seen in Figure 2.3 and referred to as normal spread distribution. A record of 2.69 kg of manure was seen at disc speed of 450 rpm and reduced with decrease in the disc speed. This might be attributed to less disc speed which leads to less deposit of manure per unit area.

In Comparing the performance of the imported manure spreader with the modified spreader (Fig 4.2 and Fig 4.4) respectively, figure 4.4 gave a better graphical understanding of how weight of manure was uniformly deposited with respect to flow height mechanism. This agreed with the result obtained by (Lary and Allan, 2012) as seen in Figure 2.3 and referred to as normal spread distribution . As the flow height was increased, the amount of manure deposited per unit area also increased.

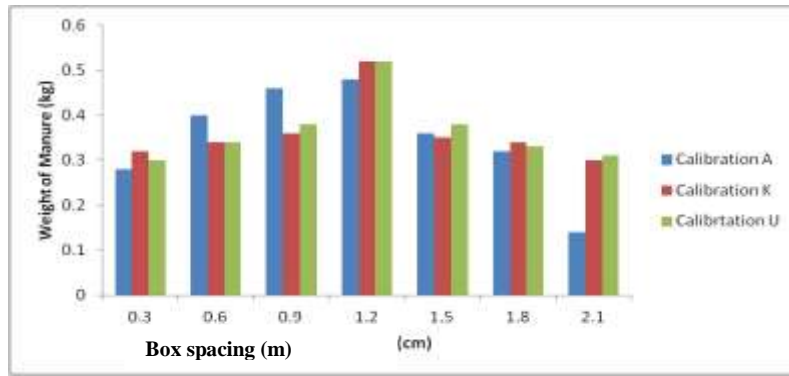


Fig 4.1: Flow height with respect to spread distribution for the imported spreader

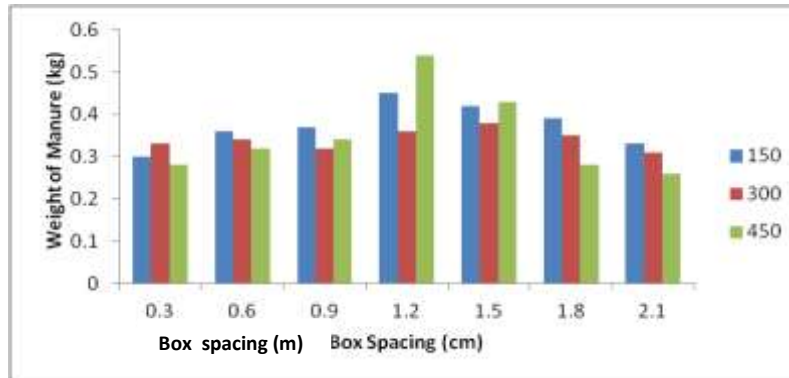


Fig 4.2: Disc Speed with respect to spread distribution for imported spreader

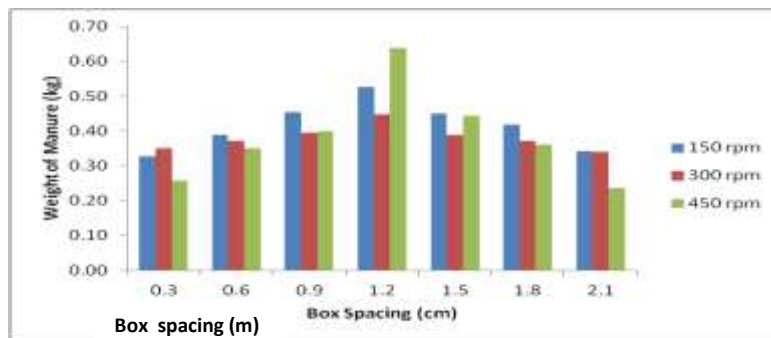


Fig 4.3 Disc Speed with respect to spread distribution for developed spreader

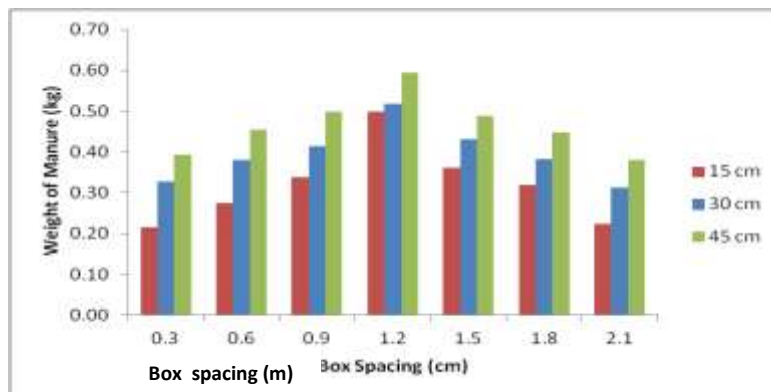


Fig 4.4: Flow height with respect to spread distribution for developed spreader

4.4 Effective Field Capacity of Developed Spreader

The result of analysis of variance (ANOVA) of the effects of flow height and disc speed on effective field capacity is presented in Table 4.3. The effect of flow height and the disc speed were highly significant on effective field capacity of the developed spreader . The interaction effect was significant on the effective field capacity, this agrees with Thakur *et al.*, (2015)

