DESIGN AND FABRICATION OF A YAM MOUND MAKING IMPLEMENT

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ABSTRACT

Yam (Dioscorea species) is among the oldest recorded food crops and rank second after cassava in the study of carbohydrates in West Africa. It also forms an important food source in other tropical countries including East Asia, Africa, South America, South East Asia (including India). Nigeria is the largest producer of the yam, producing about 38.92 million metric tons annually. A tractor operated yam mound making implement capable of producing 2,560 mounds per day was design and fabricated The field test carried out showed that the average inter and intra row spacings were 1.22 and 1.12 m respectively, while the average diameter and height of mounds produced were 1.21 and 0.50 m. The average time taken to produce a mound was 297 sec (4.95 min). Comparing the mechanical yam mound making implement with manual yam making, the work rates for producing 2,560 and 160 mounds were 12.72 h/ha and 72h/ha respectively. The yam mound making implement is expected to reduce drudgery considerably and increase the country's earning from yam exportations.

KEYWORDS: Yam, mounds, machine design, mound maker

1. INTRODUCTION

Yam (*Dioscorea species*) is among the oldest recorded food crops and rank second after cassava in the study of carbohydrates in West Africa (Agwu and Alu, 2005). It also forms an important food source in other tropical countries including East Asia Africa, South America, South East, Asia including India (Ayanwuyi et al., 2011). Nigeria is the largest producer of the crop, producing about 38.92 million metric tonnes annually (FAOSTAT 2008). Six species, namely white yam (*Dioscorearotundata*), yellow yam (*Dioscoreacayenensis*), water yam (*Discoreaalata*), Trifoliate or three- leaved yam (*Dioscoreadumentorum*). Arial yam (*Dioscoreabulbifera*) and Chinese yam (*Dioscoreaesculenta*) can be considered the principal edible yams of the tropic (Ironkwe, 2010). Yam tubers are eaten boiled, roasted, fried or pounded and could be chipped, dried and processed into yam flour. Yam represents about 20% of the daily calorie intake of Nigerians living in the forest and savannah region (Agwu and Alu, 2005). Yam constitutes a major staple food for the majority of inhabitants of Nigeria. Yam has potential for livestock feed and industrial starch manufacture. Traditionally, yam is a prestigous crop that is view and received with high respect, prominently during special gatherings such as new yam festivals in rural communities of eastern, central and some parts of south west of Nigeria. There has been a general decline in yam production in Nigeria over years (Ayanwuyi *et al.,* 2011). International Institute of tropical Agricultural (IITA, 2002) reported that both area under yam cultivation and total yam output were declining. However, yam production in Nigeria is faced with a number of constraints paramount among these constraints are pest and disease attack, procurement of the required seed yam for more yam production, its reoccurring scarcity and high cost during planting season (Ayanwuyi *et al.,* 2011).

Land preparation for yam cultivation is one of the major constraints to its production, and this restricts farm expansion and productivity of farmers as well as their income. Mounds are usually made with hoes and high cost to cover larger areas of land. However, tractor-mounted implements have been devised to fast-track the mound-making rate and cut off the laborious land preparation. The Department of Farm Power and Machinery at the National Centre for Agricultural Mechanization (NCAM), Ilorin, Kwara State, has designed and developed a mound-making implement to address the issue of making mounds during yam production.

The yam mound implement is a tractor-mounted implement designed and fabricated to make mounds for yam cultivation. The overall objective of this research is to reduce the drudgery laden with yam cultivation by reducing the effort and time taken to create heaps on a well ploughed land and to make harvesting easier as the heaps are created and spaced uniformly by the implement.

2. MATERIALS AND METHODS

The machine consists mainly of the following component parts: frame, propeller shaft, spiral gear pinion, standard, disc blade, support stand, top and lower link. The machine design was carried out using principles of engineering design with due consideration to cost, ease of operation, serviceability and durability.

2.1 Description of the Implement

The yam mound making implement was fabricated with locally sourced materials. The orthographic projection and exploded view of the implement are as shown in Figures 1 and 2, respectively. A mild steel square pipe of 5 mm was used to fabricate the frame of yam mound making machine upon which other components are attached and the pipe has the ability to withstand bending or twisting forces. The three-point linkages were constructed using a 16 mm thick mild steel flat bar to form a triangular shape, attached to the main frame which enable the mounting of the yam mound making machine on the three-point linkages of a tractor for ease of operation on the field.

