DESIGN, FABRICATION AND TESTING OF A TRACTOR DRAWN SOYBEAN PLANTER

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Abstract: A tractor drawn Soybean drum planter was designed, fabricated and tested in the DESFABENG Company Limited, Bida, Niger State. The project was undertaken due to the fact that most of the imported planters usually have maintenance and repair problems in addition to high costs of procurement that are not affordable to an average farmer. The major components of the developed planter are three drums with predetermined hole sizes at the exterior ends, a central rectangular shaft, spring soil openers, roller soil coverers, tractor hitching points, two wheels and power transmission mechanism and frame. All these components were fabricated with locally available materials. Using three test speeds, the planter was preliminarily assessed for seed rate, soil opening, covering and germination efficiencies. Results obtained indicate that desirable seed rate values of 47.7 and 61.2 kg/ha were observed for tractor/implement speeds of 20 and 16 km/hr, respectively. The highest germination efficiency of the planter was 81.3% at tractor/implement speed of 16 km/hr with corresponding soil opening efficiency of 94%.

Keywords: Design, furrow opener, germination efficiency, soybean planter, tractor drawn

Introduction

Soybean (*Glycine max* L.), is a versatile specie of the grain food legume notable for its rich source of valuable and quality protein, oils and an excellent source of food for man and animals (Aniekwe and Mbah, 2014). It is ideal for infant foods because it has minimal oligosaccharides which cause flatulence in other grain legumes and its oil content belongs to the linolenic unsaturated fatty acid group without cholesterol (Aniekwe and Mbah, 2014).

The rapid growth in the poultry sector in the past few years has also increased demand for soybean meal in Nigeria. It is believed that soybean production will increase as more farmers become aware of the potential of the crop, not only for cash and food but also for soil fertility improvement as they fix atmospheric nitrogen and thus reduce fertilizer used by farmers (Dugje *et al.*, 2009).

As the importance and awareness of soybean continues to increase, it is necessary that more soybeans be produced, but this can only be achieved through some level of mechanization of which planting activity is a very important process which needs mechanization (Khan *et al.*, 2015). Manual method of seed planting results in shallow seed placement, spacing efficiencies and serious back ache for the farmer which limits the size of field that can be planted. However, planting machines are normally required to increase production but they are beyond the buying capacity of small holder farmers (Kalay*et al.*, 2015). As a result, these small holder farmers still continue to plant manually leading to low productivity. It has therefore been advocated that appropriate planter that will reduce drudgery and enable small holder farmers to produce more foods in an environmental friendly condition be developed (Bamgboye and Mofolasayo, 2006).

Generally, different designs of multi-crop planters have been developed in the past with various advantages. However, there are disadvantages and operational limitations which require further studies to overcome. Braide and Njidda (1989) developed a combined jab planter which was found to be 73.4% efficient and was three times faster than manual planting with hoes and cutlass. Braide and Ahmadu (1990) developed a transplanter for some selected crops in Guinea Savannah of Nigeria which has 0.19ha/h field capacity and 20% field efficiency. Gupta and Herwanto (1992) also designed and developed a direct paddy seeder to match a two-wheel tractor. The machine had a field capacity of 0.5 ha/hr at a forward speed of 0.81 m/s.

In Nigeria various types of planters designed and developed to suit the local conditions have been reported. Olajide and Manuwa (2014) developed a low-cost manually-operated hand pushed row crop planter capable of planting three types of grains- maize, soybean and cowpea. An average field capacity of 0.36 ha/hr and efficiency of 71% with a percentage seed damage of 2.58%, spacing of 50.2 cm and an average depth of 4.28 cm were reported for the planter. Bamgboye and Mofolasayo (2006) developed a manually operated two-row planter. The field efficiency and field capacity were 71.75% and 0.36 ha/h while seed rate was 0.36kg/h with low average seed damage of 3.51%. Ikechukwu *et al*. (2014) designed and fabricated a manually operated single row maize planter for garden use and the field test results showed that the planter had a planting capacity of 0.0486 ha/hr. All of the above reported planters have got their obvious advantages both in efficiency and affordability. However, it is clear that most of the existing planters in Nigeria are manually operated, whereas, tractor drawn planters are usually preferred in large farms (Ani *et al*., 2016). The drive towards mechanizing the agricultural sector in Nigeria will only yield the desired results if local engineers advance towards developing not only tractor drawn planters but also planters with high efficiency, low cost of procurement and maintenance. Besides the obvious limitations associated with the existing locally developed planters, the high cost of procuring their foreign counterparts, coupled with the problem of adaptability to the Nigerian climatic and soil conditions necessitate this development.Thus, this paper is aimed at developing a tractor drawn six row soybean planter that will plant soybean with uniform spacing and depth at minimal or no seed damage and at an increased field capacity and efficiency.