Table 4.3 : ANOVA Table for the Effect of Disc Speed and Flow height on Effective Field Capacity

Source	DF	SS	MS	F-value	Pr>F
Speed (S)	2	376.1927463	188.0963731	304.34**	<.0001
Flow height (F)	2	183.0955130	91.5477565	148.12**	<.0001
S*F	4	4.8964259	1.2241065	1.98*	0.0495
Error	18	11.1248167	0.6180454		
Total	26	575.3095019			

*= Significant at ($P \leq 0.05$), **= Significant at ($P \leq 0.01$)

Further analysis using Duncan Multiple Range Test (DMRT) to rank the significance means of disc speeds and flow height and their interaction on effective field capacity were presented in Table 4.4 and 4.5 respectively. Table 4.4 showed increase in effective field capacity as disc speed and flow height increased, this agrees with Batta *et al.*, (2015). Higher effective field capacity of 8.6 and 8.5 ha/h were obtained at 450 rpm and 45 cm respectively and lower with 5.31 and 6.4 ha/h at 150 rpm and 15 cm respectively. This may be attributed to the increase in swath width as the speed increased. The effects of levels of speeds and flow height were statistically different at all levels. The effect of interaction between disc speeds and flow height on effective field capacity is shown in Table 4.5. Higher effective field capacity of 9.8 ha/h was obtained at a combination of 45 cm flow height and 450 rpm disc speed and lowest at 15 cm flow height and 150 rpm disc speed with effective field capacity of 4.4 ha/h. The effective field capacity were statistically the same at 30 cm flow height for 300 and 450 rpm disc speeds and 45 cm flow height for 300 and 450 rpm disc speeds. The table showed as the flow height increases the machine effective field capacity increases.

Table 4.4: DMRT Ranking of Disc Speeds and Flow height on Effective Field Capacity

Treatment	Effective Field Capacity (ha/h)
<u>Speed (rpm)</u>	
150	5.31c
300	8.2b
450	8.6a
SE±	0.262
<u>Flow height (cm)</u>	
15	6.4c
30	7.5b
45	8.5a
SE±	0.262

*= Significant at ($P \leq 0.05$) s followed by the same letter(s) in the column are not different statistically at $P=0.05$ using DMRT.

Table 4.5: DMRT Ranking of Interaction between Disc Speeds and Flow height on Effective Field Capacity

Treatment	Effective Field Capacity (ha/h)		
	Speed (rpm)		
	<u>150</u>	<u>300</u>	<u>450</u>
<u>Flow height (cm)</u>			
15	4.4f	6.4d	7.5c
30	5.3e	8.2b	8.6b
45	6.5d	9.4a	9.8a
SE±	0.454		

s followed by same letter(s) in the same column and row are not different statistically at $P=0.05$ using DMRT.

4.5 Field Efficiency of the Developed Spreader

The result of ANOVA for the effect of flow height and disc speeds on machine efficiency is presented in Table 4.6. The effects of disc speed and the effect of interaction for speed/flow height on the machine efficiency were not significant on the field efficiency of the developed spreader. But the effect of flow height is significant at ($P \leq 0.05$).

Table 4.6: ANOVA Table for the Effect of Disc Speeds and Flow height on Machine Efficiency

Source	DF	SS	MS	F-value	Pr>F
Speed (S)	2	17.166881	8.583440	0.01NS	0.9897
Flow height (F)	2	7396.876632	3698.438316	4.44*	0.0270
S*F	4	2135.451343	533.862836	0.64NS	0.6400
Error	18	14986.71979	832.59554		
Total	26	24536.21465			

NS= Not significant, *= Significant at ($P \leq 0.05$)

Further analysis using DMRT to rank significant means of flow height is presented in Table 4.7. The effect of flow height was statistically the same at 15 cm and 45 cm with an efficiency of 89.4 % and 100% respectively. It was statistically lower at 30 cm

Table 4.7: DMRT Ranking of Flow height on Field Efficiency

Treatment	Field Efficiency (%)
<u>Flow height (cm)</u>	
15	89.4a
30	60.8b
45	100.0a
SE \pm	9.618

NS=Not significant s followed by the same letter(s) in the column are not different statistically at $P=0.05$ using DMRT.

4.6 Flow Rate of the Developed Spreader

The result of ANOVA for the effects of flow height and disc speeds on spreading capacity is presented in Table 4.8. The effect of flow height and the disc speeds were highly significant at ($P \leq 0.01$) on the flow rate of the developed spreader this agrees with Suthakar *et al.*, (2008). The interaction effect was also significant at ($P \leq 0.05$), on the spreading capacity.