The propeller shaft is used in transmitting power from the tractor PTO shaft to the disc blades for making of mounds. Two joints were constructed at both ends of the propeller shaft for PTO shaft and pinion head respectively. Spiral gear of 420 mm diameter was used to convert linear motion into vertical motion driven by the pinion head attached to the propeller shaft. The Standard **i**s the component that connects the disc bearing to the main frame and is fabricated with mild steel flat bar of 50 mm thickness. The standard is either a movable type which can then be shifted or a type with a pivoting bearing bracket at its lower end where the disc bearing is attached. Disc blades are at an angle to the direction of travel so both radial and thrust forces are present. Radial forces push against an axle at right angle while thrust forces push along the axis. That is why taper roller bearings are used. Disc type blades are mounted for cutting of soil. Blades diameter determine mounds capacity. Concavity affects disc angle and soil turning. Shallow concavity depends on diameter of discs. Depth of cut depends on diameter of discs. About 1/3rd of blade diameter is the limit for depth. Width of cut depends on diameter of blade. Width of cut is normally 0.4 times of diameter of disc blade. As shown in Figure 3, the angle at which the plane of cutting edge of disc is inclined to direction of travel is called disc angle. It varies from 42 to 45 degree.

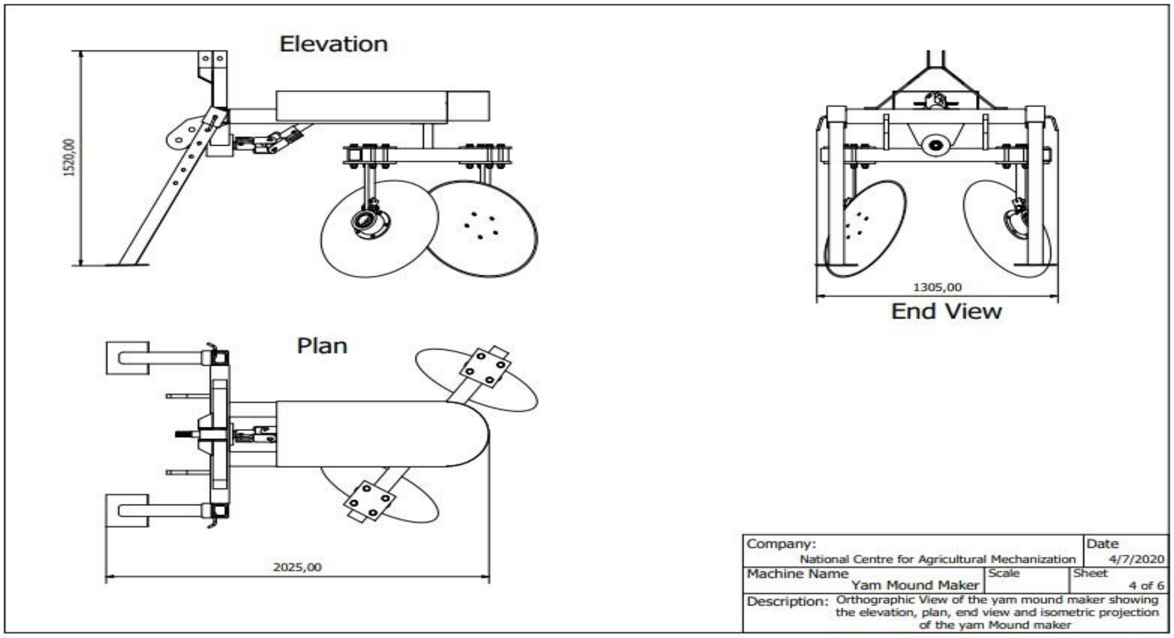
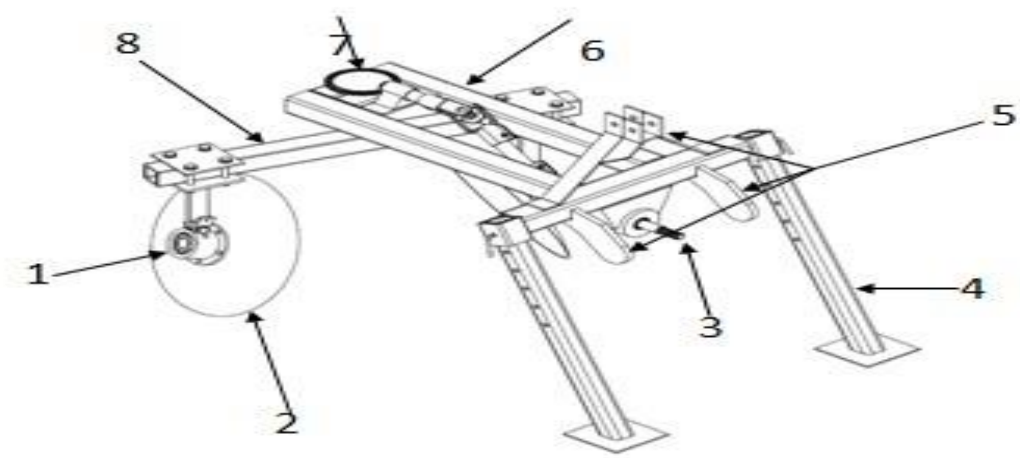


