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DESIGN, FABRICATION AND TESTING OF A MOTORCYCLE DRAWN FERTILIZER BROADCASTER

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ABSTRACT

This study was conducted to design and fabricate a motorcycle drawn fertilizer broadcaster, as well as to test its performance. Fundamental design analysis and calculations were carried out in order to determine and select materials of appropriate strength and sizes for the machine component parts. The major machine parts include hopper, agitator, fertilizer spreading disc, feed control mechanism, 3-point hitch to the motorcycle, shaft, fertilizer flow control unit, wheel, spreader disc, gear box, upper arm and lower arms and frame. Test results of the equipment using NPK and superphosphate fertilizers mixed in the ratio of 5:6 to give total of 7.3 kg reveal that the highest quantity of fertilizer delivered and application rate of 7.23 kg and 325.68 kg/Ha respectively were obtained from speed of 5 km/hr and respectively 3.12 kg and 139.64 kg/ha from speed of 20 km/hr. The quantity of fertilizer delivered, application rate and delivery efficiency all decreased with increase in the equipment forward speed. An operating speed of 15 km/hr which gave an application rate of 250.02 kg per hectres was recommended as application rate for rice plant. The development of this equipment will overcome some challenges associated with manual application of fertilizers.

1. INTRODUCTION

Plants, like all other living things, need food for their growth and development. This food is supplied in organic or inorganic forms such as fertilizer (Silva and Uchida, 2000). According to John *et al.* (2006), fertilizers are supplement that are applied to the soil to supply nutrient to plants. Adequate supply of these nutrients is required for maximum productivity of all cropping systems. All parts of a plant require nutrients to grow and major portions of these nutrients are removed when a crop is harvested (Bokhtiar and Sakurai, 2005). Therefore, for a sustainable crop production, these nutrients removed need to be replaced with either chemical fertilizers or manures. Serpil (2012) reported that the nutrition content of plant is one of the most important factors that control agricultural productivity and quality. The quantity of nutrient required by plants differs depending on many factors which include plant species and variety, yield level, soil properties, environment and management practices. According to Dong et al. (2012), continual nutrient removal with little or no replacement usually results to nutrient-related yield loss.

Appropriate fertilizer application is an important management practice to improve soil fertility and quality. Adequate nutrient control programs improve plant nutrients in adequate quantity to sustain optimum crop production and profitability while curtailing environmental impact of nutrient use on the land. The knowledge of the interactions between the soil, plant, machine and environment are critical to effective management practices (John et al., 2006).

Fertilizer can be applied using several methods which depend on type of the crop. Mohammad et al. (2014) reported that the major form of applying fertilizer is by using centrifugal machine and manual broadcasting (topdressing). Lately, there has been increase in demand for agricultural products which has led to the development of different machines, implements and equipment for different agricultural practices by agricultural mechanization experts (Karim et al., (2013).

The manual method of fertilizer application is labour-intensive and often times leads to uneven distribution of the fertilizer on the field. Also, it is slow and energy consuming. On the other hand, broadcasters that are operated by Tractor are very expensive to purchase and maintain by medium and small-scale farmers. Thus, there is a need to develop a machine to meet up with the demand at the small and medium scale levels. Therefore, the objective of this study was to design and fabricate a fertilizer broadcaster that is powered by a motorcycle and test the performance of the machine.

2. MATERIALS AND METHODS

2.1. Material Selection

Mild steel materials were used for construction of component parts of the machine in order to give a rigid support and ensure stability of the machine when in operation (Gana et al., 2017).

2.2. Machine Description

The motorcycle drawn fertilizer broadcaster is made up of the following components:

Hopper: This is a conical vessel for temporary holding of the fertilizer before it is metered onto the spreading disc. It is made from 2 mm thick mild steel sheets and has a conical bottom with a slope of 30° so that the fertilizer can easily move towards the metering aperture. It has a diameter of 400 mm at the top and 250 mm at the bottom with a total height of 600 mm as shown in Figure 1. Attached to the top of the hopper is a lid with a peep hole of 60 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 level when exposed to atmospheric moisture thereby making the fertilizer hygroscopic. The hopper bottom has two circular holes of 15 mm each for metering the fertilizer onto the spreading disc.

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.

Fertilizer Spreading Disc: This is a circular rotating disc of 200 mm diameter mounted at the bottom of the hopper just below the two aperture openings. The spreading disc has four equally spaced fins for even broadcasting of metered fertilizer granules. The spreading disc has a vertical clearance of 130 mm from the bottom of the hopper.

