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DESIGN, CONSTRUCTION AND EVALUATION OF AN ANIMAL DRAWN DISC HARROW

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Abstract

Animal traction has not been widely adopted by Nigerian farmers despite the fact that it is an appropriate technology that can be used to increase agricultural production. One of the reasons for limited use of animal power is the lack of appropriate implements. The objective of this work was, therefore, to design, construct and evaluate a single-acting animal-drawn disc harrow. The harrow consisted of several components fastened together into a unit which could be easily dismantled if necessary. The main parts were the frame; two gangs of four discs each, three pneumatic depth control wheels and a seat for the operator. The total mass of the implement was found to be 100 kg. A pair of well trained bulls weighing 429 kg and 394 kg where used to pull the implement during the experiment.

The harrow was designed to operate at various depths and disc angles. The draught measurements and quality of work of the harrow were observed at depths of 5 and 10 cm and disc angles of 15^o, 25^o and 35^o. It was found that the harrow had a draught of 530 N when set at a disc angle of 15^o and depth of 5 cm, and 778 N when set at 35^o and 10 cm depth. It was also found that the harrow had 94.76% weed destruction when set at disc angle of 15^o and depth of 5 cm and 97.90% when set at 35^o disc angle, 10 cm depth of operation. The harrow was found to have an effective field capacity of 0.23 ha/h and field efficiency of 86 %.

1. Introduction

In Nigeria, almost all agricultural operations are carried out manually by peasant farmers who dominate the agricultural sector. The hoe, cutlass and matchet are the dominant tools of cultivation in the country. These tools consume a lot of human energy, thus making their use tedious and tiresome. Their use also limits agricultural production. There is, therefore the need to increase the utilization of non-human energy in order to increase the food production to meet the demand of the country.

The use of tractors on Nigerian farm is very limited due to their high cost which beyond the reach of poor farmers. Due to fragmentation of farmlands into small and scattered units, farmers find it uneconomical to engage tractor services.. Therefore, if animal traction were to be promoted in the farming system, it would contribute positively to agricultural development in the country. This is because of the low cost of the technology which puts it within the reach of the majority of the farmers.

Animal traction provides a well-tested and proven option as a substitute for hoe cultivation. It has the potential of permitting the farmer to expand his acreage and improve yields. According to Starkey (1992), animal traction is an appropriate, affordable and sustainable technology that can be used to reduce drudgery and intensify agricultural production, so raising living standards throughout rural communities. It is in this regard that animal traction suggests itself as a potentially useful and appropriate means of improving upon the efficiency

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of the hoe system in Nigeria. However, according to Philip *et al.* (1986), animal traction has not been widely adopted by Nigerian farmers despite the fact that it is a farmer-generated and farmer-adopted technology with a successful history of adoption elsewhere. According to Kline (1970), broad adoption of animal traction was blocked by equipment inappropriately designed for African condition. Kaul (1989) reported that lots of implements have been developed world-wide, which can be adopted in Nigeria with appropriate modifications. New innovations may emerge during the development /adoption of such implements.

Although draught animals are a lot cheaper than tractors, many farmers have restricted access to animal power because of their inability to purchase them. According to Mathewman (1987), the main constraint to the use of animal traction is the cost of extra labour required to deal with increased yields and for weeding and harvesting. Another factor contributing to lack of increased utilisation of animal traction is the problem of adoption. Problems related to training animal husbandry and equipment also limit the rate of adoption of animal traction. According to Ibrahim and Kwatra (1990), farmers adopt new ideas and tools only after seeing them successfully operating in the field.