Fig.

1.Orthogrphic projection of the implement



Key	Part Name
1	Bearing Hub
2	Disc Plough
3	PTO Shaft
4	Jack Stand
5	Tri-Point Linkage
6	Main Frame
7	Bevel Gear

Fig. 2. Exploded views of the implement

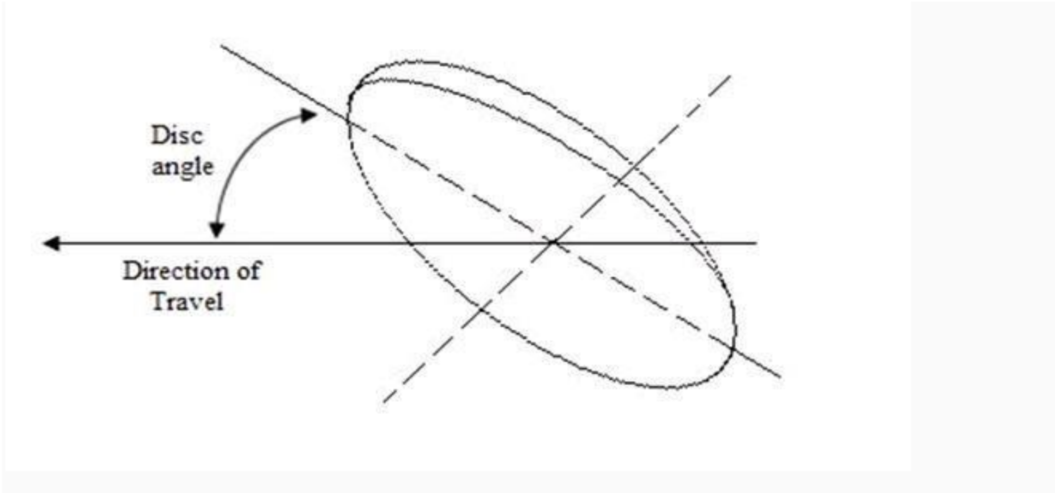


Fig. 3. Disc cutting angle

2.2 Mathematical Analysis

2.2.1 Propeller shaft

The shaft is cylindrical in shape made of mild steel material, shaft is subjected to Torsional, bending, axial load and combination of the above three loads (Khurmi and Gupta, 2005)

$$\frac{T}{J} = \frac{\tau}{R} \qquad 1$$

where, $T = Twisting\ moment\ (or\ torque) acting\ upon\ the\ shaft$ (Nm)
$J = Polar\ moment\ of\ inertial\ of\ the\ shaft\ about\ the\ axis\ of\ rotation$ (m^4)
$\tau = Torsional\ shear\ stress$ (Pa)
$R = distance\ from\ neutral\ axis\ to\ the\ outer\ most\ fibre$ (m)

$$T = \frac{\pi}{16}\tau\left[\frac{D^4 - d^4}{D}\right]\ Torsional\ load\ for\ hollow\ shaft \qquad 2$$

$$J = \frac{\pi}{32}(D^4 - d^4) \text{Polar moment of inertial for hollow shaft} \qquad 3$$

where, D^4 = Outside diameter(m)
d^4 = inside diameter (m)

