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DEVELOPMENT OF A SINGLE ROW ANIMAL DRAWN GROUNDNUT DIGGER FOR SMALLHOLDER GROUNDNUT FARMERS IN SUDAN SAVANNAH OF NIGERIA

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Abstract
Harvesting groundnut is a serious problem in the Sudan Savannah of Northern Nigeria. The small- and medium-scale farmers harvest their groundnuts manually using traditional tools such as hoe. This practice is laborious, time-consuming, and leads to pod losses due to inefficient groundnut harvesting implement. In addition, the tractor-mounted groundnut harvesters are too expensive for these farmers to acquire. In view of the aforementioned, problems, a prototype of an animal-drawn groundnut digger was developed considering the agronomical and functional requirements for digging groundnut crops. The major components of the groundnut digger include a cutting blade, depth control wheel, frame, handles, and draft pole. A pair of bullocks pull the groundnut digger. The outcome of this research study could be used in reducing the drudgery involved during the digging of groundnut from the soil. The implement would also reduce pod losses, and boost agricultural mechanization during groundnut harvesting operations in the Sudan Savannah of Nigeria.
Keywords: Groundnut harvester, Groundnut harvesting, Shaft design, Animal-drawn digger.

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1. Introduction

In West Africa, Nigeria is the largest groundnut-producing country accounting for 51% of production in the region (Muhammad & Isiaka, 2019). Groundnut is a major source of edible oil as well as livelihood for small-scale farmers in Northern Nigeria (Ajeigbe *et al.*, 2015; Ahmad *et al.*, 2018). Being a major cash crop, it generates employment for rural farmers. Groundnut is planted on about 34% of the total cultivated area and contributes 23% of household cash revenue (Ndjuenga *et al.*, 2008). In Nigeria, crop research institutes both national and international have developed many varieties of their mandate crops. These crops are high yielding, disease and pest-resistant, early maturing and aimed at increasing the productivity, income, and livelihoods of poor-resource farmers (Utoh and Ajeigbe, 2008; Muhammad *et al*., 2015). Groundnut occupies a prominent position among the mandate crops produced by research institutes in the Sudan Savannah of Nigeria. With diverse use and utilization of groundnut coupled with increased production, more efficient ways of harvesting it should be devise. The search for more efficient, cost-effective ways of harvesting groundnut is significant because of the extreme labour intensity of this task (Nautiyal, 2002). The mechanical harvesting of groundnut has advantage of reducing the cost and labour requirement, and is conducive to allow for better soil fertility as the blade of the digging implement cuts through the root below the pod zone and leaves the remaining root system in the soil (Ademiluyi *et al.*, 2011). Draught animal power is a sustainable farm power, which can greatly reduce the enormous problems encountered by the rural farmers. Most small-scale farmers cannot afford the use of tractors. Therefore, animal-drawn equipment can provide power and take the drudgery out of land preparation (Abubakar and Ahmad, 2010). The development of an animal-drawn groundnut digger with higher field capacity will encourage farmers to cultivate larger hectares of land thereby improving their economic status and export capacity of the country. Likewise, an average small farm holder uses animal in most of their farm operations, thus acquiring this equipment/machine requires minimum investment, less problem of repair and maintenance during operation.

2. Materials and methods

The design requirements and constrains considered during the design and construction of the developed groundnut digger were as follows:

Frame: The size of the main frame in terms of length, width, and height was established with respect to ridge size, number of ridges per swath and stability of the implement. Besides, the size of the frame members was selected based on strength, rigidity, and weight limitations for the comfort of the draught animal.

Width of operation: The effective width of cut was determined by direct measurement of the ridge width (0.75 m) on the field.

Cutting depth: The reported groundnut pods zone by Attanda and Adinoyi (2016) is 7 – 10 cm while Singh and Oswalt (1995) recommended that to harvest groundnut using a blade harrow, the depth of cuts of the plant roots should be 12 – 15 cm below the soil surface. The cutting depths chosen were 10 and 15 cm. This is aimed to ensure that the digger blade cuts below the pod zone to reduce pod damage due to the implement blade.

