Research Journal of Applied Sciences, Engineering and Technology 3(3): 179-184, 2011
ISSN: 2040-7467

Received: December 28, 2010 Accepted: February 02, 2011 Published: March 30, 2011

Evaluation of Plough Disc Performance on Sandy Loan Soil at Different Soil Moisture Levels

O.M. Olatunji
Department of Agricultural and Environmental Engineering, Rivers State University of Science and Technology, Nkpolu, P.M.B. 5080, Port Harcourt, Nigeria

Abstract: In this research study, dimensional analysis was used to model the relationship between depth of cut, weight of disc plough and draught on a sandy loam soil. Field experiment was carried out on a site with three different moisture content levels at five different plough speeds (0.83, 1.39, 1.94, 2.4 and 2.78 m/s). It was observed that the depth of penetration of plough disc increased with an increased draught and soil moisture content. The depth of cut was minimum at 4.9% and maximum at 9.4% moisture content. The result obtained from the validation shows that the model can be used effectively to determine the depth of cut in sandy loam soil at different soil moisture levels. Also the draught-speed relationship obtained from this study can be used to predict the power requirement of the disc plough in other soil types. The draught increase linearly with the depth of cut as predicted from the model. The result of the soil properties after tillage operation showed increased shear strength, bulk density and depth of cut.

Key words: Bulk density, depth of cut, disc plough, moisture content, sandly-loam, shear strength

INTRODUCTION

Soil tillage may be defined as the mechanical manipulation of the soil aimed at improving soil conditions for crop production. It represents the most costly single item in the budget of an arable farmer. Tillage provides good weed control with low herbicide cost; allows the control of disease and insects by destroying them through burying of crop residues. Three things are involved in soil tillage which include: The power source, the soil and the implement (Olatunji, 2007).

The draught requirement of the disc plough is very enormous when compared to other tillage implements (ASAE, 2002). For a given soil type and speed of travel. Sheruddin *et al*. (1992a) and Grisso *et al*., (1996) observed that the disc plough has a higher total and specific draught than other tillage implements. This is attributed to the design of the implement. A similar result was observed by Singh and Pederson (1979) on the comparison of mould board and disc plough on Bangkok Clay. However, the two implement were tested at different moisture content levels. In an experiment conducted by Summer *et al*. (1986), it was observed that the draught was linear with speed for chisel, discs and sweep ploughs and had a quadratic relationship with speed for mould board ploughs. Linearity was observed between draught and depth for all the tools. The author also discovers the soil properties that contribute to tillage energy. They are moisture content, bulk density, soil texture and strength.

The typical draught requirements depend on the soil texture; implement width, working depth and travel speed ASAE (1999). McGreery and Nicholas (1956) and Claude (1984) examined the effect of disc angle in penetration and die draught of disc plough and noted that a considerable bearing area of the disc is in contact with soil, resulting in soil pressure on the back of the cutting edge. They explained that increase in disc angle and reduction in titl angle improves penetration under hard soil conditions. Furthermore, they stated that depth of penetration of the disc blade during ploughing depends on the weight of the implement Sheruddin *et al*. (1992b). Kaul and Egbo (1985) reported that different speeds affect the soil aggregation as higher percentage of small soil aggregates were obtained at lower forward speeds than higher forward speeds. Claude (1984) reported that the weight on the disc is the most important factor affecting the depth of penetration of the disc.

Therefore the objectives of this study are:

- To investigate the effect of soil moisture on the plough disc performance at different tool speed.
- To determine the impact of tool speed and soil moisture level on other desirable soil parameter.
- To develop an equation for predicting the depth of cut of disc plough at a given weight of the implent at different soil moisture levels.

MATERIALS AND METHODS

The field test was carried out at NCAM, Illorin, Nigeria which is 370 m above sea level and lies on longitude 40º30′ East and latitude 8º26′ North with mean annual rainfall and air temperature of 1000 mm and 30ºC, respectively. The instruments used in the research study were: Two 75Hp Diesel Tractor, (Elcher 845 DI). A three bottom disc plough (63 cm diameter per disc), ranging poles, surveyor tape, stop watch, core soil sampler, soil samples containers, set of sieves, weighing balance, polythene bags, electric oven, desiccators, measuring cylinder, calibrated wooden bar and meter square frame.