Working ability of a draught animal depends upon many factors including its breed, sex, size, live weight, training, management, feeding and health. Heavier animals are able to perform more work than lighter ones,. Under a given set of conditions, each animal is capable of carrying out a certain amount of daily work that cannot be exceeded if the animal is to be kept in good working condition. Experimental data confirm that working cattle develop maximum power when a relatively low traction effort is made at a relatively high speed (Pyne, 1990). The power which a draught animal can provide is dependent upon the pull developed and speed of movement. The pull depends mainly on species and body weight, but is also influenced by condition of health of the animal and training. Carruthers and Marc (1992) reported that the optimum pull for bovines (ox, cow, buffalo) is about 10 to 12 percent of their body weight. For equines (horse, donkey, mule) and camels the optimum pull is about 12 to 15 percent of their body weight. Several researchers still use the concept of 10 percent of body weight as the pulling force of some species. However, Girma and Pascal (1997) reported that the pulling force required for the implements can be increased up to 25 to 34 percent of body weight, especially for donkeys

The only popular animal-drawn implement available to the Nigerian farmer is the ridger. The EMCOT ridger used as a primary tillage implement was developed, and recommended for local manufacture since 1960 (Musa,1989). However, because the use of draught animal needs to be diversified to include more farm operations, additional implements such as disc harrows need to be developed. The disc harrow is extremely useful in pulverising soil and chopping weeds and trash. Carruthers and Marc(1992) stated that animal drawn disc harrow of 400-500 mm diameter spaced at 200 mm apart could be used for secondary cultivation purposes. The maximum operating depth for a disc harrow is usually about one-fourth of the disc diameter. Small-diameter disc penetrate more readily than large discs as they require less vertical force to hold them to a given depth (Kepner *et al*., 1978). The operating depth is determined by the soil condition and the weight per unit disc of the harrow. The disc angle varies from 15^{o}-35^{o} as measured from a line perpendicular to the line of travel. Disc angles may be changed to meet different field conditions. Increasing the disc angle makes the disc cuts deeper and more aggressive, but with increased power requirement. (Ajit *et al*., 1993).

Although a lot of work has been conducted on the draught ability of cattle all over the world, there is little information on animal drawn harrows in Nigeria. Therefore, this work was aimed at producing a simple and affordable animal drawn harrow that could be used locally by farmers.

2. Materials and methods

2.1 Description of the implement

A single-acting disc harrow was designed and constructed to be drawn by a pair of bulls. The total mass of the implement is 100 kg. The harrow (Figure 1) consists of several components fastened together into a unit, which could be easily dismantled, if necessary. The main parts are the frame (1), two gangs (2) of four discs (3) each, three depth control wheels (4) and a seat (6) for the operator. The components and sizes of the materials used were selected based on their availability and affordability. The implement was constructed with the desire to have minimum labour input for its operation. Two persons are needed to use the implement.

2.2 Estimating the weight of the harrow

In order to design an implement for animal draught, it is necessary to know or estimate the total weight so that it will not exceed the capability of the animal's pulling power and to perform the expected work. Mckyes (1985) and Ajit *et al*. (1993) reported that the draught force of a standard harrow on a sandy loam soil is:

$$N = 7.8M \qquad 1$$

Where N = draught in N

M = mass of implement in kg.

Therefore, mass of implement

$$M = \frac{N}{7.8} \qquad 2$$

The draught ability of cattle is about 10 to 12 percent of their body weight (Patrick and Frank, 1995).The designed harrow was pulled by a pair of bulls of an average weight of 12 kN. Ten to twelve percent of a pair of bulls weighing 12kN is 1.2kN to 1.44kN. Therefore, from Equation 2

$$M = \frac{1200}{7.8} \; to \; \frac{1440}{7.8} = 154 \text{ to} 185 \text{ kg}$$

The total weight of implement and the operator should, therefore, be about 1850 N for the animals to pull it successfully.

2.3 Design of the gang shaft

Shafts are known to carry members which transmit torque and therefore experience both bending and torsion. It is therefore, important to determine the correct shaft diameter according to the *ASME* code for design of solid shaft to ensure satisfactory strength. The gang shaft is the shaft on which discs are mounted. The following equation was used in determining the shaft diameter (Spotts, 1988):

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

$$d = \left[\frac{16}{\pi S_s} \sqrt{(K_b M_b)^2 + (K_t M_t)^2} \right]^{\frac{1}{3}} \quad (4)$$

Where

d= diameter of shaft, mm

S_s=shear stress, N/mm^2.

Shear stress is given as $\frac{8000}{145}$ N/mm^2 for shaft without key ways (Hall *et al.*, 1982).

K_b, K_t = combined shock and fatigue factors applied to the bending and torsional moments given as 1.5 and 1.0 respectively.