Table 4.8: ANOVA Table for the Effect of Disc Speeds and Flow height on Flow rate

Source	DF	SS	MS	F-value	Pr>F
Speed (S)	2	21775407.84	10887703.92	221.67**	<.0001
Flow height (F)	2	1552966.50	776483.25	15.81**	0.0001
S*F	4	175616.23	43904.06	0.89*	0.0499
Error	18	884110.15	49117.23		
Total	26	24388100.72			

*= Significant at ($P \leq 0.05$), **= Significant at ($P \leq 0.01$)

Further analysis using DMRT to rank the effect of disc speed and flow height and their interaction on flow rate were presented in Table 4.9 and 4.11 respectively. Table 4.9 showed increase in flow rate as disc speed and flow height increased. This may be attributed to the increase in capacity as the speed increased, it also agrees with (Patil and Munde, 2017). The spread capacity at all levels of speed were statistically different at all levels and statistically the same at 30 and 45 cm flow height. The effect of interaction between disc speeds and flow height on flow rate was shown in Table 4.11. Higher flow rate of 3938.1 kg/h was obtained at 45 cm flow height and 450 rpm, and lowest flow rate of 1070 kg/h at 15 cm and 150 rpm. At 300 rpm disc speed the spread capacity were statistically the same at all levels of flow height, this also agrees with Batta *et al.*, (2015). The spread capacity at 150 rpm for flow height 30 and 45 cm are statistically the same, but higher than those values at 15 cm.

Table 4.9: DMRT Ranking on Disc Speed and Flow height on Flow rate

Treatment	Flow rate (kg/h)
<u>Speed (rpm)</u>	
150	1469.4c
300	2426.6b
450	3663.2a
SE \pm	73.875
<u>Flow height (cm)</u>	
15	2185.1b
30	2639.2a
45	2734.9a
SE \pm	73.875

*= Significant at ($P \leq 0.05$) s followed by the same letter(s) in the column are not different statistically at $P=0.05$ using DMRT.

Table 4.11: DMRT Ranking on Interaction between Disc Speed and Flow height on Flow rate

Treatment	Flow rate (kg/h)		
	Speed (rpm)		
	<u>150</u>	<u>300</u>	<u>450</u>
<u>Flow height (cm)</u>			
15	1070.0e	2251.5c	3233.8b
30	1633.3d	2466.5c	3817.8a
45	1704.8d	2561.8c	3938.1a
SE±	127.955		

s followed by same letter(s) in the same column and row are not different statistically at $P=0.05$ using DMRT.

4.7 Application Rate for Types of Machine

The result of ANOVA for the effect of flow height with respect to the types of machines on application rate was presented in Table 4. 12. The effect of types of spreaders, the flow height and their interaction were all highly significant at ($P \leq 0.01$) on the application rate for the types of machine, this agrees with Sharabasy *et al.*, (2007), who states as the gate opening of a spreader is increased the application rate also increases.

Table 4.12: ANOVA Table for the Effect of Types of Manure Spreaders and Flow height on application rate

Source	DF	SS	MS	F-value	Pr>F
Type of machine (T)	1	30693383.07	30693383.07	2376.71**	<.0001
Flow height (F)	2	4851601.46	2425800.73	187.84**	<.0001
T * F	2	535187.91	267593.95	20.72**	0.0001
Error	12	154970.58	12914.21		
Total	17	36235143.01			

**= Significant at ($P \leq 0.01$)

Furthermore DMRT, was used to rank the types of manure spreaders and flow height on application rate (Table 4.13). The developed machine has higher application rate (3599.9 kg/ha). And both machines were statistically different at all levels of flow height, with the developed and imported machines both having an application rate of 3599.9 kg/ha and 988.3 kg/ha respectively. Table 4.14 shows the effect of interaction between types of machine and flow height on the application rate. The application rate

for both the developed and imported spreader were statistically different at all levels of flow height. The modified machine indicated the highest application rate with 4082.1 kg/ha at 45 cm flow height and the imported machine indicated the lowest with 432.8 kg/ha at 15 cm flow height. The application rate increases with the increase in flow height. This trend could be due to the fact that as the flow height increases, it leads to larger opening and this increases the application rate, this agrees with (Jain and Lawrence, 2015) and Sharabasy *et al.*, (2007)

Table 4.13: DMRT Ranking on Effect of Machine type and flow height on application rate

Treatment	Application Rate (kg/ha)
<u>Type of machine</u>	
Developed type	3599.9a
Imported type	988.3b
SE±	37.880
<u>Flow height (cm)</u>	
15	1722.1c
30	2181.6b
45	2978.7a
SE±	46.394

**= Significant at ($P \leq 0.01$) s followed by same letter(s) in the same column are not different statistically at $P=0.05$ using DMRT.

Table 4.14: DMRT Ranking on Effect of interaction between type of machine and flow height on application rate of manure spread

Treatment	Application Rate of Manure spreader (kg/ha)	
	Type of machine	
	<u>Developed type</u>	<u>Imported type</u>
<u>Flow height (cm)</u>		
15	3011.3c	432.8f
30	3706.4b	656.7e
45	4082.1a	1875.3d
SE±	65.610	

s followed by same letter(s) in the same column and row are not different statistically at $P=0.05$ using DMRT.