Feed Control Mechanism: A suitable feed control mechanism with locking device is provided below the aperture to control the flow of fertilizer granules through the aperture. The mechanism is controlled by a hand lever from outside the hopper.

3-Point Hitch to the Motorcycle: The hitch is the place of connection of the implement to the motorcycle. The three-point hitch consists of the upper link and two lower links. The 3-point hitch is very effective in pulling the motorcycle broadcaster and to give it stability and support when used in the farm. The entire 3-point hitch structure of the fertilizer broadcaster was made of two shafts and an upper link welded at the top to increase strength and rigidity.

Frames and Covers: The supporting frame of the fertilizer broadcaster was fabricated with two inches angle iron and galvanized steel pipes while the machine covers were made from mild steel to cover parts of machine.

Shaft: Two shafts made of mild steel where used, with a length of 1200 mm. One of the vertical rotating shafts carries the spreading disc and also passes through the hopper to the agitator for the distribution of the solid fertilizer through the feed units; the other shaft which is 500 mm is horizontally connected from the gear box to the sprocket receiving rotational energy from the wheels through chain.

Fertilizer Flow Control Unit: This is used in metering the flow of the fertilizer to the spreading disc.

Wheels: Two wheels are located at the ends of the equipment, mainly for the stability of the machine and provision of power to the fertilizer spreading centrifugal disc. Each of them has a diameter of 406.7 mm. The wheel is connected with the shaft and transmits power to the sprocket attached to it for the operation of the sprocket and chain conveying rotation to the horizontal shaft.

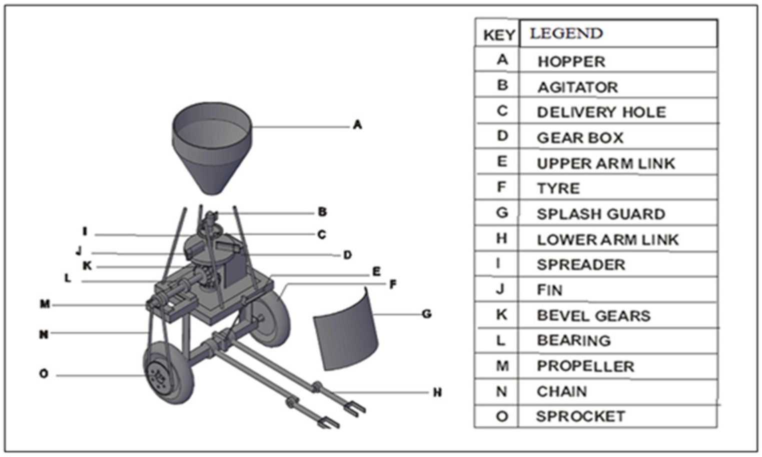
Frame: The frame gives rigidity and support to the equipment. It also helps for easy attachment to the motorcycle.

Fertilizer Spreader disc: This is a circular rotating disc that serves as a base for fertilizer throwing arms (fins) to be attached.

Gear box: This helps to increase the rotational speed of the fertilizer broadcaster

Upper arm: This is the upper linkage to the motorcycle.

Lower arm: This is the lower link connected to the motorcycle shock absorber.



KEY	LEGEND
A	HOPPER
B	AGITATOR
C	DELIVERY HOLE
D	GEAR BOX
E	UPPER ARM LINK
F	TYRE
G	SPLASH GUARD
H	LOWER ARM LINK
I	SPREADER
J	FIN
K	BEVEL GEARS
L	BEARING
M	PROPELLER
N	CHAIN
O	SPROCKET