Experimental procedure: All laboratory and field test carried out were done according to the recommendation of the Regional network for Agricultural machinery (RNAM, 1983). The experiment was conducted in a rectangular plot measuring 100m x 50m each and performance parameters studied were soil inversion, soil aggregation: depth and width of cut fuel consumption at three different forward speeds. Two tractors A and B were made available. The implement (disc plough) was mounted on tractor B and made to plough the field following the field operational pattern for five consecutive runs during which the measured data were obtained.

A hydraulic dynamometer (pull type) was attached to the front of tractor B. Another auxiliary tractor A was used to pull the implement mounted tractor through the dynamometer. The auxiliary tractor pulled the implement mounted tractor in neutral gear but with the implement in the operating position (RNAM, 1983). The draught was recorded within the measured distance of 50 m as well as the time taken to reverse it. On the same field, the implement was lifted out the ground and the rear tractor was pulled to record the idle draught force. The difference gave the draught of the implement. Additional weight of 10 kg was added to the weight o the plough and the experiment repeated.

The depth of cut was measured with a steel tape from the bottom of the furrow to the surface level of the soil at seven randomly selected places for each of different weight of the disc plow from the test plot (RNAM, 1983). A model was developed using dimensional analysis to analyses the experimental result. The model equation from dimensional analysis was validated by using the standard error of estimate (Murray and Larry, 2003).

Model derivation and validation:

Model derivation: In the ploughing process the depth of cut depends on the weight of the implement, draught, cone index, moisture content and the speed. The depth of cut is the dependent variable which must be controlled by manipulating the other variables.

Let n be the number of variable involved in this operations, then n = 5 in this case. Similarly, let k be the fundamental dimensions which is MLT, then k = 3, therefore, the number of Pi-term equals 2.

The variables are:

Depth of cut,	d
Weight of the implement,	W
Draught	D
Cone index	Cl
Moisture content,	F
Speed of Operation	V

Following methods of dimensional analysis by Olatunji (2007), the reference dimensions are M,L,T, (Mass, length and Time, respectively).

i.e., d = L

W = M

D = MLT^2

Cl = ML^{-2}

V = LT

ϕ = (Dimension less) hence f becomes a pie term. Therefore,

$$\phi = \pi_i \tag{1}$$

Since d is the dependent variable:

$$d = f\left(W, D, CI, \Phi, V\right) \tag{2}$$

But since F is dimensionless and is a pie term Eq. (2) becomes:

$$f\left(d, W, D, CI, V\right) = 0 \tag{3}$$

Let the repeating variables be W, CI and V:

$$\pi_2 = W_2^x CI_2^v x V_2^2 d \tag{4}$$

$$MLT = M_2^x x\left(ML^{-2}\right)_2^v xx\left(LT^{-1}\right)_2^2 x\,L \tag{5}$$

For

M, $x_2+y_2 = 0$ (6)

L, $-2y_2+z_2+1=0$ (7)

T, $-z_2 = 0$ (8)

From the Eq. (6), (7) and (8) above:

$z_2=0$

$y_2=1/2$ and

$X_2=-1/2$

Substituting the value of x, y and z, Eq. (4) becomes:

$$\pi_2 = W^{1/2} x\ CL^{1/2}\ x\,d \tag{9}$$

$$\pi_2 = \sqrt{\frac{CI}{W}} x\,d \tag{10}$$

$$\pi_2 = d\ x\,CL^{1/2}\ x\,W^{-1/2} \tag{11}$$

To complete the 3rd pie term

$$\pi_2 = W_3^x \ x \ CI_3^v \ x \ V_3^2 \ x \ D \quad (12)$$

$$\text{MLT} = M_3^x \ x\left(ML^{-2}\right)_3^v x\left(LT^{-1}\right)_3^2 x\left(MLT^2\right) \quad (13)$$

For,
M, $X_3 + y_3 + 1 = 0$
L, $-2y_3 + z_3 + 1 = 0$
T, $-z_3 - 2$

From the equations:

$Z_3 = -2$
$Y_3 = ½$ and $X_3 = - ½$

Substituting the value of x_3, y_3 and z_3 Eq. (12) gives:

$$\pi_3 \frac{D}{\sqrt{Wx\sqrt{CIxV^2}}} \quad (17)$$

$$\pi_3 = D\,x\,W^{-1/2}x\,CI^{-1/2}xV^{-2} \quad (18)$$

But,
$\phi = \pi_1$

Therefore, substituting all the pie terms into the functional equation we have:

$$f\left(\pi_1, \pi_2, \pi_3\right) = 0 \quad (19)$$

$$f\left(\phi, d\,x\,CI^{1/2}xW^{-1/2}xCI^{1/2}xV^{-2}\right) = 0 \quad (20)$$

$$d\,x\,CI^{1/2}xW^{-1/2} = f\left(\phi, DxW^{-1/2}xCI^{1/2}xV^{-2}\right) \quad (21)$$

The equation above is the functional relationship between the dependent and the independent variables.