4.8 Swath Wdth for Type of Machines at various Flow Heights

The ANOVA of the effect of types of machine with respect to flow height on swath width is presented in Table 4.15. The effect of type of spreader, the flow height and their interaction were all highly significant at ($P \leq 0.01$) on swath width.

Table 4.15: ANOVA Table for the Effect of Types of Manure Spreaders and Flow height on Swath Width

Source	DF	SS	MS	F-value	Pr>F
Type of machine (T)	1	1.10839506	1.10839506	35.14**	<.0001
Flow height (F)	2	13.37419753	6.68709877	212.00**	<.0001
T * F	2	2.03345679	1.01672840	32.23**	<.0001
Error	12	0.37851852	0.03154321		
Total	17	16.89456790			

**= Significant at ($P \leq 0.01$)

Furthermore DMRT, was used to rank the effect of types of manure spreaders and flow height on swath width in Table 4.16. The ranking on the effect of flow height on swath width for both the developed and imported machines showed statistical difference with 9 m and 9.5 m for both the developed and imported spreader respectively. A higher swath width of 10.2 m at 45 cm and a lowest swath width of 8.1 m at 15 cm were recorded. Table 4.17 shows the ranking on the effect of interaction between types of machines and flow height on swath width of manure spread. The effect of interaction for the types of machines and flow height mechanism on the swath width for the developed type are statistically different at all levels of flow height mechanism and statistically the same at 30 and 45 cm flow height mechanism and different from 15 cm for the imported type, this agrees with Reddy *et al.*, (2013). The imported machine has the higher swath width of 9.5 m as against 9.0 m for the developed machine.

Table 4.16: Effect of Types of Spreader on Swath Width

Treatment	Swath width (metres)
<u>Type of machine</u>	
Developed type	9.0b
Imported type	9.5a
SE±	0.059
<u>Flow height (cm)</u>	
15	8.1c
30	9.4b
45	10.2a
SE±	0.073

**= Significant at ($P \leq 0.01$) s followed by same letter(s) in the same column are not different statistically at $P=0.05$ using DMRT.

Table 4.17: Effect of Interaction between Type of Machine and Flow height on Swath Width of Manure Spread

Treatment	Swath width of Manure spread (metres)	
	Type of machine	
	<u>Developed type</u>	<u>Imported type</u>
<u>Flow height (cm)</u>		
15	7.5e	8.6d
30	9.0c	9.8b
45	10.4a	9.9b
SE±	0.103	

s followed by same letter(s) in the same column and row are not different statistically at $P=0.05$ using DMRT

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

The research work titled development of a tractor powered solid manure spreader was carried out at Department of Agricultural and Bio-resources Engineering, Ahmadu Bello University, Zaria. The preliminary study of the imported manure spreading machine was carried out and the average highest spreading capacity was found to be 2000 kg/hr with swath width of 10 m. Problems identified were addressed through modification of some of the major components of the developed spreader such as hopper, agitator, disc, screen and frame.

The developed machine was evaluated using three levels of disc speeds, three levels of flow height arraigned in $3 \times 3 \times 3$ factorial experiment. The data collected were statistically analyzed using analysis of variance (ANOVA) for field efficiency, spread capacity and effective field capacity at 1% and 5% levels of significance. Significant values were further analyzed using Duncan Multiple Range Test (DMRT). The best performance of the developed machine was found at a combination disc speed of 450 rpm and 45 cm flow height mechanism. The machine efficiency, effective field capacity, spread capacity and swath width at this combination are 82.61 %, 22 ha/h, 2734.9 kg/h and 9 m respectively.

In comparing the developed and imported machines, the imported machine has the higher swath width of 9.5 m as against 9.0 m for the developed machine, the modified machine indicated the highest application rate with 4082.1 kg/ha at 45 cm flow height mechanism and the imported machine indicated the lowest with 432.8 kg/ha at 15 cm flow height mechanism.

5.2 Conclusions

The preliminary study of the imported spreader was conducted. Problems of ineffective agitation, lower application rate, uneven spread distribution and high cost associated with the imported spreader were addressed. A tractor powered solid manure spreader was designed and a prototype was fabricated using locally available materials. The developed machine was able to accommodate large clods of manure (cow dung), break it down and spread it efficiently without clogging unlike the imported version.