Materials and Methods

Machine description

The planter comprises a spring flat bar welded to a 3-inches angle iron at an angle of 120° to form the furrow opener. Just behind the furrow opener are three seed drums with seed delivery holes for achieving a drill seeding pattern as shown in Plates 1 and 2. The major components of the planter as shown in Figs. 1 to 4 are described below;

Seed drum: This was made from a2 mm thick mild steel sheet metal. Inside the seed drum are metal sheet louvers that act as agitators in order to prevent the seeds from piling on one particular spot.

Seed delivery guard and chute: The seed guard was constructed with mild steel sheet plates while the seed deliver chute is made from a cylindrical rubber pipe.

Spring bar furrow opener: The spring bar is a specially treated mild steel flat bar of 10 mm thickness fastened to the beam with the aid of bolts and nuts. While the lower part of the furrow opener was made from mild steel.

Furrow closer: The furrow closers are constructed in form of two truncated rotary wheel to ensure proper covering and compaction of the soil over the seeds in the furrows. The material used for the design was mild steel materials rolled and welded to form truncated circular wheels. They are positioned at the back of the furrow opener for proper covering and firming of planted furrows.

Transport wheels: The wheels are located at both ends of the frame. They are circular in shape made from 2 mm mild steel plate containing 16 mm rods which serves as spokes. The wheel has lugs made from mild steel angle iron and brazed with 16 mm rods in order to improve traction both on dry and marshy lands. These spokes are used to support the centre hub (bearing housing). The spokes are arranged in such a way that it brazed the wheels circular circumference and also gives it necessary radial support. Attached to the centre of the wheels are two shafts whose one end are connected to the wheels and the other end connected to a bearing unit in order to enhance free movement during transportation.

Bearing/bearing housing: The bearings made from high speed steel are selected based on their load carrying capacity, life expectancy and reliability. Ball bearings are fixed in the hub (bearing housing) provided at the two ends of the frame in other to support the solid shaft on which the wheels are attached. The whole bearing and shaft assembly permits the free movement of the wheels.

Frame: This is the skeletal platform of the planter on which all other components are mounted. It is made of 2 and 3-inches mild steel angle iron welded together to form a rectangular chassis to which solid shafts are attached at both rear ends and linked to the transport wheels. The middle of the frame carries the rotary seed drums while the front provides hitching points for attachment to the tractor.