The power transmitted by the shaft is given as:

$$P = \frac{F \times 2\pi RN}{60}\ watts \qquad 4$$

$$P = \frac{2\pi NT}{60 \times 1000} \qquad 5$$

where, P = Power transmitted by shaft (watt), N= Number of revolutions per minute (sec), T= Torque applied (Nm)

A column factor (α) is considered when the shaft is long and subjected to compressive load is given by (Khurmi and Gupta, 2005) as:

$$\sigma_c = \frac{\alpha \times 4F}{\pi (d_o)^2 \, (1-K^2)} \quad For\ hollow\ shaft \qquad 6$$

The value of column factor (α) for compressive load may be obtained from the following relation

$$\alpha = \frac{1}{1-0.0044\left(\frac{L}{K}\right)} \qquad \text{Where } \left(\frac{L}{K}\right) < 115 \qquad 7$$

$$\alpha = \frac{\sigma_y \left(\frac{L}{K}\right)^2}{C\pi^2 E} \qquad \text{Where } \left(\frac{L}{K}\right) > 115 \qquad 8$$

where, L = Length of the shaft between bearing (m), K = least radius of gyration, σ_y = Compressive yield point stress of the shaft material and coefficient in Euler's formular depending upon the end

The equation for equivalent twisting moment (T_e) and equivalent bending moment (M_e) is given by (Khurmi and Gupta, 2005) as:

$$T_e = \sqrt{\left[K_m \times M + \frac{\alpha F d_o (1-K^2)}{8}\right] + (K_\tau \times T)^2} \qquad 9$$

$$M_e = \left[K_m \times M + \frac{\alpha F d_o\left(1-K^2\right)}{8} + \sqrt{\left\{K_M \times M + \frac{\alpha F d_o\left(1-K^2\right)}{8}\right\} + (K_\tau \times T)^2}\right] \qquad 10$$

where, T_e = Equivalent twisting moment (Nm), M_e = Equivalent bending moment (Nm), F = Maximum tensile stress (Mpa), T = Actual torque (Nm), M = actual bending moment (Nm), d = diameter of the shaft (m), K_m = combined shock and fatigue factor for bending, K_t = combined shock and fatigue factor for torsion, α = column factor and σ = principal stress

2.2.2 Crown wheel and pinion

Gears are defined as toothed members transmitting rotary motion from one shaft to another. There exist a variety of gear types, each of which serves arrange of functions. Helical gears have teeth inclined to the axis of rotation and are used to transmit motion between parallel or nonparallel shafts. Pairs of helical gears transmit power, so that the both shafts are subjected to a thrust load. Spiral teeth engage gradually (starting at one side), a feature enabling them to operate much more smoothly and quietly. The inclination of the teeth causes an overlapping action. Therefore, more than one tooth is in contact with others at all times (Ashby, 2005). Because of this continuous engagement, the load is transmitted more smoothly from the driving to the driven gear than with straight bevel gears. Spiral bevel gears as shown in Figure 4 have more load-carrying capacity together with more teeth in contact than the straight one the drive pinion in yam mound making machine are spiral bevel gears. Hypoid gears are quite similar to spiral bevel gears except that the shafts are off set and nonintersecting. This feature provides many design advantages. In operation, hypoid gears run even more smoothly and quietly than spiral bevel gears and are somewhat stronger. In addition, hypoid gears can carry more power, provided the speed is not too high (Ashby, 2005).