1. Preliminary evaluation was conducted on the imported IAR manure spreader, the machine was tested on a stationary position and a selected gear speed that runs at 8 km/h. The highest average flow rate was recorded at flow height setting 'U' with 2000 kg/h and swath width of 10 m and a swath width of 8.63 m at flow rate setting 'A'
2. The developed spreader has a maximum efficiency of 82.61% compared to the imported IAR manure spreader with 61.35%
3. The effective field capacity ranges from 4.4 ha/h at 150 rpm disc speed and 15 cm flow height to 9.8 ha/h at 450 rpm disc speed and 45 cm flow height at a tractor forward speed of 8.2 km/h
4. The flowrate of the developed spreader ranges from 1070 kg/h at 150 rpm to 3938.1 kg/h at 450 rpm respectively.
5. The constructed manure spreader gave a more uniform distribution pattern compared to the imported.
6. The developed spreader gave a capacity of 3599.9 kg/ha compared to the IAR imported machine with 988.3 kg/ha
7. The production cost of this machine stood at one hundred and sixty five thousand, four hundred and forty naira (₦ 165,440.00) only which is affordable compared to the

imported which cost (₦ 1,006,500 at the time of construction). Amazon and eBay (October 2019). This shows the developed spreader having 83.56 % reduction cost when compared with the existing one

5.3 Recommendations

For effective use and possible modification of the tractor powered manure spreader for spreading operation, the following are recommended

1. The height of flow rate control mechanism of 45 cm is recommended for effective spreading and higher spread capacity
2. The top spikes on the agitator above the screen should be made adjustable for different types of manures.
3. Machine can be evaluated using different types of manure, such as composed household waste, poultry droppings and goat droppings
4. The hopper capacity should be increased to reduce manure refilling frequency.
5. The flowrate metering mechanism can be further increased into 4 levels to increase application rate

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APPENDIX A: Determination of the Bevel Gear Size

The determination of pitch diameter, number of teeth, face width, working depth and whole depth etc. are based on durability and strength factors. The formulae, figures and tables referred to in this analysis are as given by Chironis (1967) and Stephen (2012). Though the references are in imperial unit, the final results are converted into S.I unit.

This bevel gear size determination is with respect to the bevel gear required to drive the agitator and the spreader disc with operating torque of 1.02 kNm .

But 1 kNm = 8840 lb-in

Therefore 1.02 kNm = 9016.8 lb-in

Design torque, T

T = operating torque x overload factor

$$T = 9016.8 \times 0.82 = 7393.78 \text{ lb-in}$$

Where, 0.82 is the overload factor, Chironis (1967)

Pinion Driven speed, N_p

This is the maximum speed of the spreader disc = 540 rpm. Since the pinion gear speed is less than 1000 rpm, straight bevel gear can be used Chironis (1967).

Gear ratio, m

Both the pinion and the gear have equal speed. Hence the gear ratio is unity

$$\text{i.e. } m = \frac{540}{540} = 1$$

Pinion pitch diameter

From Fig 3.1, for $T = 7393.78$ lb-in and $\frac{N_G}{N_P} = 1$, $d = 3$ in. Because this is an industrial design, Fig. 2 need not to be consulted. Since $\frac{N_G}{N_P} = 1$, the gear pitch diameter, $D = 3$ in. (76.2 mm)

Number of teeth

From Fig. 3 the pinion will have $N_P = 25$ teeth. Thus, for the gear, $N_G = 25$ teeth.

Face width, F

From Fig. 5, the face width of bath gear will be approximately $F = 0.9$ inches. (22.86 mm)

Pitch line velocity, V

$$V = \frac{\pi d S_G}{12}$$

Where,

$d =$ pinion pitch diameter = 3.0 in (76.2 mm)

$S_G =$ gear speed = 540 rpm

Therefore

$$V = \frac{3.142 \times 3 \times 540}{12} = 424.11 \text{ rpm}$$

Checking the size for durability and strength using the following factors:

Allowable contact stress , $S_C = 200,000$ psi, when both pinion and gear are made from case-hardened steel. Table viii, Chironis (1967).

Elastic coefficient, $C_p = 2800$, for steel. Table IX

Durability Geometry factor, $I = 0.016$, from Fig. 9. Load distribution factor, $K_m = 0.097$, when either the pinion or the gear is straddle mounted (i.e. one is over hanged).

Dynamic factoor, $K_v = 2.403$, from curve 2, Fig. 13.

Durability evaluation

$$T = \frac{FK_v}{2K_m} \times \left(\frac{S_c d}{C_p}\right)^2$$

$$T = \frac{0.73 \times 0.016 \times 2.403 \times (200000)^2 \times 3^2}{2 \times 0.097 \times (2800)^2} = 6643.26 \text{ lb-in (0.75kNm)}$$

Since the gears must be designed to carry the design torque, 7393.78 lb-in, the gear size should be increased slightly. To approximate the new size, multiply the trial pitch diameter by the square root of the design torque divided by the allowable torque from the first trial.

Therefore new pitch diameter:

$$d = 3.0 \times \frac{7393.78}{6643.26} = 3.34 \text{ in (84.84 mm)}$$

therefore, new face width, from Fig. 5

$$F = 0.75 \text{ in (19 mm)}$$

$$T = \frac{0.75 \times 0.016 \times 2.403 \times (200000)^2 \times (3.34)^2}{2 \times 0.097 \times (2800)^2} = 8459.99 \text{ lb-in (0.96 kNm)}$$

All the other values in equation 3 remain thesame. Use Eq. 3 to again check the allowable torque, 8459.99 lb-in exceeds the design torque 7393.78 lb-in, the size of the gear is alright base on durability.