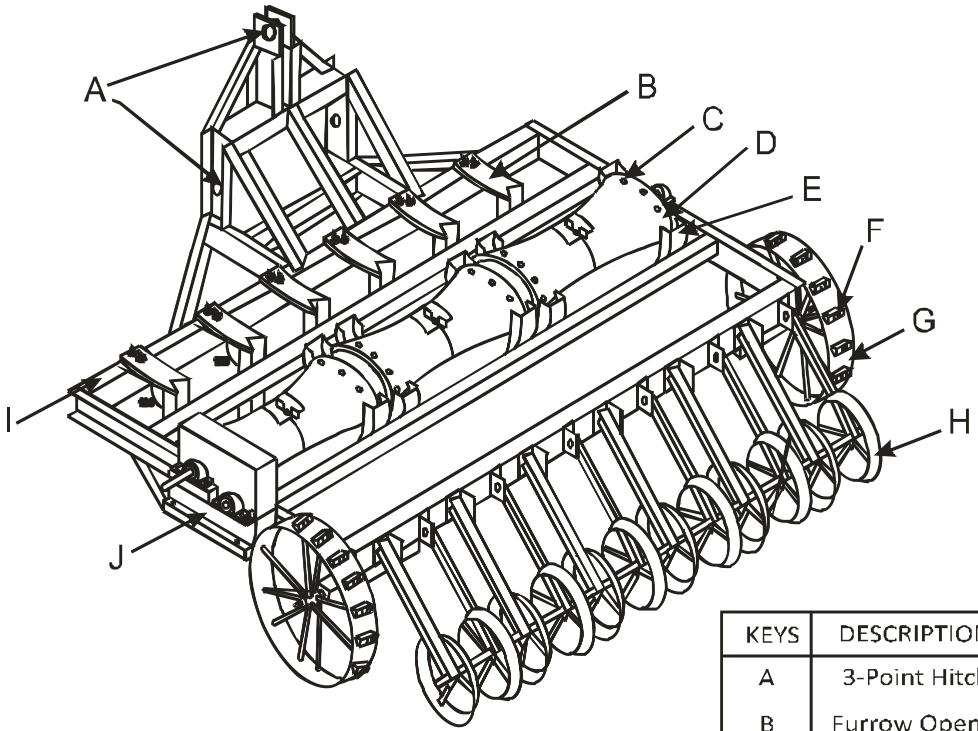

Fig.1: Isometric View of a Soyabean Planter

KEYS	DESCRIPTION
A	3-Point Hitch
B	Furrow Opener
C	Seed Delivery hole
D	Seed container
E	Seed Guide
F	Lug
G	Track Wheel
H	Furrow Closer
I	Beam
J	Gear Unit

