EVELOPMENT AND TESTING OF A CENTRIFUGAL FERTILIZER APPLICATOR

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ABSTRACT

A centrifugal fertilizer applicator which makes use of centrifugal force to broadcast fertilizer on the farm with an effective capacity of 90 hectares/day was developed and tested in Desfabeng Company Nigeria Limited Bida, Nigeria. This work was done in order to alleviate the drudgeries encountered with the manual method of fertilizer broadcasting using hand and also eliminate the problems of sudden breakdown and high cost of imported fertilizer broadcasters. The major components of the machine include the hopper, agitator, spreader disc, feed control mechanism, 3-point hitch to the tractor, power transmission unit and the frame. Successful completion of the machine would help increase crop production in Nigeria. The device was fabricated with locally sourced materials that are not difficult to get. This makes maintenance and repairs on the device easy by local artisans since damaged parts can be easily repaired and if possible replaced with new parts. The fabricated spreader was tested over a hectare of land at four different ground speeds of 5, 10, 15 and 20 km/hr with a view of ascertaining the time taken, effective capacity and distribution pattern/uniformity over one hectare of land. Test results indicate that at 5, 10, 15 and 20 km/hr ground speeds, the time taken to cover one hectare was 16, 8, 5.3 and 4 minutes respectively while the corresponding effective capacities in ha/hr are 3.75, 7.50, 11.25 and 15.00 respectively. Using the tray collection and test tube method, at 15 km/hr optimum ground speed and an effective swath width of 10 m, the fertilizer distribution was even and uniform showing an oval spread pattern. Also visual inspection of the planted seeds after germination showed a uniform plant growth confirming that the fertilizer was evenly spread on the field.

Keywords: *Fertilizer, centrifugal, spreader, crop, soil*

INTRODUCTION

Fertilizers are materials of natural or synthetic origin manufactured from various chemical treatments which when applied to the soil increases soil fertility thereby increasing the growth and development of crops (Benton, 2012). Crops obviously need nutrients to grow and develop and they draw these nutrients from the soil. If this withdrawal is not compensated for, the crop yield goes down progressively. This withdrawal is compensated through fertilizers and manures to maintain the productivity of the soil and to achieve higher yields (Yadav and Pawar, 2015). Mineral fertilizer application currently accounts for 43% of the nutrients that global crop production extracts each year, and the contribution may be as high as 84% in the years to come (FAO, 2014).

Farmers need machinery which can spread fertilizers effectively with least cost and power requirement. Fertilizer broadcasters began as ground driven units which could be pulled by a horse or team of horses. The first successful automated fertilizer broadcaster was a manure spreader designed by Joseph Kemp in 1875 (Yadav and Pawar, 2015). Sapkale *et.al* (2010) carried out a performance evaluation of a tractor operated manure spreader. The manure spreader was attached to a 45 HP tractor through the hitch point and test was conducted. A 540 rpm PTO speed was used to operate the rotary blades of the manure spreader. The distribution pattern of farm yard manure was uniformly spread over the area and little variation was found. This was due to clods in the manure. It showed that there was saving of 94 per cent in time as compared to traditional method. The field capacity of the manure spreader was also worked out in terms of area coverage per hour.

Suthakar *et.al.* (2008) evaluated the field performance of a tractor PTO operated manure spreader attached to a two wheel trailer and compared it with the traditional method of spreading manure. The machine mainly consists of a manure tub to load the manure, an endless chain conveyor for conveying the manure towards the rear end of the trailer and a hydraulically operated spreader drum to shear off manure. The machine was tested at Research Farms of the Tamil Nadu Agricultural University and at the farmer's fields. It possesses the linear relationship for the forward speed and chain conveyor speed with the application rate. But, the speed of the spreader drum did not influence the application rate of the manure.

