EFFECT OF IMPLEMENT WEIGHT ON THE PERFROMANCE OF THE DISC PLOUGH

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ABSTRACT

Crop production is the business of maximising profit in growing crops for food, feed and fibre, while ensuring environmental sustainability. Profit maximisation implies reduction in the cost of field operation while environmental sustainability requires that the soil be left in state in which it serves the next generation optimally. Unfortunately, tillage that is meant to prepare the soil for improved crop production has been described as the single most expensive factor in crop production, and yet leaves the soil in an undesirable condition of compaction in the long run owing to the heavy machineries used, thereby negating the principle of sustainability. A lot of research has gone into proffering solutions to these problems but most have not considered the contribution of implement weight to the problem. It is generally believed that higher implement weight aids tool soil penetration. This work therefore aims at studying the actual effect of implement weight on the depth of cut of the disc plough in a gravelly sandy soil. A two factor Latin Square with repeated treatment of weight was used to study the effects of weight on depth of cut using ANOVA. Factors considered were tilt angle (α_1=16°, α_2=22°, α_3=26°,), disc angle (β_1=37°, β_2=40°, β_3=43°) and weight (λ_1=253.1kg, λ_2=327.7kg, λ_3=370.4kg). The implement was powered by a 47.7kW (64 hp) tractor, weighing 2757 kg. Results obtained showed that there was insufficient evidence to prove that implement weight had significant effect on the depth and width of cut of the disc plough. Disc angle was significant on width of cut at 5% only while tilt angle was significant on both depth and width of cut, even at 1%. It may be concluded therefore that varying the weight of the disc plough may not significantly affect its depth and width of cut, and that depth and width of cut are affected by tilt angle while disc angle only affected the width of cut. It is recommended from this result, that ploughs with lighter weight be designed so as to be pulled by smaller tractors to reduce energy requirement and soil compaction.

KEYWORDS: Implement Weight, Disc plough, Tilt angle, Disc angle

1. INTRODUCTION

The disc plough is the most popular primary tillage implement used in southern and north central regions of Nigeria. Tillage in agriculture is the mechanical manipulation of soil with the aim of changing the structure of the soil, making it suitable for crop production. Tanam (1994) explained that tillage is the most energy intensive operation in farming, and described by Sheruddin *et al* (1988) and davis (1983) as the single most expensive input. Similar observation was made by Kepner *et al* (1987). Moitzi *et al* (2009), cited by Oduma *et al* (2021) reported that land preparation by conservative tillage methods consumed over 50% of energy input. Manian *et al* (2000) cited by Olatunji *et al* (2009) gave a range of 30 – 35% of total energy consumption. This is equally considered high when compared to other inputs. Conservation tillage practices however, requires that soil be manipulated, if necessary, up to conventional tillage, and be left in state that meets present, and continuous future needs for crop production. Moitzi *et al* (2006) further explained that energy consumption in land preparation increases progressively with depth of cut. Results reported by Oduma *et al* (2021) however, showed that high speed ploughing and soil type were major contributors to depth and hence, increase in energy requirements. ASABE (2015) agrees with this assertion by stating that draught requirements for tillage depends primarily of implement width, depth of cut, operating speed, soil texture and tool geometry.

The high cost of tillage operation can be traced the complex and heavy design of the implement. Mamman and Oni (2005) reported that the first consideration in the design of a tillage tool is its shape and size, and added that size determines the energy required to pull the tool through the soil. This agrees with the findings of Upadhyaya *et al* (1981), cited by Sale *et al* (2013). Size refers to the physical dimensions and weight of the implement. In attempts to reduce the energy requirements, and hence, the cost of tillage operations, much work (McGreery and Nicholas, 1956, Kawuyo *et al*, 2017, Asoegwu *et al*, 2018, Fadele *et al*, 2021,) has been done to determine an optimum tillage practice. None of these however, has considered the contribution of the weight of the implement to energy consumption, yet implement weight remains a major contributor to soil compaction (Chamen *et al*, 1990, Adeoti, 1992, Tanam, 1994 and Kalu *et al*, 2023) thereby negating the principles of sustainability due to its adverse effects on the soil.