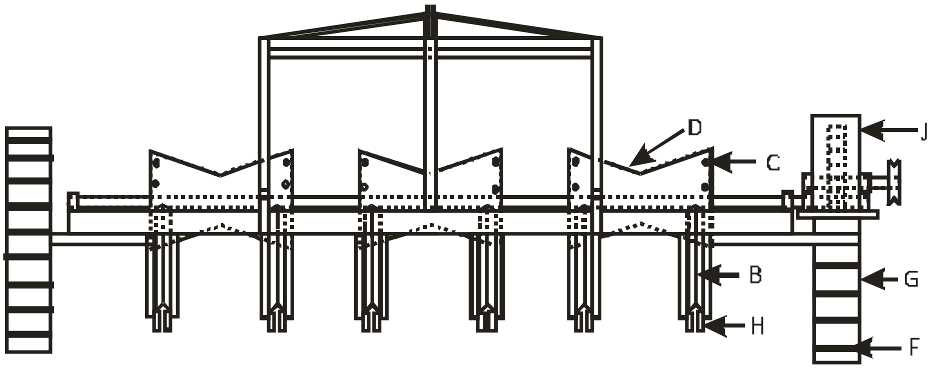

Fig.2: Orthographic Front View

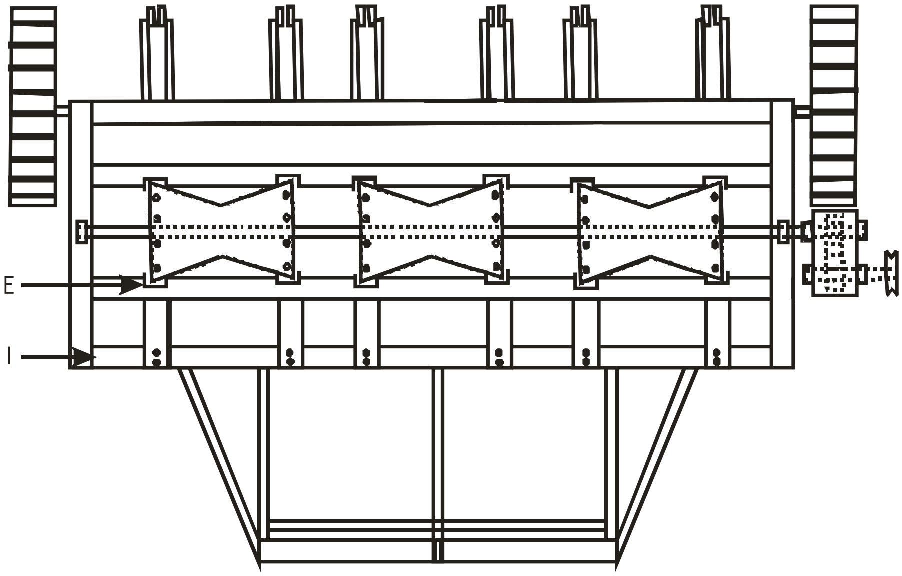

Fig.3: Orthographic Plan View

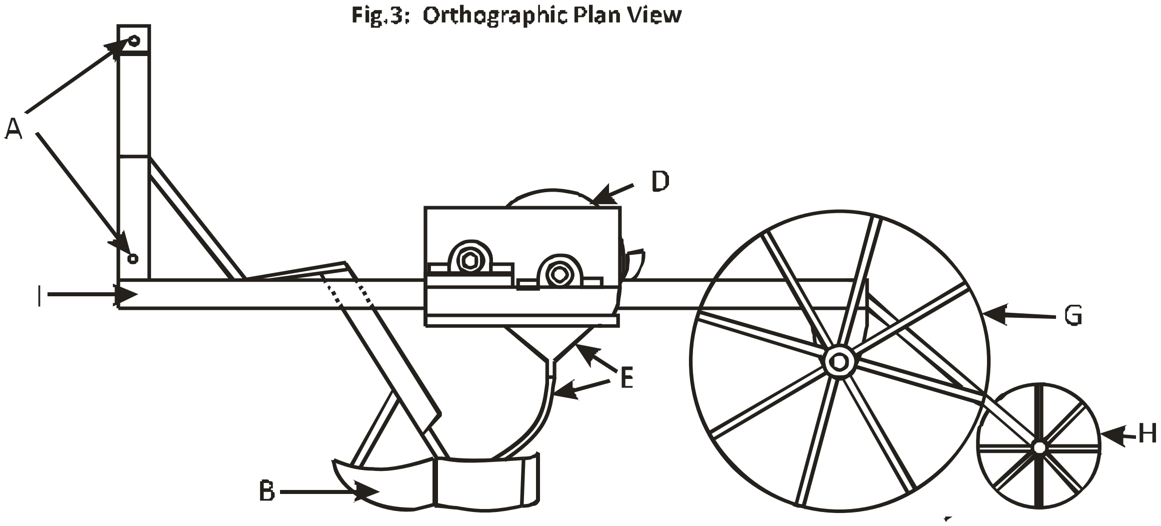

Fig.4: Orthographic Side View

Design analysis

The design analysis was carried out with a view to evaluating the necessary design parameters, strength and size of materials for consideration in the selection of the various machine parts in order to avoid failure by excessive yielding and fatigue during the required working life of the machine.

Determination of weight of the frame

The weight of the beam was determined in order to know the amount of load being exerted on the frame by other components of the planter. Therefore the weight of the frame was computed using the following equation:

$$W = mg \qquad 1$$

$$\text{And } m = \rho v \qquad 2$$

Where, W = weight of the frame (N); M = mass of the frame (kg);

g = acceleration due to gravity (m/s^2); $\rho = density\ of\ the\ frame$ (kg/m^3)

v = volume of the frame (m^3)

But V = L x B x H   3

Where: L = Length of frame (m); B = Breadth of frame (m); H = Height of frame (m)

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 shaft with little or no axial load, the diameter of the shaft was determined using American society of Mechanical Engineers (ASME)

$$d^3 = \frac{16}{\pi S_s} \times \sqrt{(K_b M_b)^2 + (K_t M_t)^2} \qquad 4$$

Where, d= is the diameter of the shaft (m); $S_s =$ is the allowable stress (Nm^{-2})

K_b= is the combine shock and fatigue factor applied to bending moment = 1.5

M_b= is the bending moment (Nm)

K_t= is the combine shock and fatigue factor applied to torsional moment = 3.0

Determination of the speed reduction ratio of the gear unit

The speed reduction ratio of the gear unit is a function of the tractor speed, recommended speed of the rotary seed drum connected to the gear unit and the number of teeth on the two gears. This was computed from established relationship as described by Gbabo (1991).