Figure 1: Parts of the equipment

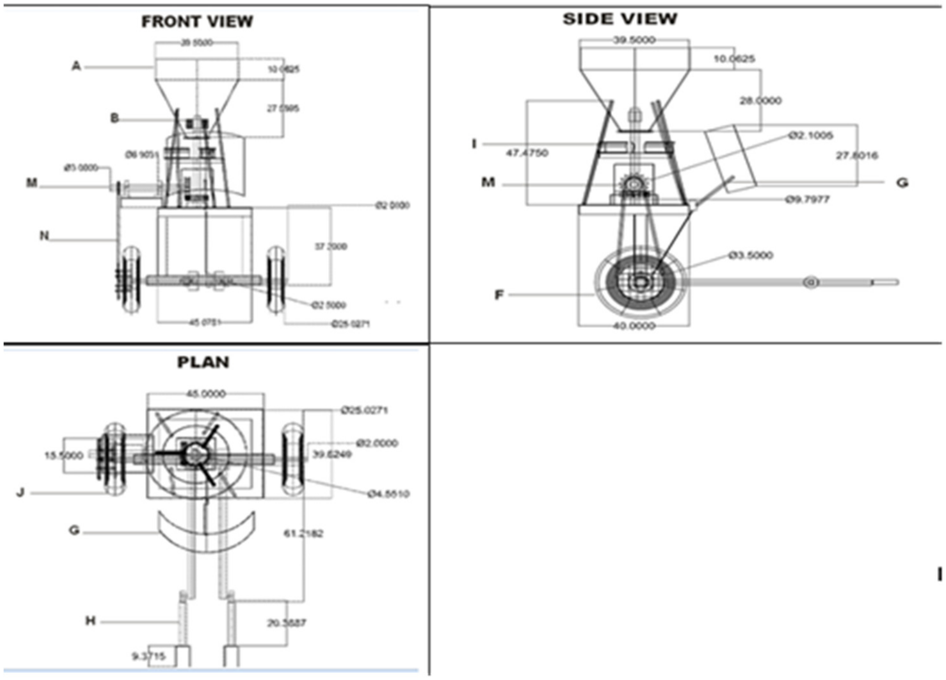


Figure 2: Orthographic view of the equipment

Figure 3: The developed equipment

2.3. Mode of Operation of the Machine

The hopper is loaded with the fertilizer and the stopper which controls the flow of fertilizer is adjusted to the desired discharge rate. The implement is engaged by first attaching the three-point linkage to the motorcycle. When the motorcycle is engaged to move, it rotates the wheel of the applicator which in turn rotates the shaft with the aid of chain and sprocket. 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 that drops on it to be directed tangentially away from the center of the spreading disc thereby enhancing even distribution of the fertilizer.

2.4. Design Analysis of Machine Components

The following fundamental design analysis and calculations were carried out in order to determine and select materials of appropriate strength and sizes for the equipment parts as reported by Gana et al. (2017).

2.4.1. Determination of the centrifugal force

The centrifugal force generated was determined as reported by Gbabo et al. (2016), and is given as:

$$Fc = \frac{M_t w^2 D}{2} \quad (1)$$

Where, Fc is centrifugal force, M_t is total masses of spreader disc and shaft (kg), ω is $angular\ velocity$ (rad/s) and D is d$iameter\ of\ spreader\ disc$ (m)

2.4.2. Speed of the broadcasting disc

The linear speed of the spreader disc is related to the revolution per minute and diameter of the spreader disc as as reported by Gbabo et al. (2016) and is given in Equation 2.

$$V = \pi N D \tag{2}$$

Where, V is linear speed of the spreader disc assembly (m/s), N is expected number of revolution per minute of the spreader disc assembly (rpm), D is diameter of the spreader (m)

2.4.3. Allowable thickness of the material for the construction of the agitator

The expected thickness of the agitator to withstand the centrifugal force to be generated, was computed using the equation reported by Gbabo and Igbeka (2003).

$$\mathrm{t_{bs}} = \delta_\mathrm{b} \mathrm{d_b}/2\mathrm{S_S} \tag{3}$$

where, t_{bs} *is* expected thickness of the conical basket (m), δ_b is stress that is developed and acts on the agitator (KN), $\mathrm{d_b}$ *is* diameter of the agitator (m), $\mathrm{S_S}$ is shear stress of material used for construction of the agitator.

2.4.4. Power required to drive the shaft

This was calculated in order to determine the power required to drive the shaft and pull the implement as well. It was computed as reported by Gana *et al.* (2017) and Khurmi and Gupta, (2005) and is given as:

$$P = 2 \times \pi \times N \times \tau / 60 \tag{4}$$
$$\tau = F \times r_d \tag{5}$$
$$F = M \times r_d \times \omega^2 \tag{6}$$
$$\omega = 2 \times \pi \times N / 60 \tag{7}$$
$$M = (M_H + M_F + M_A + M_S + M_{AH}) \tag{8}$$

where, P is power required by the equipment (watts), F is the total force (N), V is the velocity of auger (m/s), τ is the torque generated (Nm), M is total mass of the hopper assembly and its content (kg), ω is angular speed of the shaft (rpm), M_F is mass of the fertilizer (kg), M_A is mass of the auger (kg), M_S is mass of shaft (kg), M_{AH} is mass of the auger housing (kg), g *is* acceleration due to gravity (9.81m/s^2), π is constant = 3.142, r_d is radius of the auger housing (m), N is revolution per minute.