M_t = torsional moment, N mm

M_b = bending moment, N mm

The torsional effect on the shaft becomes negligible if bearings are used (Spotts, 1988). This implies that $M_t = 0$.

Therefore, Equation 4 reduces to

$$d = \left[\frac{16}{\pi S_s} (K_b M_b) \right]^{\frac{1}{3}} \quad (5)$$

The total vertical and horizontal forces acting on the implement was 2205 N which is transmitted to the shaft through the four legs. Each leg transmitted about 51.3 N (Figure 2). From the analysis of load distribution on the shaft, it was found that the maximum bending moment, M_b was 17917.25 Nmm. Substituting values in Equation 5, the shaft diameter was found to be 14 mm. Therefore, the minimum diameter of the shaft to be used was 14 mm. However, for this work, 20 mm universal shaft was used as no shaft between 14 and 20 mm was available in the market.

2.4 Construction of the harrow

The frame that supports all the components of the implement was constructed from mild steel of 5 mm thickness forming a T-shaped beam. The two gangs consisting of four standard plain discs of 450 mm diameter were mounted in series on a shaft of 20 mm diameter and 420 mm long. Spacers of 100 mm were provided between disc blades. The gangs were attached to the frame of the harrow by four legs (9) which carried the bearing housing (Figure 1). Each leg was constructed from an angle iron of 2.4 mm thickness and 270 mm long. The gangs were attached to the frame in such a way that the angle they make with the line of travel could be varied. Two angle-adjusting rods (5) of 10 mm diameter and 500 mm long were used for changing the gang angle. The rods were attached to each gang at one end and the other end on to the frame on a common bracket, which could slide forward and backwards along the frame beam depending on the angle desired. Holes are provided into which a bolt can be slotted. When the hole on the bracket aligns with the hole on the frame a certain degree of gang angle is obtained. The holes on the frame were drilled to give 15, 25 and 35^o of gang angle. Three depth control pneumatic land wheels of 420 mm diameter were provided, two of which were attached at the rear and one at the front. The two rear wheels were mounted to the implement in such a way that they could be lifted up or lowered down depending on what depth to operate the harrow. The disc can be above the ground during transport. An operator's seat was constructed from a sheet metal of 1 mm thickness and mounted on the frame. All other components of the harrow were also made of mild steel.

2.5 Experimental design and performance evaluation

A field test of the implement was carried out at the University of Maiduguri research farm during the rainy season in July of 2000. The soil is of sandy loam texture classified as Typic Ustipsamment made up of 77% sand, 6% silt and 17% clay (Rayar, 1984). The experimental design was a randomized complete block design for both the draught force evaluation and for the soil work quality assessment with an 18-plot experiment consisting of six treatments with three replicates each. The treatments were: 5cm depth, 15^o disc angle (T_1); 5 cm depth, 25^o disc angle (T_2); 5 cm depth, 35^o disc angle (T_3); 10 cm depth, 15^o disc angle (T_4); 10 cm depth, 25^o disc angle (T_5) and 10 cm depth, 35^o disc angle (T_6). The plot size for each replicate was 20 m x 2 m as suggested by FAO (1994). Two well-trained bulls weighing 429 kg and 394 kg were used for pulling the harrow. For performance evaluation of the harrow, the following major parameters were considered: (i) weed destruction as described by FAO (1994), (ii) implement draught, (iii) implement field capacity and efficiency. The implement draught was calculated using Equation 6 (Patrick and Frank, 1995).

$$H = F \cos \alpha \qquad 6$$

Where H = draught, N

F = force of pull, N

α = angle of pull with the horizontal.

Field efficiency of the implement was determined using Equation 7 (FAO, 1994)

$$\eta = \frac{C_e}{C_t} \times 100\% \qquad 7$$

Where η = Field Efficiency of the implements %

C_e = Effective field capacity, ha/h

C_t = Theoretical field capacity, ha/h

Effective field capacity, $C_e = \frac{Total\ area\ cultivated\ (ha)}{Total\ field\ time\ (h)}$, and

Theoretical field capacity C_t = Mean working width (cm) x mean speed (m/s) x 0.0036. *8*

3. Result and discussion

3.1 Effect of disc harrowing on weed destruction

The average number of weeds and stubble counted per square meter of the experimental field before treatment was 1031. The number of weeds and stubble counted for each treatment after harrowing is presented in Table 1.