Determination of the length of the chain

A chain was used to transmit power from the sprocket of the transport wheel to the speed reduction unit. The length was calculated from the formulae below.

$L = 2(C) + (^F/_4 + {}^R/_4 + 1)$ (Khurmi and Gupta, 2005)   5

Where: L = Length of chain (m); C = Center to center distance of both sprockets (m)

F = Number of teeth on front sprocket; R = Number of teeth on rear sprocket

Determination of the speed of the chain

The speed of the chain was determined by using the expression below,

$V = \frac{P \times T \times N}{1000}$ (Khurmi and Gupta, 2005) 6

Where: V= Speed of chain (m/s); P = Chain pitch (m); T = Number of teeth

N = Revolution per minute of the wheel (rpm)

Determination of the power required for creating and closing the furrow

The power required to create and close the furrow was determined from the following expression:

P = Tv (Khurmi and Gupta, 2005)   7

Where P = power required to create and close the furrow (watt)

T = torque of the tractor engine (Nm); v = forward speed of the tractor (m/s)

Determination of the total length of the frame

This was determined as a function of the six furrow openers spaced uniformly from each other on the frame:

$$L = 5s + 2f \qquad 8$$

Where L= Total length of the frame (m); s = Uniform distance between furrows (m)

f = Distance from the edge of the frame to the first and last furrow opener (m)

Determination of the thickness of the spring flat bar

The thickness of the spring flat bar was determined by applying the formula:

ð = $\frac{WL^3}{48EI}$ (Khurmi and Gupta, 2005)   9

Where: W= weight of the spring flat bar (N); L= Length of the bar (m); E=Young modulus (N/m^2)

I = Moment of inertia (m^4); ð = Deflection during operation (m)

But moment of inertia is given as:

$$I = \frac{bh^3}{12} \qquad 10$$

Where b = width of bar (m); h = Thickness (m)

From equations 13 and 14,

h = √12WL^3/48Eðb   11

Determination of the maximum shear stress of the shaft

The shaft is under a combined load of bending moment and torque and is given as:

$\tau_{max} = \frac{16}{\pi d^3}\sqrt{(M^2 + T^2)}$ (Khurmi and Gupta, 2005)
12

Where:τ_{max} = Maximum shear stress (N/m); T= Torque (Nm); M= Bending moment of shaft (Nm)

d= shaft diameter (m)

Vertical resolution of forces

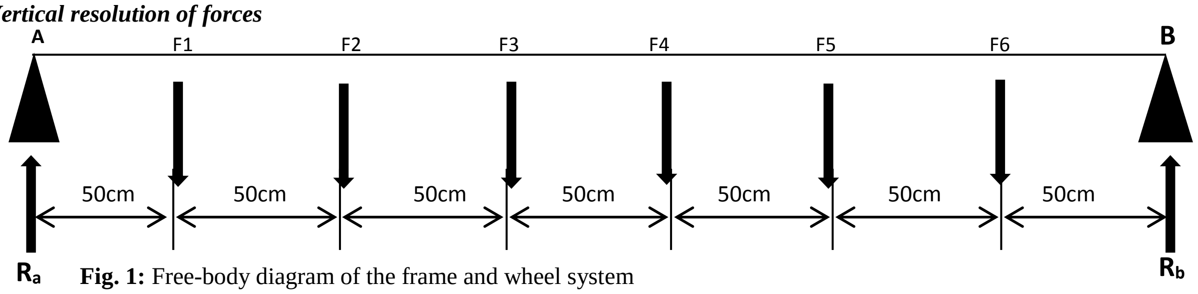

Fig. 1: Free-body diagram of the frame and wheel system

Where: R_a and R_b = vertical soil reactions acting on the transport wheels; F1 – F6= vertical forces acting on the individual (Flat spring bar) furrow openers

Resolving forces acting on the frame/furrow opener assembly vertically, using the relationship below;

$F_v = W cos\theta$ 13

Where, F_v-is vertical force

W- is the weight of frame with the furrow opener and other components

θ-is the angle of inclination of the furrow opener

For this design θ is taken to be 120^0.