The majority of farmers now use a broadcast spinner spreader, also known as centrifugal spreader, because of their large working width, low cost, robustness and spreading efficiency. The working principle is simple: the fertilizer particles fall onto a disk equipped with vanes. The disk rotates at 400 to 1000 rpm and consequently throws the particles into the field. Several factors affect the fertilizer distribution in the field such as the spreader settings and the fertilizers physical properties. This distribution or spreading pattern should correspond to the crop's needs as closely as possible. In fact, applying an imprecise amount of fertilizer might actually decrease the production efficiency (Olieslagers *et al.*, 1996; Scharf, 2009). For example, lodging of cereals due to an excess of nitrogen input decreases profit substantially (Grinsven *et al.*, 2012). To be able to spread the correct amount of fertilizer on the right place in the field, correct spreader settings are determined by performing a calibration test taking into account both machine and fertilizer properties. In most cases the fertilizer particles are collected in standardized trays and then weighed (Reumers *et al.*, 2003).

In Nigeria, most fertilizer broadcasting in the field are still done manually. Manual broadcasting is time consuming and the distribution is non-uniform. Also most of the fertilizer applicators used in the country are imported and very expensive to purchase and maintain. Most of them do not last especially the gearbox and they are not durable. The materials used often times are also made of light inferior materials which are not able to withstand our harsh climatic and soil condition.

To overcome these aforementioned problems, a centrifugal fertilizer applicator was designed and fabricated using locally available materials. The fabricated machine would be relatively cheap compared to the imported ones. It would help in applying fertilizer on the farm effectively. As such this paper explains the development and testing of a centrifugal fertilizer applicator which would comprise of a hopper that would house the agitator which continuously stirs the fertilizer in the hopper, two aperture openings for metering the fertilizer, a spreading disc connected to a gear box and then to the P.T.O. of the tractor for broadcasting the fertilizer on the field. This would help alleviate the drudgeries encountered during an entirely manual broadcasting operation and it would also help correct the abnormalities and problems encountered from other fertilizer applicators. Thus, increasing agricultural productivity in the country by an increase in the growth of crops. The fertilizer applicator was found to be relatively cheap, durable and easy to repair and maintain.

DESIGN CONSIDERATIONS

In carrying out this design work, much effort was directed towards obtaining a system that would give the desired compactness. The dimensions of the various components was calculated so as to minimize size and weight of the machine and at the same time not compromise the standard, strength and efficient functioning of the various parts. The angle of repose and particle size of granular fertilizer was also considered as this would play a vital role during the metering and distribution of fertilizer on the farm.

Other criteria that were considered in designing the components of the centrifugal fertilizer applicator are as follows:

i. Capacity of the hopper.
ii. The rate of fertilizer discharge.
iii. The thickness and strength of the hopper that can withstand the load.
iv. Maximum swath width of the fertilizer distributed as a function of PTO speed.
v. Ease of passage/metering of the fertilizer to the spreader disc.
vi. Magnitude of centrifugal force developed by the spreader disc
vii. Thickness of the agitator for its intended purpose
viii. Thickness and length of shaft
ix. Stability and strength of the frames to carry other components and necessarily withstand further impacted load.

DESIGN CALCULATION

The aim of the design analysis, calculations and other necessary considerations is to evaluate the required and necessary design parameters. This would enhance the selection of appropriate materials and strength of the materials to be used for the construction of the various component parts of the centrifugal fertilizer applicator

Determination of the Centrifugal Force Developed

A centrifugal force is set up on the spreader disc assembly due to the rotation of the shaft when working and in line with the principle of centrifugal force; the direction of action of the force is from the centre towards the edges of the spreader disc. The centrifugal force generated is determined by applying equation 1.

$$F_C = \frac{M_T \omega^2 D}{2} \quad (1)$$

Where,

$F_C = Centrifugal\ Force$

$M_T = Total\ mass\ of\ spreader\ disc\ and\ shaft\ (kg)$

$\omega = angular\ velocity\ of\ the\ spreader\ disc\ assembly\ (rad/s)$

$D = Diameter\ of\ spreader\ disc\ (m)$

Linear Speed of the Spreader Disc Assembly

The linear speed of the spreader disc is related to the revolution per minute and diameter of the spreader disc as given by equation 2.