Weight: The weight of the implement considered was based on the allowable weight the draft animal can pull and enable penetration of the implement blade into the soil with minimal soil compaction. The minimum permitted weight of bull for draught was chosen as 1500 N (Goe and Mcdowell, 1980). For this study, 3000 N was chosen as the minimum weight of the bull used.

Handle: The stability of the implement during operation and the comfort of the operator are important factors considered in designing the handle of the animal drawn groundnut digger. It was designed to enable variation in height depending on the operator's height. Gite (1991) reported that the optimum handle height for a mould board plough is between 732 and 842 mm and for a fixed handle 770 mm is recommended. The digger handle height was adjustable and range from 750 to 800 mm was selected to suit individual operator's height.

3. Design Calculations

The design procedures and calculations used for the component parts designed to form the whole digger are discussed in subsequent sections.

Cutting blade: The blade size in terms of width was established based on ridge spacing (Fig. 1). The average inter-row spacing based on agronomic practice of groundnut farming is 750 mm (Ajeigbe *et al.*, 2015). Since the developed implement is a single row digger, and to ensure that the cutting blade cut through the ridge completely from one end of the ridge to the other during operation, the width of the blade selected is wide enough to cover the width of the entire ridge.

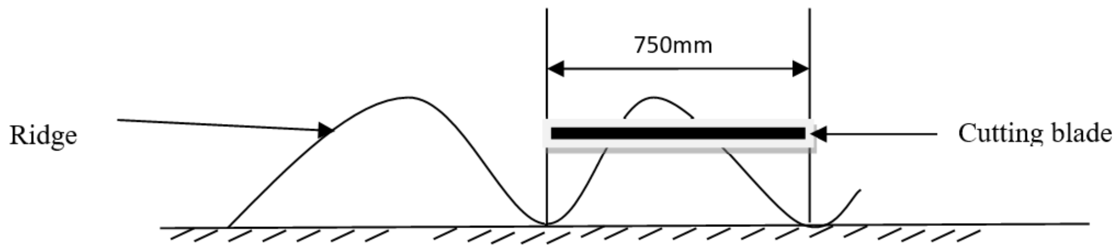

Fig. 1. Diagram showing the cutting blade width in relation to the ridge spacing

Machine width: The overall implement width of 890 mm was selected. The choice of this dimension was to ensure stability of the implement and it manoeuvrability. It is approximately 20% wider than inter-row spacing.

Machine cutting depth: The cutting depth of the blade was adjusted by means of calibration made on the two depth control wheels. This was achieved by taking measurements on the depth control wheel brackets and drilling three holes which are 15 mm each apart. For the depth verification, five (5) measurements for each graduation were taken with five (5) run to verify the set depth of operation for each treatment. This parameter is the vertical distance between the soil surface and depth of cut as the blade cuts through the ridge. A meter rule was used to determine this value. The mean values were recorded as the depth of operation. Fig. 2 shows the cutting depth arrangement in relation to the implement blade and wheel.