Strength evaluation

Some factors used for durability evaluation and the following factors are used for checking the new size for strength. Strength Geometry factor, $J = 0.19$, from Fig. 11 size Factor, $K_s = 0.625$. from Fig. 14 when Diametral pitch,

$$P_d = \frac{N_p}{F} = \frac{22}{3.34} = 6.56$$

Allowable bending Stress, $S_t = 30,000$ psi, from Table VIII

$$\text{Diametral pitch} = \frac{22}{3.34} = 6.56$$

All other factors remain the same as for the durability evaluation, hence

$$T = \frac{FJK_v(S_t d)}{2K_s K_m P_d}$$

$$T = \frac{0.75 \times (0.19) \times (2.403) \times (30000) \times (3.34)}{2(0.625) \times (0.097) \times (6.56)} = 43137 \text{ lb-in, (4.88 kNm)}$$

Therefore, allowable torque for strength = 1275 lb-in (0.14 kNm)

Safety factors

$$\text{Safety factor for surface durability; } = \frac{\text{Allowable durability}}{\text{Design torque}} = \frac{8459.99}{7393.78} = 1.14$$

$$\text{Safety factor for strength, } = \frac{\text{Allowable torque for strength}}{\text{Design torque}} = \frac{43137}{7393.78} = 5.83$$

Working depth, h_k , in, from Table IV

$$h_k = \frac{2.000}{P_d}, \text{ for straight bevel gears}$$

$$= \frac{2000}{6.56} = 0.305 \text{ in (8.0 mm)}$$

Whole depth, h_t , in. From Table IV

$$h_t = \frac{2.188}{P_d} + 0.002 = \frac{2.188}{6.56} + 0.002 = 0.336 \text{ in (19 mm)}$$

Shaft angle, ε

The power is to be transmitted at right angle. Therefore the shaft angle, $\varepsilon = 90$ degree

Pitch angles; $\gamma = \gamma$

The pinion and the gear are of the same size. Therefore, the sizes of their pitch angle are equal.

$$= \tan^{-1} \frac{\sin \varepsilon}{\frac{N_G}{N_P} + \cos \varepsilon} = \tan^{-1} \frac{\sin 90}{1 + \cos 90} = 45 \text{ degree}$$

Outer Core distance, A_o

$$A_o = \frac{D}{\sin 45} = \frac{3.34}{\sin 45} = 2.37 \text{ in (59 mm)}$$

Circular pitch, P

$$P = \frac{3.1416}{P_d} = \frac{3.1416}{6.56} = 0.479 \text{ in (12 mm)}$$

Addendum, $a_{op} = a_{oG}$

$$= \frac{0.540}{P_d} + \frac{0.460}{P_d(N_G/N_P)^2} = \frac{0.540}{6.56} + \frac{0.460}{6.56(1)^2} = 0.152 \text{ in (4.0 mm)}$$

Dedendum, $b_{op} = b_{oG}$

$$= h_t - a_{op} = 0.336 - 0.152 = 0.184 \text{ in (4.6 mm)}$$

Clearance, C

$$C = \frac{0.188}{P_d} + 0.002 = \frac{0.188}{6.56} + 0.002 = 0.031 \text{ in (1 mm)}$$

Dedendum angle $\delta_p = \delta_G$

$$\delta_p = \tan^{-1} \frac{b_o}{A_o} + \Delta\delta$$

Where,

$\Delta\delta = 0$, for straight bevel gears (Chironis, 1967)

$$\text{Therefore, } \delta_p = \tan^{-1} \frac{0.184}{2.36} = 4.46 \text{ degree (4}^\circ 27' \text{)}$$

Face angle of blank, $\gamma_0 = \gamma_0$

$$\gamma_0 = \gamma + \delta_G = 45 + 4^\circ 27' = 49^\circ 27'$$

Root angle; $\gamma_R = \gamma_R$

$$\gamma_R = \gamma - \delta_p = 45 - 4^\circ 27' = 40^\circ 33'$$

Outside diameter. $d_o = D_o$

$$d_o = d + 2a_{op} \cos \gamma = 3.35 + 2(0.152) \cos 45 = 3.564 \text{ in (89 mm)}$$

pitch apex to crown, $X_o = x_o$

$$X_o = A_o \cos \gamma - a_{op} \sin \gamma = 2.36 \cos 45 - 0.152 \sin 45 = 1.561 \text{ in (39 mm)}$$

Circular thickness, $t = T$

$$T = \frac{P}{2} - (a_{op} - a_{oG}) \frac{\tan \phi}{\cos \phi} - \frac{k}{P_d}$$

Since $a_{op} = a_{oG}$

Therefore,

$$T = \frac{P}{2} = \frac{0.479}{2} \text{ in (6 mm)}$$

Where,

ϕ = pressure angle

φ = spiral angle (not applicable to straight bevel gear)

k = circular thickness factor.