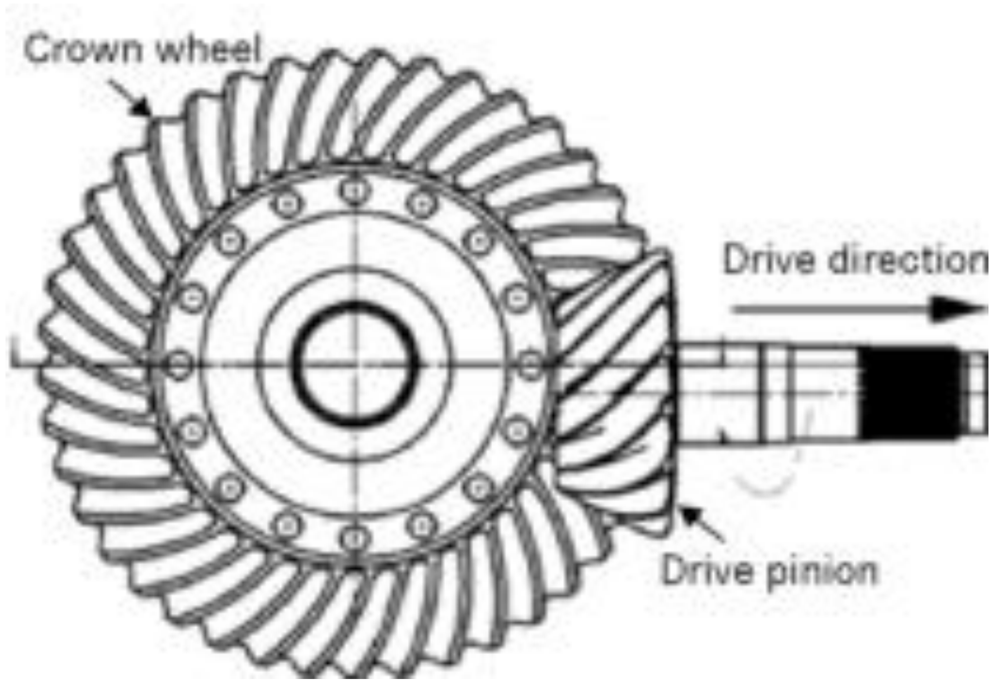


Fig. 4. Spiral toothed bevel gears with hypoid intersection between drive pinion and crown wheel axes

2.2.3 Shaft and bearing

The term shaft refers to a member of a round cross section that rotates and transmits power while the word bearing, applied to a machine or structure, refers to contacting surfaces through which a load is transmitted. Together shaft and bearing provide the axes of rotation of elements gears. The shaft transmits the stresses to the supports in which reactions are created and it transmits the torque to or starting from gears. Shafts should be supported by bearings which produce radial and axial bearing reaction (Klingelnberg, 2008).

The drive pinion consists of the spiral bevel gear and the shaft. The latter is subjected to various combinations of axial, bending, and torsional loads which are fluctuating. The drive pinion as a rotating component, transmitting power, is subjected to a constant torque (producing a mean torsional stress) together with a completely reversal bending load (producing an alternating bending stress). Furthermore, the applied bearings for the drive pinion shaft are tapered roller bearings. The bearing forces on the drive pinion can be calculated from the tooth forces and additionally acting external forces. The radial force to the bearing in this case contains components from the tangential, the axial and radial tooth force and the additional external forces. The axial force to the bearings is the axial tooth force plus the external forces (Klingelnberg, 2008).

Teeth contacts in bevel gears generate stresses that are tangential, radial and axial in relation to wheels. The axial stresses are parallel to the shaft and they create stresses due to bending as shown in Figure 5. The resolution of resultant tooth force F is into tangential, radial and axial components, designated as Ft (tangential forces), Fr (radial forces) and Fa (axial forces) and is shown in Figure 5, these forces are acting at the gear tooth, when contacting the crown wheel. Two taper roller bearings are located near the gear part (Klingelnberg, 2008).