$$V = \pi N D \quad (2)$$

Where,

V = Linear speed of the spreader disc assembly (m/s)

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

$D = Diameter\ of\ spreader\ disc\ (m)$

Allowable Thickness of the Material for the Construction of the Agitator

In order to withstand the expected stress on the edges and surface of the agitator, an appropriate thickness of the agitator has to be determined to prevent avoidable system failure. Kreg (1975) stated that the thickness of an agitator to withstand the stress is a function of the agitator and the maximum permissible stress of the material expressed by equation 3

$$t_k = \frac{\delta_b D}{2\delta_b} \quad (3)$$

Where,

$t_k = Thickness\ of\ the\ agitator\ blades\ (m)$

$\delta_b = Permissible\ stress\ of\ the\ material\ of\ the\ agitator$

$D = Diameter\ of\ hopper\ bottom\ (m)$

Determination of Weight of the Spreader Disc

Determination of the bearing shaft Diameter

The bearing shaft diameter is needed in order to determine the load carrying capacity of the shaft. For a solid s with little or no axial load, the diameter of the shaft is determined using equation 8

$$d^3 = \frac{16}{\pi S_s} \times \sqrt{(K_b M_b)^2 + (K_t M_t)^2}$$ (Khurmi and Gupta, 2005) (8)

Where,

d= is the diameter of the shaft

S_s= is the allowable stress

K_b= Combine shock and fatigue factor applied to bending moment= 1.5 (Hall *et al.*, 1980)

M_b= is the bending moment

K_t= Combine shock and fatigue factor applied to torsional moment = 3.0 (Hall *et al.*, 1980)

Determination of the Maximum Shear Stress of the Shaft

The shaft is under a combined load of bending moment and torque and is given by equation 9

$$\tau_{max} = \frac{16}{\pi d^3}\sqrt{(M^2 + T^2)}$$ (Khurmi and Gupta, 2005) (9)

Where,

τ_{max} = Maximum shear stress (N/m)

T= Torque (Nm)

M= Bending moment of shaft (Nm)

d= shaft diameter (m)

Determination of Angle of Twist

The angle of twist helps to know whether the diameter of the shaft is safe to carry the applied load. According to *et al.* (1980) the amount of twist permissible depends on particular application and varies about 0.3 degree per m for a machine tool shaft and about 3 degree per meter for line shafting.

Therefore, angle of twist (θ); for solid shaft is given by equation 10

$$\theta = \frac{584 M_t L}{G d^4}$$ (10)

Where

L = length of shaft (m)

M_t = torsional moment (Nm)

G = torsional modulus (Nm^2)

Determination of the Speed Reduction ratio of the Gearbox

The speed reduction ratio of the gear unit is a function of the tractor PTO speed and the recommended speed of rotary spreader connected to the gearbox. Thus, it is computed from equation 11

The fertilizer spreader cannot operate at its theoretical capacity at all times while it is in the field due to turning and idle travel, operating at less than full width, reloading of fertilizers, cleaning clogged equipment, machine adjustment, lubrication and re-fueling during the day. Consequently, the field efficiency is always less than 100percent.

From the operation data recorded during the testing of the machine,

S = 15km/hr. (Optimum speed from the four speeds used)

For a basis of eight (8) working hours per day (8hrs/day)

$S = 15km/hr \times 8hrs/day = 120km/day$

$\therefore S = (120 \times 1000)m/day = 120{,}000m/day$

$W = Swath\ Width\ of\ fertilizer\ spread\ on\ the\ Field$

$W = 10m$

From equation 14

$A_T = 120{,}000m/day \times 10m$

$$\therefore A_T = 1{,}200000\ m^2/day \tag{15}$$

Substituting equation 15 into equation 13

$$C_F = \frac{1{,}200000m^2/day}{10{,}000m^2/hectare}$$

$C_F = 120hectares/day$

Therefore, the theoretical field capacity of the fertilizer spreader is 120hectares/day.