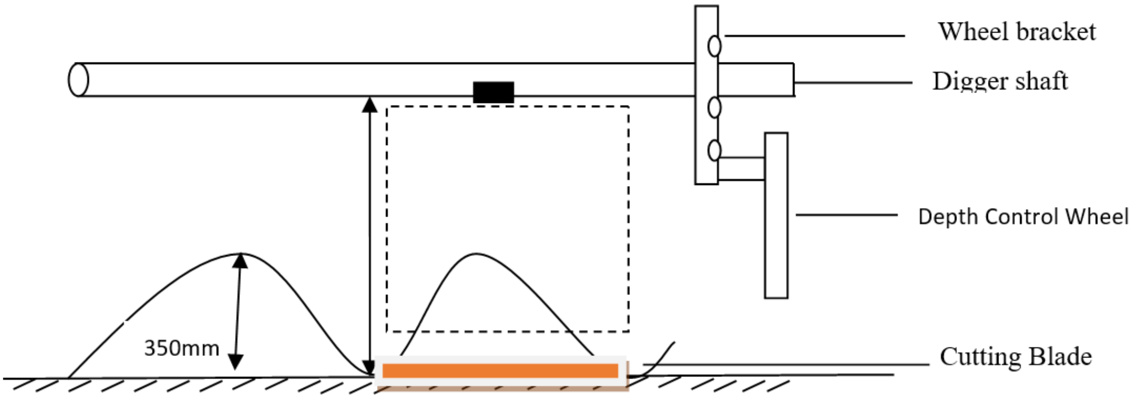

Fig. 2. Cutting depth arrangement in relation to the implement blade and wheel

Determination of weight of the cutting blade. The average weight of a work bull was given by FAO (1969) as 600 kg. Therefore, for a pair of work bulls, the total weight was 1200 kg. Oni (2011) reported that a pair of working animals (work bulls) is capable of supplying an equivalence of one-tenth of their body weights working continuously for about 3 to 4 h. Hence, 120 kg (one-tenth of 1200 kg) was chosen as the maximum limit weight on the implement. However, Sean *et al.* (2000) reported that maximum tractive thrust of a traction member (H) of a vehicle is dependent upon the weight (W) on the vehicle, the coefficient of cohesion (C), the angle of friction (θ) and the wheel contact area (A) and can be calculated using the equation (1).

$$H = CA + W \tan(\theta) \tag{1}$$

$$A = 0.78bL \tag{2}$$

Where: b = contact wheel width = 50 mm; L = contact wheel length = 20 mm; A = wheel contact area (mm); $A = 7.8 \times 10^{-4}\ m^2$;

$H = (7.8 \times 10^{-4} \times 10) + (120 \tan 21^o)$

H = 46.07 kN = 0.45 hp

According to Sean *et al.* (2000) tractive force horse power is given as:

$$\text{Tractive Hp} = \frac{Draft \times Speed}{270} \tag{3}$$

$$\text{Draft} = \frac{Tractive(Hp) \times 270}{Speed} \tag{4}$$

$$\text{Draft} = \frac{0.45 \times 270}{2} = 60.75\ \text{N}$$

From equation (5); the draft force, can be determined (Onwualu and Watts, 1998)

$$\text{Fa} = \gamma b d v^2 \times \frac{\sin\alpha}{\sin(\alpha + \beta)} \quad (5)$$

Where: Fa = draft force, γ = soil bulk density, b = blade width, d = cutting depth = 0.15 m (Sigh and Oswalt, 1995), v = average working speed of a bull = 2 m/s (FAO, 1994), α = digger rake angle = 20^o (Moayad *et al.*, 2014), β = Angle of internal friction = 21^o (determined from the experimental site). Moayad *et al.* (2014) stated that a lower implement rake angle of 20^o reduces draft significantly; hence rake angle of 20^o was adopted.

$$\text{b} = \frac{Fa \sin(\alpha + \beta)}{\gamma d v^2 \sin\alpha} \quad (6)$$

$$\text{b} = \frac{60.75\ \sin(20+21)}{0.346 \times 0.15 \times 2^2 \sin(20)} = 599.23\ mm \approx 600\ \text{mm}.$$

Considering 25% of 600 mm for edge clearance,
b = 600 + 150 = 750 mm

Digger weight. The design weight of the digger was based on the minimum permitted weight of 1500 N for a bull as reported by Goe and Mcdowell, (1980) in consideration of the design of the implement shaft.
Shaft design. The implement shaft diameter was determined based on bending moment only since the shaft under consideration is not subjected to any torsional stress. The maximum bending moment on the implement shaft was determined by considering the total weight of the implement carried on the shaft of 770 mm length. Similar approach was reported in Muhammad and Isiaka (2019). The total weight of implement comprised of weight of cutting blade, mainframe and that developed on the shaft as result of pulling force by the draft animals. The vertical loading being the weight of other components on the digger shaft (cutting blade, handle and draft pole) was measured to be approximately 540 N, while the maximum horizontal loading of the implement was considered as permitted weight of a work bull given as 1500 N.