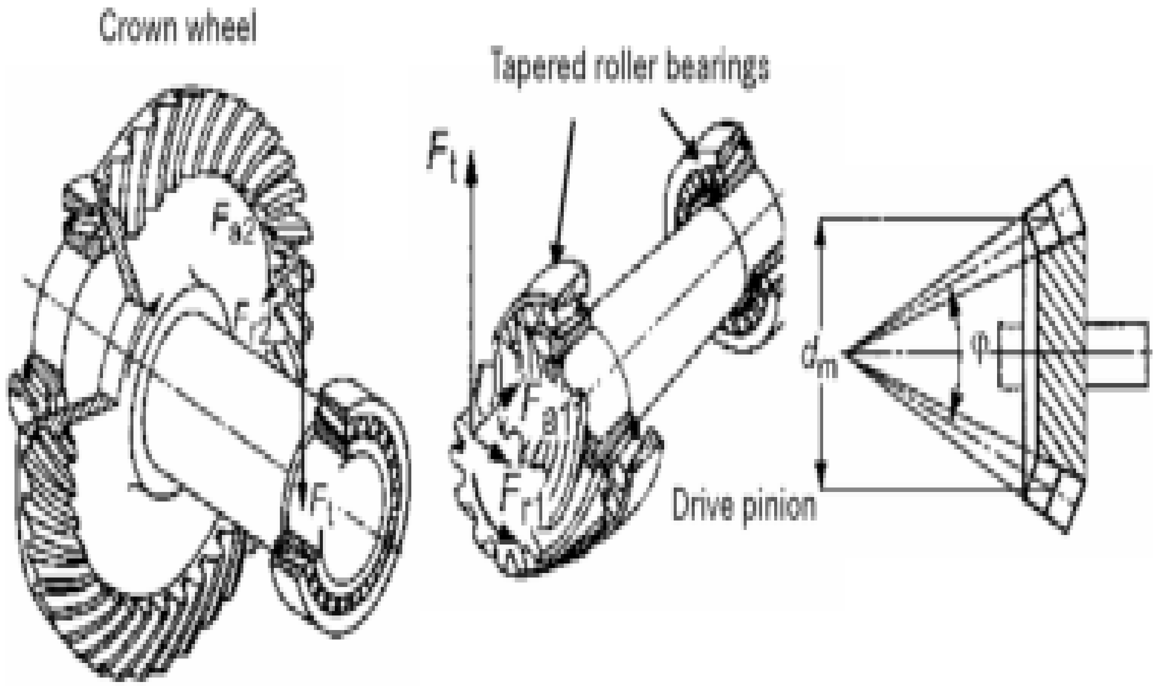


Fig. 5. Forces acting on spiral-toothed bevel gears

These factors can be calculated from the tangential, the axial and radial forces for the right-hand spiral with clockwise motion as:

$$F_a = \frac{F_t}{\cos\beta_m}(\tan\alpha_n \sin\varphi + \sin\beta_m \cos\varphi) \qquad 11$$

$$F_r = \frac{F_t}{\cos\beta_m}(\tan\alpha_n \cos\varphi - \sin\beta_m \sin\varphi) \qquad 12$$

where, ϕ = is the reference cone angle of examined gearwheel and

αn = is the meshing angle normal

βm = represents the spiral angle at the reference cone in tooth center.

The gear ratio is also defined as the ratio of the number of teeth of the wheel to the number of teeth of the pinion (Klingelnberg, 2008).

$$U = \frac{Number\ of\ teeth\ of\ the\ crown\ wheel}{number\ of\ teeth\ of\ the\ drive\ pinion} = \frac{Z_1}{Z_2} \qquad 13$$