Using a field efficiency of 75% for fertilizer distributors as reported by ASAE (1993).

$$Effective\ field\ capacity = Theoretical\ field\ capacity \times field\ efficiency \tag{16}$$

Substituting $C_F = 120hectares/day$ into equation 16, we have

Effective field capacity = $120hectares/day \times 75\%$

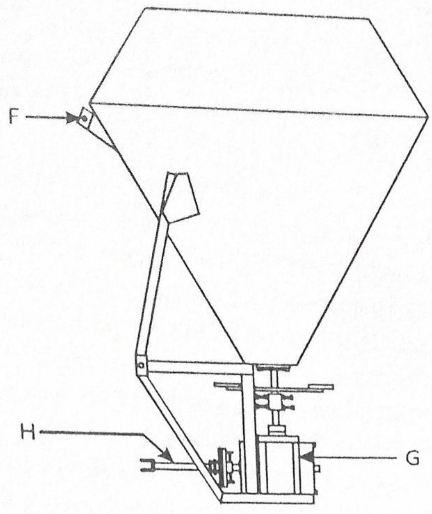
∴Effective field capacity (EFC) $= 90hectares/day$

MACHINE DESCRIPTION

The centrifugal fertilizer applicator is made up of the following components.

Hopper: This is a conical container for temporarily holding the fertilizer before they are metered onto the spreading disc. It is made from guage 14 mild steel sheets and has a conical bottom with a slope of 30° so that the fertilizer contained in it easily moves towards the metering aperture. It has a diameter of 800 mm at the top and 250 mm at the bottom with a total height of 1200 mm as shown in figure 1. Attached to the top of the hopper is a lid with a peep hole of 80 mm for observing the quantity of fertilizer left in the hopper during operation. The lid helps to prevent fertilizer in the hopper from attaining its critical relative humidity when exposed to moist thereby making the fertilizer hygroscopic. The hopper bottom has two circular holes of 20 mm each for metering the fertilizer onto the spreading disc. The hopper is very strong in order to avoid buckling when filled with fertilizer.

Agitator: This is a stirring device made from spring steel which mechanically initiates the stirring of the fertilizer within the hopper so as to prevent agglomeration of the fertilizer granules. The agitator was kept at a vertical clearance of 3 mm above the aperture.



KEYS	DESCRIPTION
A	HOPPER
B	LOWER LINK ARM
C	SPREADER DISC
D	FIN
E	GEARBOX
F	UPPER LINK ARM
G	GEARBOX FRAME
H	PROPELLER SHAFT
I	SPLASH GUARD
J	FLANGE
K	AGITATOR
L	DELIVERY HOLE

Fig.2: Side View

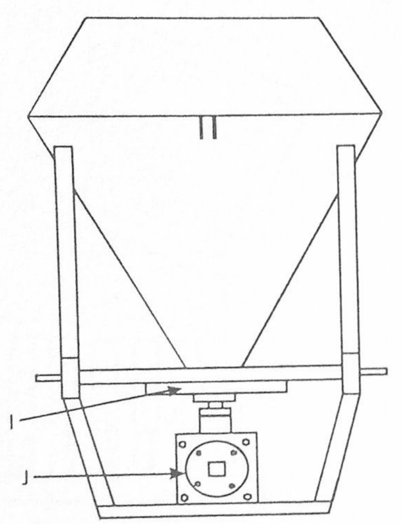


Fig.3: Front View

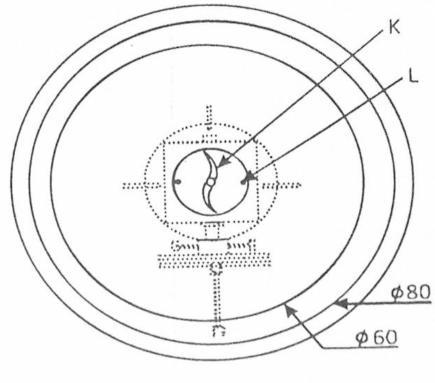


Fig.4: Plan View

PRINCIPLE OF OPERATION

With the various parts of the machine been assembled, the developed machine was then tested without any fertilizer or seed poured into the hopper. This was done to study the behaviour of the machine.