Soil type and bulk density have been reported as other critical factors affecting soil compaction (Klenin *et al*, 1985, Adeoti, 1992 and Kalu *et al*, 2023). For a given soil type and bulk density, moisture content is critical. Danbaba and Tanam (2023) stated that soil workability becomes low in soils with high moisture content as a result of increased share strength from pore water pressure, or as wheel slip in molten state of the soil. Danbaba and Tanam (2023) reported that optimum tillage time is when the soil is in its friable stage. Unfortunately, this is the period the soil is most susceptible to compaction, and heavy machinery trafficating the soil would aid this. Although many factors lead to soil degradation, this paper focuses on the contribution of implement weight, with the hope mitigating its undesirable consequences.

2. MATERIALS AND METHOD

2.1 Implement Description Location of Site

A NARDI ITALIA model 3-bottm disc plough was used in this test. It has a gang ground clearance of 67 cm and disc spacing of 55 cm. The implement has provision for adjusting the tilt and disc angle. Tilt and disc angles selected were 16°, 22° and 26°, and 37°, 40° and 43° respectively. Three weights of the implement were test. The first weight (λ_1) was the dead weight of the plough (253.1 kg). An iron block weighing 74.6 kg was added to the plough to form the second weight (λ_2, 327.7

kg) while a precast concrete block weighing 42.7 kg was added to λ_2 to form the third weight (λ_3, 370.4 kg). The implement was pulled by a 47.7kW (64 hp) tractor, weighing 2757 kg. Figure 1 is a photograph of the plough. The plough was pulled at an average speed of 7 km/h.

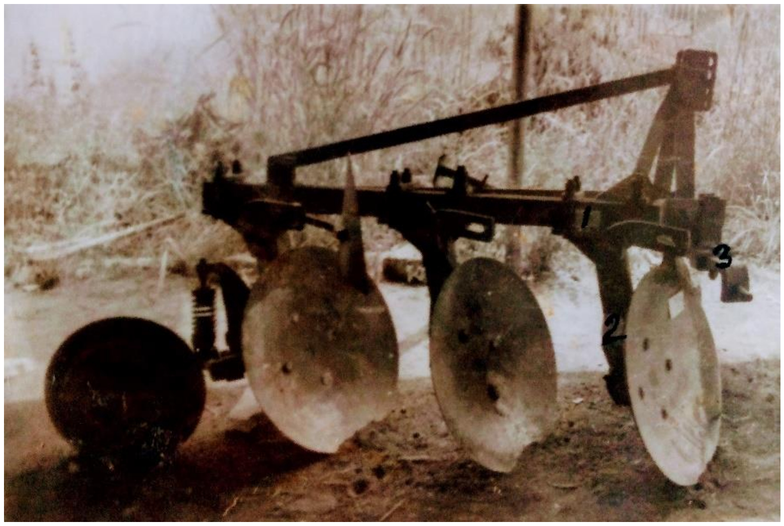

Figure 1: The 3-Bottom Disc Plough with adjustable Tilt and Disc Angles used for this work

Experiment was conducted on the demonstration farm of the university of Ilorin. Ilorin is the capital city Kwara State, Nigeria, located on latitude 8° 29′ 50″North and longitude 4° 32′ 32″ East at an altitude of 307 m above sea level with average annual rainfall between 1200 mm and 1500 mm.

2.2 Soil Test

2.2.1 Soil Particle Size

Standard sieve method, employing British Standard Sieve model BS 410 was used to the texture of soil in the field. Sieve set shaking was however done manually. Soil samples were collected from two random locations on the field and percentage soil passing through each sieve was determined using Equation 1.

$$P_s = \frac{M_p}{M_o} \times 100 \qquad (1)$$

where

P_s = Percentage of soil passing through each sieve
M_p = Mass of soil passing through each sieve
M_o = Original mass of soil placed on top-most sieve

2.2.2 Moisture Content

Standard oven method was used to determine soil moisture content. Three samples were collected and Equation 2 was used to determine the moisture content.

$$M_c = \frac{M_w}{M_T} = \frac{M_T - M_s}{M_T} \quad (2)$$

where

M_c = Moisture content (wet basis)
M_w = Mass of water removed
M_T = Total mass of wet soil
M_s = Total mass of dry soil