APPENDIX B: Complete Randomize Design with Three Replications

A sample field experimental layout of a $3 \times 3 \times 3$ factorial experiment involving 3 disc peripheral speed (S_1, S_2, S_3), three levels of flow height (F_1, F_2, F_3), arranged in Complete Randomize Design with three replications.

Rep I

S_3F_1	S_1F_3	S_2F_2
S_2F_3	S_3F_2	S_1F_1
S_1F_2	S_2F_2	S_3F_3

Rep II

S_1F_2	S_2F_3	S_3F_1
S_2F_1	S_3F_2	S_1F_3
S_3F_3	S_1F_1	S_2F_2

Rep III

S_2F_3	S_3F_2	S_1F_1
S_1F_2	S_2F_1	S_3F_3
S_3F_1	S_1F_3	S_2F_2

APPENDIX C: Experimental Data Collected during the Field Test (Developed)

TREATMENTS	TIME (Sec)			SWATH WIDTH H (m)	TRACTOR FORWARD SPEED (Km/hr)	FIELD EFFICIENCY (%)	MACHINE FIELD CAPACITY (ha/hr)	SPREAD CAPACITY (Kg/hr)
	Te	Td	Tt					
S1F1R1	90	15	105	5.3	8.2	85.7	4.35	2000
S1F2	65		65	5.8	8.2	100.0	4.76	2769.231
S1F3	72		72	8.5	8.2	100.0	6.97	2500
S1F1R2	87		87	5.7	8.2	100.0	4.67	2068.966
S1F2	58	130	188	6.5	8.2	30.9	5.33	3103.448
S1F3	69		69	7.8	8.2	100.0	6.40	2608.696
S1F1R3	78		78	5	8.2	100.0	4.10	2307.692
S1F2	61	80	141	7	8.2	43.3	5.74	2950.82
S1F3	65		65	7.5	8.2	100.0	6.15	2769.231
S2F1R1	75		75	8	8.2	100.0	6.56	2400
S2F2	53	240	293	9.8	8.2	18.1	8.04	3396.226
S2F3	47		47	11.7	8.2	100.0	9.59	3829.787
S2F1R2	72		72	8.2	8.2	100.0	6.72	2500
S2F2	57	120	177	10.1	8.2	32.2	8.28	3157.895
S2F3	50		50	11.5	8.2	100.0	9.43	3600
S2F1R3	72		72	7.8	8.2	100.0	6.40	2500
S2F2	50		50	10.5	8.2	100.0	8.61	3600
S2F3	45		45	11.3	8.2	100.0	9.27	4000
S3F1R1	43	180	223	8.8	8.2	19.3	7.22	4186.047
S3F2	38		38	10.5	8.2	100.0	8.61	4736.842
S3F3	30		30	12.2	8.2	100.0	10.00	6000
S3F1R2	44		44	9.2	8.2	100.0	7.54	4090.909
S3F2	40	134	174	10.7	8.2	23.0	8.77	4500
S3F3	31		31	11.7	8.2	100.0	9.59	5806.452
S3F1R3	41		41	9.5	8.2	100.0	7.79	4390.244
S3F2	35		35	10.2	8.2	100.0	8.36	5142.857
S3F3	32		32	12	8.2	100.0	9.84	5625

APPENDIX D: Manure Spread Capacity and Uniformity Laboratory test for Developed Spreader

			B1	B2	B3	B4	B5	B6	B7
TREATMENT	TIME (SEC)	SPREAD CAPACITY (Kg/hr)			(Kg)				
S1F1R1	65	1107.692	0.28	0.46	0.48	0.54	0.32	0.3	0.28
S1F2	45	1600	0.3	0.44	0.51	0.52	0.52	0.49	0.3
S1F3	42	1714.286	0.42	0.46	0.51	0.62	0.53	0.48	0.44
S1F1R2	69	1043.478	0.19	0.22	0.42	0.52	0.31	0.27	0.25
S1F2	48	1500	0.32	0.36	0.46	0.47	0.45	0.38	0.36
S1F3	40	1800	0.41	0.48	0.5	0.61	0.53	0.52	0.46
S1F1R3	68	1058.824	0.19	0.2	0.31	0.42	0.51	0.5	0.24
S1F2	40	1800	0.32	0.34	0.35	0.36	0.37	0.32	0.27
S1F3	45	1600	0.51	0.54	0.55	0.67	0.52	0.5	0.48
S2F1R1	32	2250	0.22	0.24	0.26	0.26	0.27	0.25	0.2
S2F2	27	2666.667	0.41	0.42	0.44	0.47	0.45	0.44	0.39
S2F3	25	2880	0.43	0.43	0.39	0.48	0.4	0.43	0.42
S2F1R2	31	2322.581	0.2	0.24	0.29	0.42	0.31	0.25	0.2
S2F2	32	2250	0.42	0.44	0.46	0.5	0.46	0.44	0.42
S2F3	29	2482.759	0.44	0.46	0.51	0.52	0.44	0.45	0.44
S2F1R3	33	2181.818	0.21	0.24	0.31	0.41	0.29	0.24	0.19
S2F2	29	2482.759	0.41	0.43	0.43	0.43	0.42	0.38	0.36
S2F3	31	2322.581	0.41	0.44	0.47	0.54	0.46	0.46	0.44
S3F1R1	22	3272.727	0.21	0.34	0.35	0.63	0.41	0.32	0.25
S3F2	21	3428.571	0.25	0.34	0.36	0.63	0.42	0.35	0.24
S3F3	19	3789.474	0.27	0.43	0.54	0.65	0.52	0.4	0.24
S3F1R2	24	3000	0.21	0.24	0.3	0.62	0.43	0.41	0.21
S3F2	19	3789.474	0.26	0.32	0.36	0.65	0.4	0.32	0.22
S3F3	17	4235.294	0.25	0.44	0.52	0.64	0.49	0.41	0.26
S3F1R3	21	3428.571	0.22	0.29	0.32	0.67	0.41	0.33	0.2
S3F2	17	4235.294	0.25	0.33	0.35	0.64	0.4	0.32	0.26
S3F3	19	3789.474	0.4	0.42	0.5	0.61	0.51	0.39	0.25