A known mass of granular fertilizer was then poured into the hopper and covered. With the PTO working, the agitator stirs the fertilizer in order to allow the fertilizer move freely under gravity onto the spreading disc for even distribution. The centrifugal force developed by the spreading disc makes any fertilizer granule that drops on it to be directed tangentially away from the center of the spreading disc thereby enhancing even pattern distribution of the fertilizer. With the tractor in motion, the fertilizer was evenly dispersed on the field.

MACHINE EVALUATION

500 kg NPK granular fertilizer (15:15:15) was purchased from a major fertilizer distributor in Bida Local Government Area, Niger state. The fertilizer was inspected to ensure that they were dry and granular so as to ensure maximum performance of the machine. With the tractor set in motion, the fertilizer was evenly dispersed on the field. The field experiments were conducted over one hectare of KGA rice farms Bida under the supervision of Desfabeng Company Limited. The machine was tested at four different ground speeds of 5, 10, 15 and 20 km/hr and the time taken was recorded using a stop watch. The capacities of the machine were calculated at different speeds with the corresponding distribution pattern evaluated and results tabulated in table 1. Each of the experiment was done in triplicate.

i) *Time taken*: The time taken for the machine to complete operation in 1 ha of land was recorded with a stop watch that reads both minutes and seconds.

ii) ***Effective and total width of swath***: Effective width (WE) of the fertilizer spreader was measured by placing collection trays 0.5 m × 0.5m in a row 0.3 m apart from each other perpendicular to the direction of travel according to the ASAE 341.2 standardized collection tray method as described by Lawrence and Yule (2005).

iii) ***Effective Field capacity and efficiency of spreader***: Effective field capacity (EFC) of the spreader was calculated in ha/day using equation 16 by considering 75% field efficiency and effective swath width of the spreader as 10m. The effective capacity was also calculated in ha/hr via dividing an hour (60 minutes) by the time taken for the tractor and spreader to cover one hectare of land.

iv) ***Fertilizer spreading pattern and uniformity***: Spreading uniformity was determined by placing a row of collection trays (0.5 m x 0.5 m), 0.3 m apart from each other at right angles to the direction of travel. Fertilizer from each collection tray was collected and placed in polythene bags and labelled. The samples were immediately weighed over digital scale and further poured into graduated test tubes as shown in Figure 5. The spread pattern is easily seen when the trays are emptied into tubes

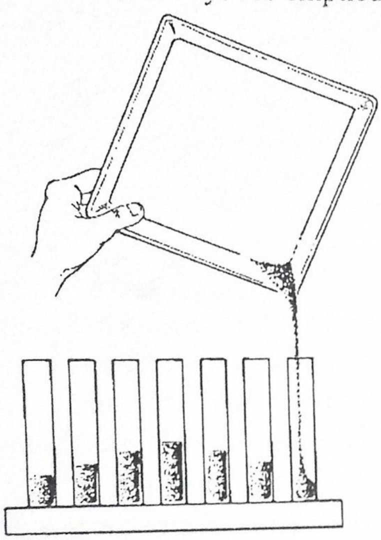


Fig.5. Spread Pattern Using Test Tube Method

Plate 1: Fertilizer being applied in the field

RESULTS AND DISCUSSION

The results obtained from the field test of the centrifugal fertilizer application on a hectare of land is presented in table 1.