2.4.5. Determination of the area of the spreader disc

The area of the spreader disc was calculated in order to help ascertain the dimension of the hopper bottom. Since the area of the spreader disc must be larger than that of the hopper bottom, the area of the spreader disc was calculated using Equation 9.

$$A = \pi r2 \tag{9}$$

Where A is area of the spreader disc (m^2), r is radius of spreader disc (m)

2.4.6. Determination of the rate of fertilizer discharge

The rate of fertilizer discharge will determine the rate of spread/swath width of fertilizer dispersed. The rate of fertilizer discharge and spread is determined by the Equation 10.

$$Q = VA \tag{10}$$

Where, Q is discharge rate (m^3/s), A is area of fertilizer delivery hole (m^2), V is speed at which fertilizer is delivered and spread (m/s).

2.4.7. Determination of shaft diameter

The shaft diameter was determined to ensure satisfactory strength and rigidity when the shaft is transmitting power under various operating and loading conditions. The diameter was determined as reported by Khurmi and Gupta (2005) and Gana *et al.* (2017) and is given as:

$$d^3 \;= 16/\pi S_s \sqrt{(K_b M_b)^2 + (K_t M_t)^2} \tag{11}$$

Where, d is expected diameter of shaft(m), M_t is belt torque moment (Nm), M_b bending moment (Nm), d is diameter of the shaft (m), K_b is shock and fatigue factor applied to bending moment, K_t is shock and fatigue factor applied to torsional moment, S_a = allowable stress.

2.4.8. Determination of angle of twist

The angle of twist was determined as stated by Khurmi and Gupta (2005) and reported by Gana (2011), as:

$$\theta = \frac{584MtL}{Gd^2} \tag{12}$$

Where, θ is angle of twist, L is length of shaft (m), d is diameter of the shaft (m), Mt is torsional moment (Nm), G is torsional modulus (Nm^2).

2.4.9. Critical speed of the shaft

The critical speed of the shaft was determined as reported by Khurmi and Gupta (2005) as:

$$\omega_S = \sqrt{48\varepsilon I/ML} \tag{13}$$

Where, ω_S is the critical speed of the shaft, ε is the modulus of elasticity of steel (N/m), M is the mass of the shaft, L is length of the shaft.

2.4.10. Torsional deflection of the shaft

The torsional deflection for the shaft was determined as reported by Khurmi and Gupta (2005) and given as:

$$\alpha = 58\tau L/D^4 G \tag{14}$$

Where, α is the angular shaft deflection in degrees, L is length of the shaft (m), G is modulus of elasticity of steel (N/mm)

2.5. Testing of the Machine

2.5.1. Material preparation

NPK and Superphosphate fertilizers of 40 kg and 48 kg respectively were procured from a dealer in Minna main market for testing of the equipment. The NPK and superphosphate fertilizers were mixed in the ratio of 5:6 as recommended by Dugje *et al.* (2009) since nitrogen and potassium fertilizers are needed only when deficient.

2.5.2. Testing Procedure

The equipment was run on no load condition in order to determine the functionality and smoothness of all parts of the system. A sample of 7.3 kg of fertilizer was formed by mixing 3.3 kg of NPK fertilizer with 4.0 kg of superphosphate fertilizer. Four samples were prepared and applied to cover marked out field of 0.0222 hectares using four different speeds of 5, 10, 15 and 20 km/hr. Each of the experiment was replicated three times. The quantity of fertilizer delivered per experimental plot was determined by weighing the fertilizer left in the hopper and subtracting the value from the initial quantity of fertilizer that was put into the hopper. The machine performance was then determined based on area covered, delivery rate and delivery efficiency.

2.5.3. Area Covered Per Travel

This is the total area cover in one path and it is computed as reported by Gbabo *et al.* (2016), and is given as:

$$A_C = D\text{x}\mathrm{W} \tag{15}$$

Where, A_C is the area covered per travel (m^2), D is distance travelled (m), W is width of fertilizer spread per travel by the equipment (m).