For vertical loading;

$$RA_V + RB_V = 540$$

Taking moment about B

$$RA_V \times 850 = 540 \times 425$$
$$RA_V = \frac{540 \times 425}{850}$$
$$RA_V = 270\ \text{N}$$
$$RB_V = 270\ \text{N}$$

For horizontal loading;

$$RA_H + RB_H = 1500$$

Taking moment about B

$$RA_H \times 850 = 1500 \times 425$$
$$RA_H = \frac{1500 \times 425}{850}$$
$$RA_H = 750\ \text{N}$$
$$RB_V = 750\ \text{N}$$

The vertical and horizontal bending moments were obtained by considering clockwise and anticlockwise moment to be positive and negative, respectively about point A, B, and C.

Vertical bending moment

At A, $x = 0 \quad M_A = R_A = 0$

$M_A = 270 \times 0 = 0$

At C, $M_{C,} x = 425$

$M_C = R_A . x$

$M_c = 270 \times 425 = 114750 \ Nmm$

At B, $M_B = R_A . x - R_C . {}^1/_2 \, x$

$= 270 \times 850 - 540 \times 425 = 0 \ Nmm$

Horizontal bending moment

At A, $x = 0 \quad M_A = R_A . x$

$= 750 \times 0 = 0 \ Nmm$

At C, $x = 425$

$M_C = 750 \times 425 = 318750 \ Nmm$

At B, $x = 850$

$M_B = R_A . x - R_C . {}^1/_2 \, x$

$= (750 \times 850) - (1500 \times 425) = 0 \ Nmm$

The resultant bending moment of the shaft at C is

$$M_C = \sqrt{(M_{CV})^2 + (M_{CH})^2}$$

$$M_C = \sqrt{(114750)^2 + (318750)^2} = 338775.84 \ Nmm \quad \approx 338.78 \ Nm$$

The maximum resultant bending moment M_C of the shaft is 338.78 Nm

Determination of maximum allowable stress. The strength properties given by ASME (1948) for the selected shaft material (C1040 mild carbon steel) are;
Yield (Proof) Stress, Sy = 568.7 × 10^6 N/m^2
Tensile Stress, St = 668.8 × 10^6 N/m^2
Allowable shear stress, T_a for C1040 = 30% Sy = 170.61 × 10^6 N/m^2
Allowable shear stress, T_a for C1040 = 18% St = 120.38 × 10^6 N/m^2
Using the ASME code for steel, the lower value of T_a for C1040 obtained from either 30% Sy or 18% St is used. Hence, the T_a of 120.38 × 10^6 N/m^2 is selected for the shaft design.

Determination of the shaft diameter. Shafts are normally acted upon by gradual and sudden loads (Kurmi and Gupta, 2007). Hence, the shaft diameter can be determined using equation (7) by considering a suitable load factors.

$$d_s = \left\{\frac{16}{\pi T_a} \ . \ \sqrt{(k_m M)^2 + (k_t T)^2}\right\}^{\frac{1}{3}} \qquad (7)$$

Where: d_s = shaft diameter, (m); T_a = allowable shear stress = 120.38 × 10^6 N/m^2; M = bending moment = 338.78 Nm; T = torsional moment (Nm), K_m = combine shock and fatigue factor applied to bending moment = 1.5 to 2.0 for load suddenly applied with minor shock; K_t = combined shock and fatigue factor applied to torsion moment =1.0 to 1.5 for load suddenly applied with minor shock.