2.2.3 Bulk Density

Standard method described by Tanam (1994) was used to determine the bulk density of the field soil. With the aid of Core Samplers, soil samples were collected from three random locations and their bulk densities were determined using Equation 3.

$$\rho_b = \frac{M_s}{V} = \frac{4M_s}{\pi D^2 L} \quad (3)$$

where

ρ_b =Bulk Density
M_s = Mass of dry soil
V = Volume core sampler = volume of soil
D = Diameter of core sampler
L = Length of core sampler

2.3 Experimental Design

A two factor Latin Square experimental design with implement weight as treatments was used for data collection. Factors considered were highlighted in section 2.1 above, weight of the implement being the central focus. Factors measured were depth of cut and width of cut. A general layout of this design is presented in Table 1.

Table 1: General Layout of a Latin Square Experimental Design

	α_1	α_2	α_3
β_1	λ_1	λ_2	λ_3
β_2	λ_3	λ_1	λ_2
β_3	λ_2	λ_3	λ_1

Nine strips of plots measuring 50 m each were selected. On each strip 25-m lengths portions were marked out as shown in Figure 2.

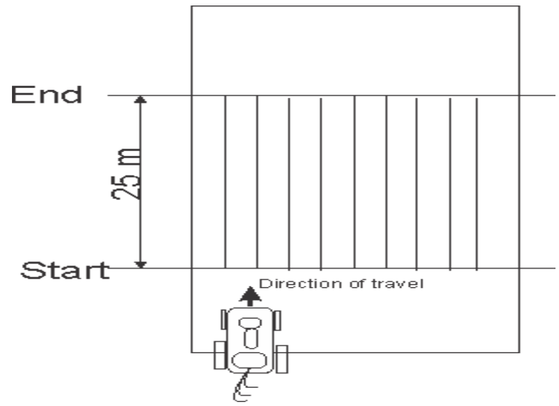

Figure 2: Layout of Treatment runs, showing direction of run

For each run, the tractor was allowed to attain uniform speed and hydraulic lever maintained at uniform level before reaching the start of the 25-m mark. This was maintained until the plough crossed the end of the 25-m mark. Five random locations along each run were selected where depth and width of cut were measured and treated as replicates for the treatment. Data obtained were analysed by methods described by Davies (1956) and Ott (1977) and subjected to Analysis of Variance (ANOVA) to determine the effects of the parameters. Table 2 shows the general layout of ANOVA for a Latin Square experimental design.

Table 2: General ANOVA Table for Latin Square Design

Source	Sum of Squares (SS)	Degree of freedom (df)	Mean Square (MS)	F-ratio
Treatment, λ Rows, β Columns, α Error	SSt SSR SSC SSE	$b - 1$ $b - 1$ $b - 1$ $rb^2 - 3b + 2$	MSt = SSt/df MSR = SSR/df MSC = SSC/df MSE = df	F-ratio = MSt/MSE F-ratio = MSR/MSE F-ratio = MSC/MSE
Total	SST	$b^2r - 1$		

b = number of parameters = 3
r = number of replications = 5

Significance was tested at 5% and 1%

3 RESULTS AND DISCUSSION

3.1 Soil Properties

Particle size analysis of soil from the field revealed that the soil is made up of 73.3% sand and 26.7% gravel. Oni (1981) described a soil of this nature as gravelly sand. Figure 3 is a graph from the soil particle size analysis. Coarse grained soils are usually not very compressible at low moisture content as the grains are mostly in contact with each other. This is evident from the value of the mean bulk density obtained (1.39 ±0.02 g/cm^3) of the soil.