2.2.4 Calculating the Radius of Curvature of Discs

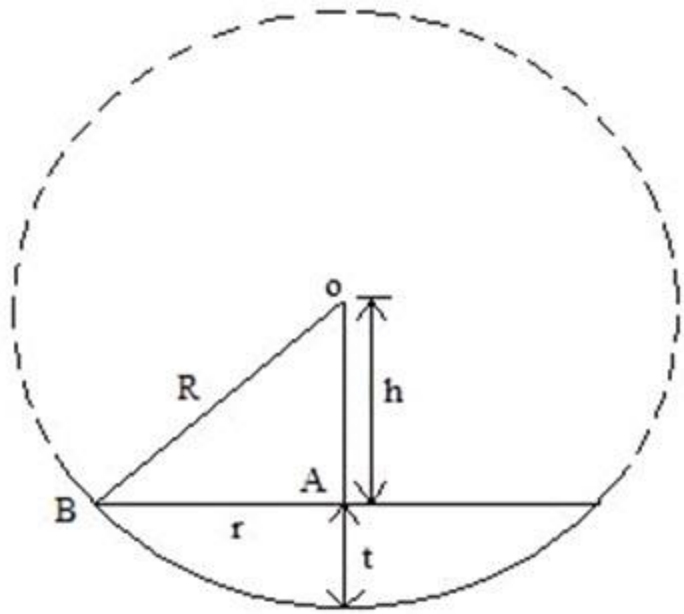


Fig. 6. Radius of Curvature of Discs

$R - Radius\ of\ Curvature$

$r - Radius\ of\ disc$

$t - Depth\ or\ concavity$

OAB

$$R^2 = h^2 + r^4$$

Also, $h = R - t$

$$h^2 = (R - t)^2$$

$$h^2 = R^2 - 2Rt + t^2$$

$$R^2 = R^2 - 2Rt + t^2 + r^2$$

$$2Rt = t^2 + r^2$$

$$R = \frac{t^2}{2t} + \frac{r^2}{2t}$$

$$R = \frac{t}{2} + \frac{\left(\frac{D}{2}\right)^2}{2t}$$

$$R = \frac{t}{2} + \frac{D^2}{8t} \qquad 14$$

2.3 Performance Evaluation of the Yam Mound making Machine

2.3.1 Field evaluation procedures

The performance evaluation of the yam mound making machine was carried out in the department of Farm power machinery at National Centre for Agricultural Mechanization (NCAM) Ilorin Kwara State. One hectare of land was plough for the evaluation of the yam mound making machine. Demarcation of the prepared land into three portion was done using survey tape and ranging poles, digital stop watches were used for time taken to make a mound and time interval between a mound to the other, the diameter, height, inter and intra row spacing were measured using steel rule and measuring tapes respectively. The parameters were taken randomly in the three fields.

The inter, intra row spacing, height and diameter of the mounds were determine using the steel rule, survey tape and ranging poles, a ranging pole is stake vertically beside a mound then steel rule is placed horizontally at the tip of the mound intercepting with the ranging pole for the height determination, two ranging poles are stake vertically at the base of a mound opposite to each other while measuring tape is use to determine the distance apart of the two ranging poles which give the diameter of the mounds, determining inter and intra row spacing is carried out by measuring the distances between mound to mound and row to row respectively.

2.3.2 Performance parameters

Field performance parameters measured included time, field capacity, field efficiency, inter and intra row spacing and height of mounds.

2.3.2.1 Theoretical Field Capacity

Theoretical field capacity of yam mound is the rate of field coverage that would be obtained if the yam mound maker performing its function100% of the time at the rated forward speed and cover 100% of its rated width. It is expressed as hectare per hour and determined (Aniekwe and Mbah 2014).

$$TFC = \frac{W \times S}{100} \qquad 15$$

where,

TFC= Theoretical Field capacity, (ha/h)
W =Eeffective width of implement (m)
S =Speed of operation, (km/h)

2.3.2.2 Field efficiency

Field efficiency is the ratio of effective field capacity to theoretical field capacity. The formula below was used to determined field efficiency (Aniekwe and Mbah 2014).

$$FE(\%) = \frac{EFC}{TFC} \times 100 \qquad 16$$

where,

$FE = Field\ Effieciency$
$EFC = Effective\ field\ capacity\ (ha/h.)$
$TFC = Theoritical\ field\ capacity (ha/h.)$

2.3.2.3 Effective field capacity

Effective field capacity of the yam mound was actual rate of work covered by the yam mound machine based upon the total field time and a function of rated width of the machine actually utilized and expressed as hectare per hour (Aniekwe and Mbah 2014).

$$\mathrm{EFC} = \frac{\mathrm{A}}{\mathrm{T}} \qquad 17$$

where,

$\text{EFC} = \text{Effective field capacity} \left({}^{\text{ha}}/_{\text{h}} \right)$

$\text{A} = \text{Actual area covered, ha}$

$\text{T} = \text{Time required to cover the area, h}$

3. RESULTS AND DISCUSSION

The results are presented in Tables 1 and 2. Table 1 shows yam mounds made mechanically with yam mound making machine while Table 2 shows the manually produced mounds by manpower with a single labourer. Table 3 shows the compared parameter analysis of mechanically and manually mounds made respectively.

The results obtained from Table 1 indicate mechanical mounding. The average inter and intra row, diameter and height of mounds were taken randomly from the field as carried out judging the machine. The average result in table1 shows that inter and intra row spacing is 1.62 and 1.45 m while the average diameter and height of 1.35 and 0.42 m at the average time of 7.40 sec. respectively

Table 2 present the results for manually mounding. The average inter and intra row is 1.22 and 1.12 m while the diameter and height of mounds 1.21 and 0.50 m at the average time of 297 sec (4.95 min)

Table 3 shows the analysis and comparison of the field parameters of mechanical and manual yam mound making which indicate that 2560 mounds were made within the work rate of 12.72 h/ha mechanically while 160 mound were made within the work rate of 72 h/ha manually.

The inter, intra row spacing, height and diameter of the mounds were determine using the steel rule, survey tape and ranging poles, a ranging pole is stake vertically beside a mound then steel rule is placed horizontally at the tip of the mound intercepting with the ranging pole for the height determination, two ranging poles are stake vertically at the base of a mound opposite to each other while measuring tape is use to determine the distance apart of the two ranging poles which give the diameter of the mounds, determining inter and intra row spacing is carried out by measuring the distances between mound to mound and row to row respectively.