APPENDIX E: Means of Weight of Manure Spread in Boxes Based on Distances, Disc Speed and Flow Height Mechanism for both Developed and Imported Manure Spreaders

Imported Spreader

Boxes	B1	B2	B3	B4	B5	B6	B7
Speed (rpm)							
150	0.3	0.36	0.37	0.45	0.42	0.39	0.33
300	0.33	0.34	0.32	0.36	0.38	0.35	0.31
450	0.28	0.32	0.34	0.54	0.43	0.28	0.26
Height (cm)							
A	0.28	0.4	0.46	0.48	0.36	0.32	0.14
K	0.32	0.34	0.36	0.52	0.35	0.34	0.3
U	0.3	0.34	0.38	0.52	0.38	0.33	0.31
Boxes Spacing							
	0.3	0.6	0.9	1.2	1.5	1.8	2.1

Developed Spreader

Boxes	B1	B2	B3	B4	B5	B6	B7
Speed(rpm)							
150	0.33	0.39	0.45	0.53	0.45	0.42	0.34
300	0.35	0.37	0.40	0.45	0.39	0.37	0.34
450	0.26	0.35	0.40	0.64	0.44	0.36	0.24
Height (cm)							
15	0.21	0.27	0.34	0.50	0.36	0.32	0.22
30	0.33	0.38	0.41	0.52	0.43	0.38	0.31
45	0.39	0.46	0.50	0.59	0.49	0.45	0.38
Box Spacing							
	0.3	0.6	0.9	1.2	1.5	1.8	2.1

APPENDIX F: Means of Spreading Capacity, Time and Swath Width as Influenced by Flow Height Mechanisms for both Imported and Developed Manure Spreader.

Flow rate settings	Rep	Effective Time (min)	Delay Time (min)	Total Time (min)	Machine Capacity (kg/hr)	Swath Width (m)	Machine Efficiency (%)	Average Time (min)	Average Capacity (kg/hr)	Average Swath (m)
Imported Spreader										
	1	3.42	2.15	5.57	430.87	8.6	61.40			
A	2	2.13	3.30	5.43	441.98	8.8	39.22	5.54	432.79	8.63
	3	3.32	2.32	5.64	425.53	8.5	58.86			
	1	2.0	1.50	3.5	685.71	9.6	57.14			
K	2	1.35	2.5	3.85	623.37	9.9	35.06	3.66	659.75	9.8
	3	2.81	0.82	3.63	661.16	9.9	77.41			
	1	1.24	0	1.24	1935.48	9.8	100			
U	2	0.92	0.50	1.42	1690.4	10	64.79	1.21	1875.21	10
	3	0.7	0.5	1.2	2000	10	58.33			
Developed Spreader										
	1	0.98	0.29	1.27	2862.02	7.37	77.16			
F1	2	0.94	0.31	1.25	3105.92	7.70	75.20	0.92	3011.31	7.50
	3	0.76	0.3	1.06	3065.98	7.43	71.69			
	1	0.98	0.29	1.27	3634.10	8.70	77.16			
F2	2	1.26	0	1.26	3587.11	9.10	100	0.85	3706.37	9.01
	3	1.0	0.21	1.21	3897.89	9.23	82.64			
	1	1.03	0.20	1.23	4109.93	10.50	83.73			
F3	2	0.82	0.41	1.23	4005.05	10.33	66.66	0.82	4082.13	10.37
	3	1.09	0	1.09	4131.41	10.27	100			

APPENDIX G: Autocard Drawings Detailing Designed Machine Parts and Dimensions for the Developed Spreader (Sheet 1 – 20)