To get d, a new pie group can be determined from the existing pie groups by combining π_2 andπ_3.

$$\pi_2 = \pi_2\,x\,\pi_3 \quad (22)$$

$$\frac{D}{\sqrt{Wx}\sqrt{CI\,xV^2}}\,x\frac{\sqrt{CI}}{\sqrt{W}}\,x\,d \quad (23)$$

$$\pi_2 = \frac{D\,x\,d}{W\,xV} \quad (24)$$

$$f\left(\pi_2, \pi_2\right) = 0 \quad (25)$$

$$\frac{D\,x\,d}{W\,xV} = k\phi \quad (26)$$

Shown combining results. Therefore,

$$d = \frac{k\phi WV}{D} \quad (27)$$

k is a constant and can be determined experimentally. k value for sandy loam soil is 6.7, for soft soil is 5.7 and for firm soil is 7.8 (ASAE, 2002).

Data collection and analysis: Data were collected as described above. The model equation from dimensional analysis was used to compute the values of depth of cut from the field data obtained.
The computed result was validated using:

$$\pi_2 = \frac{D\,x\,d}{W\,xV} \quad (28)$$

$$f\left(\pi_1, \pi_2\right) = 0 \quad (29)$$

$$\frac{D\,x\,d}{W\,xV} = k\phi \quad (30)$$

Therefore,

$$d = \frac{k\phi WV}{D} \quad (31)$$

k is a constant and can be determined experimentally. k value for sandy loam soil is 6.7, for soft soil is 5.7 and for firm soil is 7.8 (ASAE, 2002).

Data collection and analysis: Data were collected as described above. The model equation from dimensional analysis was used to compute the values of depth of cut from the field data obtained. The computed result was validated using the standard error of estimate. Also, analysis of variance was carried out to determine the effect of soil moisture and tool speed on the drawbar pull of the tractor.

RESULTS AND DISCUSSION

Effect of soil moisture and tool speed on soil strength properties: Table 1 and 2 show the average soil properties determined before and after tillage operation, respectively. The shear strength and cone index decreased with increased speed and soil moisture content but decreased with depth of cut. This shows that the draught force changes with depth of cut. These results

Table 1: Average soil properties before tillage

Sub plot	Depth (cm)	Moisture content (%)	Shear strength T	Conc index N/M^2	Bulk density $Y(g/cm^2)$
1	7	3.47	30.17	60.66	1.30
	14	4.00	38.32	83.32	1.42
	21	3.77	49.12	49.12	1.48
2	7	5.29	22.41	45.66	1.23
	14	5.55	43.00	86.78	1.26
	21	5.70	45.42	103.56	1.29
3	7	8.75	20.32	32.76	1.22
	14	7.66	42.64	62.13	1.31
	21	7.59	53.57	38.24	1.35

Table 2: Average soil properties after tillage

Sub plot	Depth (cm)	Moisture content (%)	Shear strength T	Conc index N/M^2	Bulk density $Y(g/cm^2)$
1	7	3.71	15.45	12.06	1.26
	14	4.22	21.40	34.67	1.38
	21	4.03	32.67	86.43	1.39
2	7	5.28	19.20	42.72	1.42
	14	5.54	42.10	81.40	1.17
	21	5.52	37.00	101.57	1.20
3	7	7.14	21.50	8.42	1.09
	14	6.85	23.50	30.10	1.24
	21	7.03	37.24	63.21	1.29

Table 3a: Effect of speed and soil moisture content on draught and power requirement of disc plough at 4.9% moisture levels