For the same disc angle, the number of weeds left after operation was higher in the 5-cm depth treatments than those in the 10-cm depth treatments. This may be because the implement operated at a shallower depth and therefore was not able to destroy a high percentage of weeds. At the same depth level, it was found that the number of weeds left after treatment reduced as the disc angle increased. This is probably as a result of the aggressiveness with which the disc worked on the soil. Statistical analysis revealed that there was a significant ($P<0.01$) difference between the treatments as regard to number of weeds.

Table 1: Values of various parameters studied during the evaluation of the implement

Treatment	Number of weeds after operation, m^2	weed destruction, %	Draught, N
T_1 (5cm,15^o)	54 a	94.76 d	530 b
T_2 (5cm,25^o)	31 b	96.96 abc	641 a
T_3 (5cm,35^o)	25 b	97.57 ab	660 c
T_4 (10cm,15^o)	48 a	95.31 d	641 a
T_5 (10cm,25^o)	30 b	97.05 abc	700 d
T_6 (10cm,35^o)	22 b	97.90 a	778 e
SE	±4.68	±0.46	±1.51

a, b, c, d, e: Means in the same column followed by same letter are not significantly different at 5%.

Table 1 shows the percentage weed destruction by the implement in each treatment. The average values were 94.76%, 96.96%, 97.57%, 95.31%, 97.05% and 97.90% for T_1, T_2, T_3, T_4, T_5 and T_6 respectively. The value was highest in T_6 and lowest in T_1. Comparing percentage weed destruction at different depths, it can be seen that the high values were obtained in 10 cm depth treatment than in 5 cm depth treatment. This may be as a result of soil inversion achieved by the discs.

3.2 Effect of dept and angle of cut on implement draught

The draught values in each treatment are also presented in Table 1. The values did not exceed 10 percent of total body weight of the animals used and they reasonably agree with the average value of 490-785 N as stated by Hopfen (1969). At 5 cm depth, the draught was lowest in treatment T_1 and increased as the disc angle increased. Similarly, at 10 cm depth the draught was lowest in treatment T_4 and increased as the disc angle increased. It was also observed that for the same disc angle the draught values were higher at 10 cm depth than those recorded at 5 cm depth. The increase in draught with increase in disc angle and depth of operation may be attributed to the fact that the discs scooped greater volume of soil at higher disc angle and depth.

3.3 Field capacities and efficiency of the implement

The time taken to cultivate an area of 360 m^2 was 94 minutes. The effective and theoretical field capacities were 0.23 ha/h and 0.28 ha/h. The field efficiency was 86%.

4. Conclusion and recommendations

4.1 Conclusion

An animal-drawn disc harrow was designed and constructed to operate at various depths and disc angles. Materials that are readily available were used in its construction. The implement was found to have total weight of 100 kg with a working width of 0.9 m. It was found that the implement had a minimum draught of 530 N when set at 15^o disc angle and 5 cm depth, and a maximum draught of 778 N when set at 35^o disc angle and 10 cm depth. At both depths of 5 and 10 cm, the quality of work, in terms of percentage weed destruction, was best when the implement was operated at a disc angle of 35^o. The average theoretical and effective field capacities of the implement were 0.27 ha/h and 0.23 ha/h respectively. The field efficiency of the implement was found to be 86%.

4.2 Recommendations

Based on the result obtained from the field test, the following recommendations are made to improve the working efficiency and strength of the implement:

1) It is recommended that the implement should be set at 10 cm depth and 35^o disc angle for heavy animals (500-900 kg), because of higher draught. For light animals (350-450 kg), the implement should be set at 10 cm depth and 25^o disc angle.
2) Provision should be made to vary the number of discs used to accommodate the variation in the type and size of animals used.
3) A shield should be constructed in front of the discs for the safety of the operator.
4) The implement was tested only on a sandy loam soil. Therefore, it is recommended that it should be tested on other soils.

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