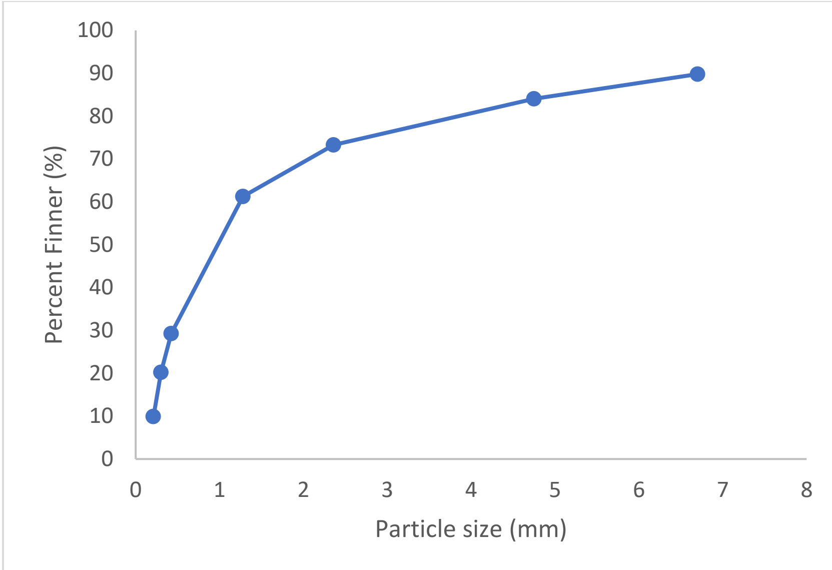

Figure 3: Graph of Soil Particle size Analysis

This bulk density falls within the range of 1.3 g/cm^3 and 1.8 g/cm^3 for coarse grain soils as reported by Millar *et al* (1965), cited by Kirkham (2023). This level of bulk density would normally require higher levels of energy to break. Moisture content of the soil was found to be 5.89% (wet basis).

3.2 Effect of Weight on Depth of Cut

Table 3 is the ANOVA for depth of cut. At 5% confidence, critical $_{0.05}F_{2,38} = 3.25$, while at 1% confidence, critical $_{0.01}F_{2,38} = 5.22$

Table 3: ANOVA Table for Depth of cut

Source	SS	df	MS	F-ratio
Weight, λ	52.03	2	26.02	2.40
Disc Angle, β	56.23	2	28.12	2.59
Tilt Angle, α	796.63	2	398.32	36.71^{++}
Error	412.41	38	10.85	
Total	1317.30	44		

++ Significant at 1% confidence level

Table 3 shows that the computed F-ratios for implement weight and disc angle were less than critical values at 5%, therefore showing no sufficient evidence to prove a significant effect of weight and disc angle on the depth of cut. It is likely therefore that increasing implement weight may not necessarily increase depth of cut.

Figure 4 shows that at 16° tilt angle there was a significant increase in tool penetration. However, there was an insignificant difference in depth of cut with increase weight levels.

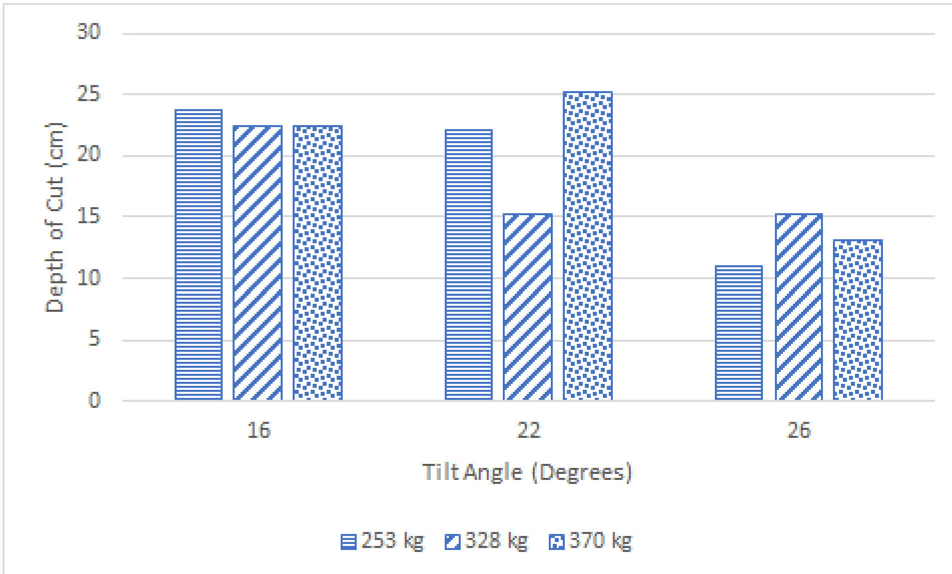

Figure 4: Effect of Implement Weight on Depth of Cut under varying Tilt Angle

Except at 22º tilt angle, increasing implement weight did not increase depth of cut. These results are not in agreement with general believe and the findings of. The variation could be due to differences in soil texture, operating speed and soil moisture. It is likely that as tilt angle increases, the convex area of the disc in contact with the ground increases thereby increasing soil reaction forces on the plough so that penetration is hampered. However, at low tilt angles, the edge of the tool forms a knife on the soil surface and so may be pushed down by the weight of the implement. Implement weight may therefore be significant only at low tilt angles.