2.5.4. Fertilizer ddelivery rate

This was calculated to know the amount of fertilizer delivered per area covered in a travel. It was determined using the expression reported by Gbabo *et al.* (2016), and is given as:

$$F_D = M_a/A_C \tag{16}$$

Where F_D is fertilizer delivery rate per area covered in a travel (kg/m^2), Ma is mass of fertilizer delivered per travel (kg), Ac is area covered per travel (m^2).

2.5.5. Fertilizer delivery efficiency

This is index of how effective the machine delivered the fertilizer in terms of delivery rate expressed in percentage. It was computed using the expression reported by Gbabo *et al.* (2016), and is given as:

$$E_D = \frac{Ma}{Mb} \times 100 \tag{17}$$

Where, E_D is the delivery efficiency (%), Ma is quantity of fertilizer delivered in a given area (kg), Mb quantity of fertilizer fed into the machine (kg).

3. RESULTS AND DISCUSSION

The equipment was designed, fabricated and the result of the performance testing is presented in Table 1. The highest quantity of fertilizer delivered was 7.23 kg at a speed of 5 km/hr while the lowest quantity of fertilizer, 3.12 kg was delivered at a speed of 20 km/hr. Similarly, the highest delivery rate of 325.68 kg/ha was obtained at speed of 5 km/hr and low delivery rate of 139.64 km/hr was obtained at speed of 20 km/hr. Delivery efficiency (99.02 %) was also higher with a value of at the lowest speed of 5 km/hr while the lower value of 42.74 % was obtained at the highest speed of 20 km/hr.

Table 1: Result of effects of speed on the equipment performance

Speeds (km/hr)	Area covered (m^2)	Quantity of fertilizer Delivered (kg)	Fertilizer delivery rate (kg/ Ha)	Delivery efficiency (%)
5	0.0222	7.23	325.68	99.04
10	0.0222	7.04	317.12	96.45
15	0.0222	5.56	250.02	76.16
20	0.0222	3.12	139.64	42.74

These results indicate that increasing the speed from 5 km/hr to 20 km/hr decreased the quantity of fertilizer delivered from 7.23 to 3.12 kg (a decrease of 56.85 %). This could be due to increase in rotational speed of the centrifugal fertilizer spreading disc which obtains power from the broadcaster's wheel through a bevel gear system. The average quantity of fertilizer delivered as shown in Table 1 reveals that the equipment forward speed of 5 and 10 km/hr gave an average fertilizer delivered rate of 325.68 and 317.12 kg per hectares respectively. These values are greater than the recommended value of 250 kg per hectares reported by Dugje *et al.* (2009). Also, this increase in application rate would in turn hasten the growth of weeds and further impede the proper growth of crops (Gbabo *et al.* 2016). The machine operating speed of 15 km/hr gave an average fertilizer delivered rate of 250.02 kg per hectare which are in line with the recommended value of 250 kg per hectares reported by Dugje *et al.* (2009). On the other hand, the operating speed of 20 km/hr gave an average fertilizer delivery rate of 139.64 kg per hectare which is far below the recommended value which means insufficient nutrient supplement needed for the proper growth and development of rice plant. According to Silva and Uchida, (2000), the deficiency of N.P.K fertilizer would result to stunted growth due to reduction in cell division. Pale green to light yellow color (chlorosis) will appear firstly on older leaves, usually starting at the tips. Depending on the severity of deficiency, the chlorosis could result in the death and/or dropping of the older leaves. Also the deficiency may result to delayed maturity and poor seed and fruit development.

4. CONCLUSION

A motorcycle drawn fertilizer broadcaster has been developed and tested. Testing of the equipment using 7.3 kg of mixed NPK and superphosphate fertilizers in the ratio of 5:6 was carried out. From results obtained, the following conclusions are made:

i. The quantity of fertilizer delivered per area of 0.222ha reduced with increase in speed of the equipment/motor cycle from 7.23 kg to 3.12 kg at speeds of 5 km/hr and 20 km/hr respectively.
ii. The fertilizer delivery rate was also found to reduce from 325.68 kg/ha to 139.64 kg/ha with increase in equipment speeds from 5 km/hr to 20 km/hr respectively.
iii. Fertilizer delivery efficiency was also observed to be higher, 99.02% at lower equipment speeds of 5 km/hr and lower, 42.74% at higher equipment speed of 20 km/hr.

iv. The machine operating speed of 15 km/hr gave an average fertilizer delivered rate of 250.02 kg per hectare which is in line with the recommended value of 250 kg per hectares reported by Dugje *et al.* (2009).

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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