From the figure 1, the summation of vertical forces is equal to zero(0)

$$+\uparrow \sum V = 0$$

$$R_a + R_b - F_1 - F_2 - F_3 - F_4 - F_5 - F_6 = 0$$

$$\therefore R_a = F_1 + F_2 + F_3 + F_4 + F_5 + F_6 - R_b \quad 14$$

Taking moment about point A

$$+\uparrow \sum M_A = 0$$

$$50F1 + 100F2 + 150F3 + 200F4 + 250F5 + 300F6 - 350R_b = 0$$

$$R_b = \frac{50F1+100F2+150F3+200F4+250F5+300F6}{350} \quad 15$$

Determination of the size of welded joints

Considering the form of welding used in forming the frame, furrow opener and the 3-point hitch, let the throat thickness be denoted as t, the length as L and the size of weld joint as S.

t = 5sin45^o 16

t = 0.70715

The force in each column is given by the relationship

F= 2 x throat area x allowable stress (double fillet)

F= 2tlð 17

F=2x0.70715lð

S= f/2x0.70715lð 18

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 Hall *et al*. (1980) the amount of twist permissible depends on particular application and varies about 0.3 degree per meter for a machine tool shaft and about 3 degree per meter for line shafting.

Therefore, angle of twist (θ); for solid shaft is given as follow:

$$\theta = \frac{584M_tL}{Gd^4} \quad 19$$

Where:L- is the length of shaft (m)

M_t-is the torsional moment (Nm)

G-is the torsional modulus (N/m^2)

d- is the diameter of the shaft (m)

Determination of the capacity of the seed drums

The seed drum design was based on the volume of frustum of a horizontal cone. The seed drum is made up of two horizontal conical frustum welded together to form one unit. The volume of the two welded conical frustums was obtained by taking a horizontal angle of repose 20^o so that when the soybean seeds are poured into the seed drum, they will flow towards the seed holes. The capacity of the hopper of this planter was designed according to the principle of determining volumetric and gravimetric capacity of hopper as given by Ilori *et al.* (1997).

Operation and test procedure of planter

The planter was hitched to a 75 horse power Massey Ferguson 375 tractor with the aid of the tractor three point linkage (Plate 2). The depth of penetration of the furrow opener into the soil was controlled from the adjustment of the tractor's three point linkage controlled by the hydraulic control lever. Furthermore, a reduction system comprising of gears, chain and sprockets was used to connect the transport wheel to the rotary seed container so as to reduce the speed of the transport wheel to the speed required for effective planting of soybean seeds. Viable soybean seeds were then poured into the rotary seed drums which were refilled whenever the level of the seeds get to about 1/8th of the drums volume.

The six row tractor drawn rotary drum planter (Plate 1) was tested for its capacity, furrow opening efficiency and seed germination using 1 hectare of flat land ploughed and harrowed properly at Essa village in Niger state, Nigeria in October, 2015 which is the rainy and planting season. From a desired starting point, the planter was lowered and adjusted to a depth of 5 cm which is the recommended depth for planting soybeans with the aid of the upper and two lower links of the tractor. The planter was then pulled along at four different speeds, 8, 12, 16 and 20 km/h to open the soil, drop the seeds and cover the seeds with soil. The seeds were left to germinate in the field for 3 weeks and the germination rate was assessed.

The actual depth of soil opened by the equipment, its efficiency in opening the soil relative to the adjusted depth and seed germination were assessed as follows:

I) Depth of furrow: This was assessed by measuring the depth with a measuring tape. A flat bar was laid horizontally across the furrows at random points and the metric tape was used to measure the vertical height.