Similar pattern was observed as disc angle was increased except at high disc angles where increasing implement weight was observed to increase tool penetration. This is presented in Figure 5. At lower disc angles however increasing weight did not show significant change in depth of cut. There was actually a drop in depth of cut with increase in weight at low disc angles.

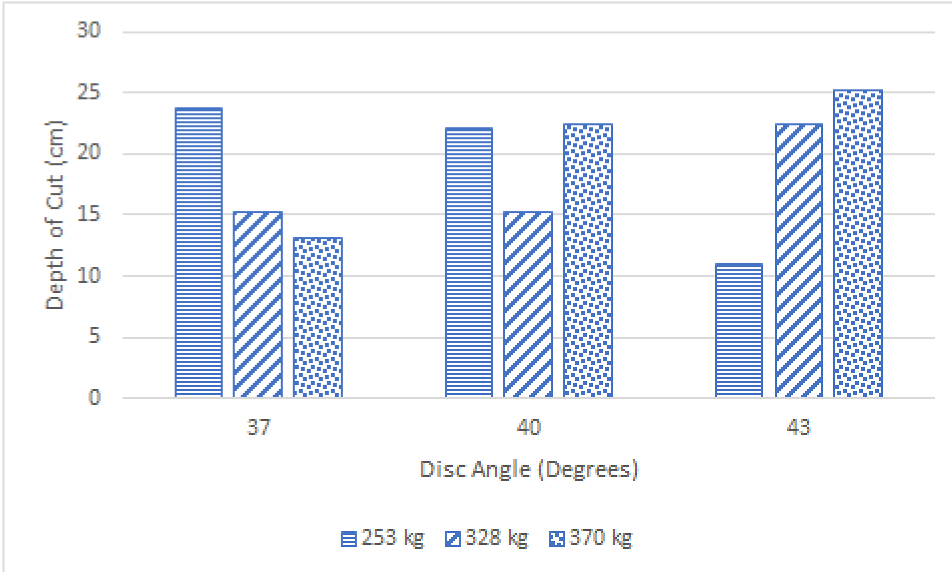

Figure 5: Effect of Implement Weight on Depth of Cut under varying Disc Angle

3.3 Effect of Implement Weight on Width of Cut

Table 4 is the ANOVA for width of cut of the disc plough. Table 4 shows that the computed F-ratio for weight was lower than critical value, even at 5% level, indicating insufficient evidence to prove a significant effect of weight of implement on the width of cut of the plough. Disc angle was found to have a significant effect on width of cut and tilt angle was highly significant. It is clear therefore that implement tilt and disc angles are greater contributors to width of cut, in agreement with many researchers, than the weight of the implement. These are clear from Figure 6.

Table 4: Table 2: ANOVA Table for Width of Cut

Source	SS	Df	MS	F-ratio
Weight, λ	2047.60	2	1023.8	2.58
Disc Angle, β	3328.53	2	1664.27	4.20^{+}
Tilt Angle, α	41876.13	2	20938.07	52.83^{++}
Error	15059.74	38	396.31	
Total	62312.0	44		