Table 1: Machine performance using NPK fertilizer for 1 ha of land at varying speeds

Speed(km/hr)	Replications	Time (mins)	Machine Capacity	Average Time(mins)	Average Capacity	Distribution pattern
5	1	16.03	3.74	16.00	3.75	More fertilizer in the tray. Thus, giving a py Pattern
	2	15.97	3.76			
	3	16.00	3.75			
10	1	7.98	7.52	8.00	7.50	Evenly distributed curved pyramidal pa the apex
	2	8.03	7.47			
	3	7.98	7.52			
15	1	5.25	11.43	5.3	11.25	Evenly distributed oval spread pattern
	2	5.42	11.07			
	3	5.33	11.25			
20	1	3.92	15.31	4.0	15.00	Not evenly distribut high speed
	2	4.07	14.74			
	3	4.02	14.93			

i) Time taken

As presented in table 1, four different ground speeds of 5, 10, 15 and 20 km/hr were used to test the fertilizer sprea The time taken for the spreader to cover one hectare of land was estimated using a stop watch. The result in tab reveals that increase in the forward speed of the spreader leads to a reduction in the time taken for the spreader to co a hectare of land. Thus, as the speed of the tractor increases from 5 km/hr to 20 km/hr, the time taken reduces fron average time of 16 minutes to 4 minutes. It therefore means that the speed of operation is inversely proportional to time taken to accomplish the desired task.

ii) Machine Capacity

The average effective capacity gives an index of the application rate of the fertilizer. The average effective capaci shown in table 1 reveals that at a tractor forward speed of 5 km/hr the average capacity obtained was 3.75 ha/hr. I field test conducted, the low speed resulted to an increase in application rate of 350 kg/ha. This increase in applic rate would in turn hasten the growth of weeds and further impede the proper growth of crops. At an operating s of 10 km/hr, the corresponding field capacity obtained was 7.5 ha/hr. At this speed and effective capacity application rate was still high at 290 kg/ha. At 15km/hr operating speed, an effective capacity of 11.25 ha/h obtained. At this operating speed and effective capacity, the application rate from the field test conducted wa kg/ha which is in agreement with the required application rate for rice crop as reported by Parish (2006). Wh tractor was operating at 20 km/hr, the effective capacity was 15 ha/hr and the application rate obtained was 180 which means insufficient nutrient supplement needed for the proper growth and development of the rice crop.

iii) Fertilizer distribution pattern

Using the tray method and later transferring the collected weighed samples into graduated test tubes, it was ob as recorded in table 1 that at a forward speed of 5 km/hr, a pyramidal pattern was obtained when the collected s were emptied into the test tubes. At a forward speed of 10 km/hr, a pyramidal pattern with a convex apex was ob At an operating speed of 15 km/hr, the fertilizer was evenly distributed thereby giving an oval spread pattern w in agreement with the spread pattern reported by Mahmood *et al.* (2014) as an acceptable spread pattern. At 20 the fertilizer was not evenly distributed due to high speed.

CONCLUSION

A tractor drawn centrifugal fertilizer applicator which makes use of centrifugal force to broadcast fertilizer on the farm was developed and tested. From the test result on the fabrication and testing of the machine, the following conclusions were made:

i) The machine was able to effectively distribute fertilizer on the farm in an efficient and uniform manner at an optimum application rate of 250 kg/ha. Thus, eliminating time wastage and drudgery associated with manual method of fertilizer application.

ii) The effective spread width during the operation of the machine on the farm was found to be ten meters (10 m).

iii) The forward speed of the tractor that gave the most uniform and even spread was recorded at 15 km/hr. At this operating speed, the required application rate of 250 kg/ha was achieved at an effective capacity of 11.25 ha/hr. Increase in forward speed leads to a corresponding increase in the effective field capacity and a decrease in the application rate and time taken to cover one hectare

iv) At the optimum forward speed of 15 km/hr, the machine was found to have an effective capacity of 90 hectares per day which an entirely manual method would require large labour force to accomplish within a day.

v) The machine should be operated at an optimum forward speed of 15 km/hr as it would help alleviate the drudgeries encountered with manual methods.

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