Table 1. Mounds made with yam mound implement

S/N	Time taken to make a mound (sec)	Time interval between mounds (sec)	Inter–row spacing (m)	Intra-row spacing (m)	Diameter of mounds (m)	Height of mounds (m)
1	12	3	1.53	1.47	1.35	0.33
2	7	3	1.71	1.32	1.13	0.38
3	5	2	1.53	1.56	1.12	0.44
4	3	2	1.38	1.53	1.25	0.38
5	7	2	1.75	1.45	1.41	0.37
6	8	3	1.73	1.40	1.35	0.45
7	10	2	1.48	1.34	1.30	0.38
8	5	2	1.60	1.30	1.44	0.48
9	10	3	1.72	1.45	1.40	0.45
10	5	2	1.77	1.36	1.37	0.43
11	9	3	1.72	1.34	1.42	0.41
12	7	3	2.00	1.59	1.42	0.42
13	5	2	1.90	1.39	1.42	0.46
14	8	4	1.58	1.34	1.44	0.45
15	7	3	1.46	1.43	1.38	0.46
16	5	3	1.52	1.41	1.37	0.43
17	7	4	1.50	1.43	1.36	0.44
18	11	3	1.59	1.40	1.38	0.44
19	12	4	1.58	1.62	1.42	0.45
20	5	4	1.42	1.63	1.36	0.45
AVG	**7.40**	**2.90**	**1.62**	**1.45**	**1.35**	**0.42**

Table 2. Manual making of mounds with manpower

S/N	Time taken to make a mound (sec)(min)	Time interval between mounds (sec)	Inter–row spacing (m)	Intra-row spacing (m)	Diameter of mounds (m)	Height of mounds (m)
1	360(6)	3	1.30	0.98	0.88	0.48
2	300(5)	4	1.31	0.92	1.00	0.50
3	300(5)	2	0.89	0.87	0.99	0.53
4	180(3)	4	1.38	0.90	1.25	0.56
5	420(7)	2	0.90	1.15	1.40	0.46
6	480(8)	5	1.25	1.10	1.34	0.47
7	240(4)	5	1.48	1.99	1.35	0.55
8	300(5)	6	1.31	1.32	0.99	0.48
9	300(5)	3	1.12	1.16	1.39	0.50
10	300(5)	10	0.95	0.98	0.90	0.55
11	240(4)	6	1.40	1.20	1.40	0.47
12	180(3)	3	0.98	1.12	1.20	0.48
13	300(5)	5	0.90	1.14	1.32	0.52
14	240(4)	4	1.20	0.98	1.32	0.59
15	420(7)	12	1.16	0.99	1.34	0.54
16	300(5)	3	0.95	1.15	1.33	0.39
17	420(7)	4	1.40	1.19	1.10	0.54
18	240(4)	3	1.32	1.22	0.99	0.53
19	120(2)	4	0.89	1.00	1.35	0.49
20	300(5)	2	1.31	0.99	1.28	0.36
AVG	**297(4.95)**	**4.50**	**1.22**	**1.12**	**1.21**	**0.50**

Table 3. Analysis of mechanical and manual mounds

S/N	Parameters	Mechanical yam mound produced	Manual yam mounds produced
1	Number of mounds per day	2560	160
2	Number of mounds per hour	320	20
3	Number of mounds per hectare	4070	1440
4	Effective field capacity (ha/h)	0.0786	0.0138
5	Work rate (h/ha)	12.72	72
6	Height of mounds (m)	0.42	0.50
7	Diameter of mounds (m)	1.35	1.21
8	Inter row spacing (m)	1.62	1.22
9	Intra row spacing	1.45	1.12
10	Fuel consumption		
	(l/ha)	28.57	-
	(l/h)	1.99	-
11	Labour requirement	1	1
12	Tractor capacity (Hp)	95	-
13	Tractor PTO speed (rpm)	500	-

4. CONCLUSION

A yam mound making implement was designed, fabrication and evaluated, capable of making 2560 mounds per day at work rate of 12.72 h/ha. The yam mound making implement is recommended proper performance and evaluation with different soil types and content in different geo-political zones of the country where yam is cultivated for further improvement and adaptation of the implement

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