+ Significant at 5% confidence level

++ Significant at 1% confidence level

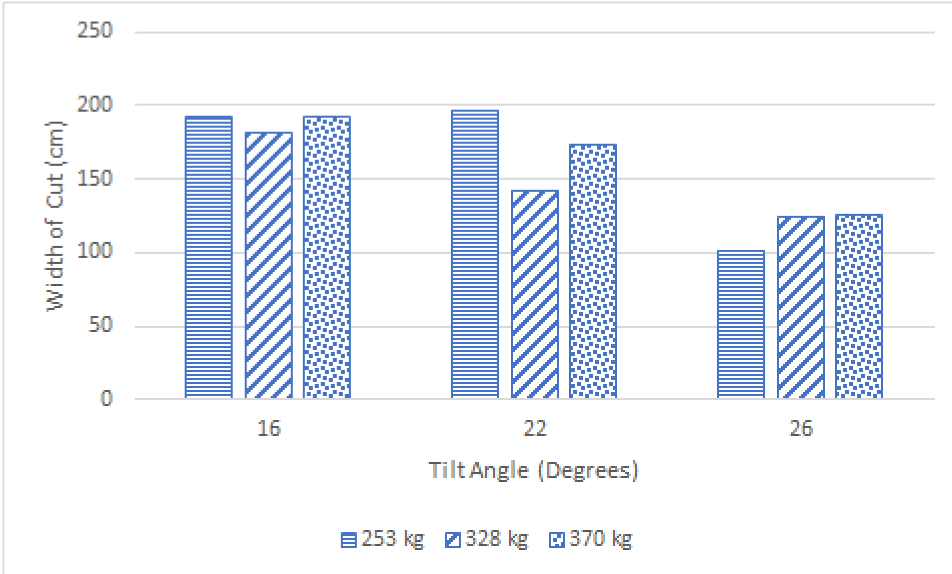

Figure 6: Effect of Implement Weight on Width of Cut under varying Tilt Angle

Although there was a high level of width of cut at 16º and 22º tilt angles, Figure 6 shows that there was insignificant difference in width of cut at different weight levels at all tilt angles. Figure 7 shows that a given disc angle, increasing implement weight reduced the width of cut. Again this is not in agreement with Olatunji *et al* (2009).

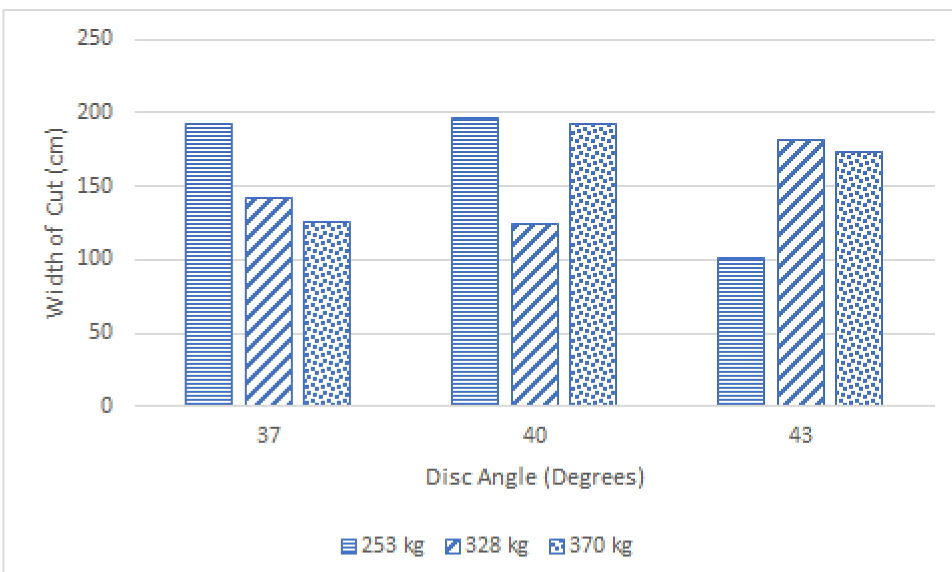

Figure 7: Effect of Implement Weight on Width of Cut under varying Disc Angle

CONCLUSION

Effect of weight on the depth and width of cut of a disc plough was studied in conjunction with its tilt and disc angles. Observations made showed that the implement tilt and disc angles made more contributions to depth and width of cut than the weight of the plough. It may be concluded therefore, that since there was insufficient evidence that implement weight aided tool penetration, increasing the weight of the plough may not have significant effect on depth and width of cut. A redesign of the disc plough may therefore be necessary with the aim of producing lighter ploughs that may be pulled by lighter tractors. This would reduce soil compaction and energy requirements for ploughing and hence, cost of operation

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