II) Furrow Opening efficiency: The furrow opening efficiency of the implement was computed as the ratio of the actual depth of the furrows created by the implement to the adjusted furrow depth before commencing operation expressed in percent :

$$F_o = \frac{F_{ad}}{F_{id}} \quad 20$$

Where F_o is Furrow opening efficiency (%); F_{ad} is Actual furrow depth (cm)

F_{id} is initial adjusted depth before commencement of operation (cm)

III) Germination rate: The germination rate was determined by marking out and counting the number of seeds drilled within a given area at different points. The number of seeds that germinated after three weeks was also counted and was expressed as percentage relative to the seeds number of seeds drilled originally at each point as follows:

$$G_r = \frac{s_g}{s_d} x\ 100\% \quad 21$$

WhereG_rGermination is rate (%); $s_g$is number of germinated seeds; $s_d$is Number of drilled seeds

Plate 1: completed planter

Plate 2: Planter mounted on tractor

Results and Discussion

Table 1 presents the results of the performance evaluation of the designed and constructed planter.

Table 1: Performance of planter

S/N	Tractor/ Implement speed (km/h)	Replic-ations	Seed rate at two areas of outlets(Kg/ha)		Furrow depth (cm)	Germi-natioin (%)	Average seed rate at two areas of seed outlet(kg/ha)		Average Furrow Depth (cm)	Average germination (%)	Furrow opening efficiency (%)
			Full	3/4			Full	3/4			
		1	85.3	68.6	4.0	80.2					
1	8.0	2	88.6	66.3	4.0	74.4	84.4	67.2	4.3	74.2	86.0
		3	79.2	66.7	5.0	68.3					
		1	70.1	65.3	3.0	82.4					
2	12.0	2	78.4	60.6	4.0	75.3	75.9	62.8	4.0	79.5	80.0
		3	79.3	62.5	5.0	80.8					
		1	62.0	45.2	5.0	81.0					
3	16.0	2	58.2	43.9	4.0	79.3	61.2	44.1	4.7	81.3	94.0
		3	63.3	43.1	5.0	83.6					
		1	48.4	33.8	3.0	75.1					
4	20.0	2	44.7	37.2	3.0	68.0	47.7	36.7	2.7	66.9	54.0
		3	50.1	39.0.	2.0	57.5					

As shown in table 1, the furrow opener performed better at tractor and implement speeds of 8, 12 and 16 km/h by opening up the soil up to depths of 4.3 cm at 8 km/h, 4.0 cm at 12 km/h and 4.7 cm at 16 km/h. These values are comparable with the values reported by Olajide and Manuwa (2014). The lowest furrow depth of 2.7 cm was recorded for the highest speed of 20 km/h. This could be due to the imperfectly levelled soil condition which makes the implement to skip some portions of land. It is also an indication that operating the implement at that speed (20 km/h) is not ideal if optimum performance is required. Also, the highest average germination rate of the soybean seeds was 81.3 % for tractor/implement speed of 16 km/hr and lowest, while at a speed of 20 km/h, the lowest average germination rate of 54% was obtained. The low germination rate for the highest tractor speed is attributable to the shallow furrow which enabled rodents, birds and pests to pick them up. The best and optimum speed for desirable performance of the implement is therefore recommended to be 16 km/h. Results obtained from the test carried out indicates better performance of the tractor mounted planter compared to the garden planter constructed by Ikechukwu *et al.* (2014).

Conclusion

A six row tractor soybean planter was successfully designed, fabricated and tested. The optimum performance (94% furrows opening efficiency and 81.3% seed germination efficiency) of the planter was achieved with tractor/implement speed of 16 km/h. The machine was found to have promising performance if the development of the equipment is perfected. It reduced drudgery associated with manual planting. From test results of the machine, the following findings were observed:

i) The planter gave the best average germination and furrow opening efficiencies of 81.3% and 94%, respectively at a forward speed of 16 km/h.
ii) The furrow opening depth of 4.7 cm at a speed of 16 km/h was found to be adequate compared with recommended standard of 5 cm.
iii) Seed germination was found to be 94% at 16 km/h tractor speed.

However, the following modifications on the planter are recommended to improve the overall efficiency of the planter:

i) Incorporation of a central seed locking devise to prevent seed losses at turnings
ii) Replacement of the spring shoe type furrow openers with disc openers to avoid packing trashes
iii) A device to stabilize the furrow coverers during operation to cover the seeds appropriately should be incorporated.

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