From equation (7), $d_s = \left\{\frac{16}{\pi \times 120.38 \times 10^6} \times \sqrt{(2 \times 338.78)^2 + (0)^2}\right\}^{\frac{1}{3}}$

d = 0.03060 m

30 mm diameter shaft was chosen being the nearest available shaft diameter to 30.6 mm.

Force acting on the wheel. The diameter of the traction wheel was established based on a number of factors, which include the ridge height given as 350 mm (Buba, 2003), implement stability and the self-weight of the implement chosen on the measured weight of the designed implement shaft (25 kg). Thus:

$$r = P = \frac{W}{A} \quad (8)$$

Where: W = weight on the wheel [with frame weight (7.8 kg) inclusive] = 32.8 kg; r = wheel radius
A = wheel contact area = 0.78bL

$$r = \frac{32.8}{0.000195} = 168.2\ mm$$

Wheel diameter (d) = 2r = 336 mm

The designed wheel diameter of the digger = 336 mm

Construction of Groundnut Digger Component. The materials selection for the construction of the groundnut digger was based on durability, availability and cost. The fabrication process consisted of construction of the basic components and assembly of the prototype digger. The outline of the procedure used for the construction of the component parts of the digger are stated in this section.

Wheel and depth control frame. The frame was constructed from 50 × 50 mm mild steel angle iron having thickness of 5 mm. The size is selected primarily for rigidity and stability of the implement. The wheel and depth control frame serves as the skeleton for other parts, and a means of coupling the parts together. The angle bar is welded into a rectangular shape with length and width dimensions equal 490 × 65 mm and 460 × 40 mm, respectively. The wheel frame at one end is welded to the implement shaft by means of 30 mm diameter slots. The other end is provided with a square groove of 40 mm, which allows the depth control frame to be fitted with the help of slots of 15 mm diameter made on the upper end of the depth control frame at 50 mm apart. At the lower end, a stud of 20 × 70 mm was welded to the depth control frame on which the ground wheel is coupled.

Implement shaft. A solid shaft medium carbon steel of 30 mm diameter was used base on calculation. It has a total length of 770 mm. The shaft is finally welded to the two wheel frames via a 30 mm diameter slots at the other end of the frame.

Ground wheels and draft pole. Each of the ground wheels was constructed from mild steel flat bar of 4 × 50 × 1055 mm. The length (1056 mm) is then rolled to form a wheel of designed diameter of 336 mm. Eight spokes placed at 75^{o} interval are use to reinforce each ground wheel. The wheel is then allowed to rotate freely on the stud welded to the depth control frame with the help of plain journal bearing place at the centre of the wheel. To improve upon traction, 20 flat rectangular metals of dimension 3 × 50 × 10 mm were welded on the outer circumference spaced at 40 mm at an offset of 100 mm adjacently to proceeding member of each of the ground wheel. The draft pole is made-up of two galvanized steel pipe with dimensions of 50 × 1000 × 5 mm and 50 × 700 × 5 mm. It was designed to be a collapsible member, the one with the smallest diameter slide into the larger pipe, and slots were created at 100 mm intervals on both pipes. This allow for specific length adjustment.

Implement handle and cutting blade. A galvanized steel pipe of 25 mm diameter was used for the handle. 50 × 4 mm mild steel flat bars were used for the construction of the two handles height control member. The handle was fitted on the implement shaft with the help of two (2) bearings and bearing housing spaced 500 mm apart. Two bolts and nuts were welded to the two handles likewise the frame of the implement. Provisions were made to adjust the height of the handle to suit the operator's height via four (4) holes that were drilled and equally spaced at 50 mm apart. The cutting blade was constructed from 750 × 160 × 5 mm rectangular mild steel sheet; and welded at both ends to two 18 mm mild steel rods of 700 mm length rolled into an arc. The other end of the two (2) arc rods were welded to the implement shaft.

Hitching system. The digger was set and hitched to a pair of bullocks for operation. Two animals hitched to a two-wheeled with a collar harness. The collar harness was made from wood. The advantage of the collar harness is that it is good for work at different draught forces. It spreads the force of pulling over a wider surface of contact with the animal.

Assembly of the Prototype Groundnut Digger Components. The prototype digger is made up of the wheel and depth control frame, cutting blade, ground wheel, handle and handle height control flat bars, shaft and draft pole. The depth control frame is connected to the ground wheel via a stud and bearing arrangement is mounted on the wheel frame. The wheel frame is connected to the implement shaft and is coupled with the cutting blade assembly. The digger handle and draft pole are mounted on the implement shaft by means of bearings. A pair of bullocks is used as draught for pulling the prototype during the groundnut harvesting (digging) operation. A detailed drawing and pictorial view of the groundnut digger prototype are shown in Fig. 3 and 4.

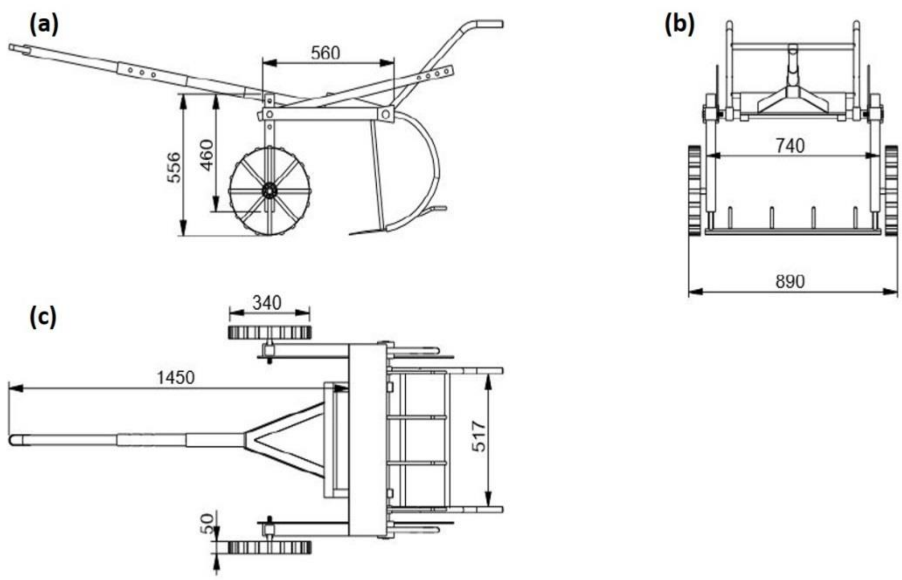

Fig. 3. (a) Side, (b) front and (c) top views of the Developed Groundnut Digger

Fig. 4. Assembled Prototype Digger

Principle of Operation of the Prototype Groundnut Digger. The developed prototype groundnut digger was designed as an animal drawn implement and to dig a row at a swath. In operation, the two ground wheels are placed in separate furrow, living the ridge in between the digger wheels. The draft pole is then hitch to the work bulls and the implement blade is adjusted to the desired depth of cut through the calibration made on the two depth control wheels. The handle can be adjusted for the comfort of the operator. As the work bulls are made to move forward and pulling the implement, the blade cut the ridge below the groundnut plant. The plant then move over the digger blade which is coupled with levelers spaced at interval to facilitate the separation of the groundnut plant from the soil that has being cut by the blade. The groundnut plant is then discharged behind the digger on top of the ridge.

4. Conclusion

A single row animal draw groundnut digger was developed to improve groundnut harvesting by reducing the drudgery involved. The digger can also reduce pod loses faced by farmers during harvesting. It can also boost productivity due to the mechanizing of the groundnut harvesting operation. The single row animal draw groundnut digger has an overall width of 890 mm with a blade width of 750 mm that can be effectively used for harvesting of groundnut crop at low soil moisture content and depth of 350 mm. This constitutes a considerable drudgery reduction compared to the manual labour. What remains is to carry out comprehensive performance evaluation of the digger to ascertain its performance indices to allow for further improvement.

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