Moisture level (%)	Speed of ploughing (M/S)	Draught (kN)	Specific draught (KN/M^2)	Power requirement (KW)
4.9	0.83	3.19	19.9	2.65
	1.39	3.27	20.4	4.55
	1.94	5.20	32.5	10.10
	2.50	6.58	39.1	15.63
	2.78	3.78	23.6	18.29

Table 3b: Effect of speed and soil moisture content on draught and power requirement of disc plough at 5.7% moisture levels

Moisture level (%)	Speed of ploughing (M/S)	Draught (kN)	Specific draught (KN/M^2)	Power requirement (KW)
5.7	0.83	3.78	23.6	3.14
	1.39	4.23	26.4	5.88
	1.94	5.47	34.2	10.61
	2.50	6.94	43.4	17.35
	2.78	7.35	45.9	20.43
	0.83	2.76	17.35	2.29

Table 3c: Effect of speed and soil moisture content on draught and power requirement of disc plough at 9.4% moisture levels

Moisture level (%)	Speed of ploughing (M/S)	Draught (kN)	Specific draught (kN/M2)	Power requirement (KW)
9.4	1.39	3.65	22.8	5.07
	1.94	5.45	34.1	10.57
	2.50	7.34	45.9	18.35
	2.78	7.45	46.6	20.71

corroborate with the findings of Singh and Perderson (1979) and Thormas and Singh (2002).

Effect of speed and moisture on draught and depth of cut: The changes in draught with respect to speed and soil moisture content are shown in Table 3a, b and c.

From the model derived, draught for disc ploughing increased with speed and soil moisture content (4.9, 5.7 and 9.4%), respectively. However, at the three soil moisture level, 4.9, 5.7 and 9.4% the draught and power requirement increased with speed. But draught requirement was lowest at soil moisture 9.4% and ploughing speed of 0.83 m/s compared to soil moisture 4.9 and 5.7% at 0.83 m/s. This is because higher moisture content of the soil, hence the plough require less energy to carry out its function.

A comparative analysis of Table 3a, b and c shows that a tool speed of 1.94 per ms gives a better performance in the area of depth of cut and draught required than the speed of 1.34 and 2.5 per ms,

Table 4: ANOVA Showing effect of soil moisture and tool - speed on draught

Source of variation	SS	df	MSS	F-cal	F-tab
Treatment (tool speed)	68.3877	4	17.0994	94.8912*	3.06
Block (moisture content)	2.1773	2	1.0887	6.0416*	3.60
Interaction (tool speed moisture content)	1.8092	8	0.2262	1.2553	
Error	2.7024	15	0.1802		
Total	75.0866	29			

SS: Sum of square; df: degree of freedom; MSS: Mean sum of squares; *: Significant at 0.05 Level of Significance

Table 5: Measure computed depth of cut and weight of implement at various speeds

Replication	Measured depth cut (cm)	Computed depth cut (cm)	Weight (kg)
a. Speed of ploughing at 0.83 m/s			
1	8.12	9.00	450.00
2	8.32	8.90	460.00
3	8.97	9.23	470.00
4	9.10	9.45	480.00
5	9.62	9.87	490.00
6	10.30	10.20	500.00
7	10.04	10.04	510.00
8	10.87	11.21	520.00
9	11.32	11.01	530.00
10	11.89	12.00	540.00
b. Speed of ploughing at 1.39 m/s			
1	11.45	13.00	450.00
2	11.95	13.31	460.00
3	12.78	13.60	470.00
4	13.28	13.89	480.00
5	13.79	14.18	490.00
6	14.57	14.47	500.00
7	14.76	14.76	510.00
8	14.87	15.05	520.00
9	15.39	15.34	530.00
10	15.45	15.62	540.00
c. Speed of ploughing at 1.94 m/s			
1	13.96	14.41	450.00
2	14.37	14.90	460.00
3	14.90	15.12	470.00
4	15.22	15.56	480.00
5	15.78	16.00	490.00
6	16.42	16.78	500.00
7	17.00	17.25	510.00
8	17.99	17.90	520.00
9	18.00	18.04	530.00
10	19.45	19.00	540.00
d. Speed of ploughing at 2.50 m/s			
1	27.02	29.01	450.00
2	27.87	29.68	460.00
3	28.69	30.32	470.00
4	29.68	31.00	480.00
5	31.11	31.61	490.00
6	31.89	32.26	500.00
7	32.67	33.00	510.00
8	33.63	33.55	520.00
9	34.16	34.19	530.00
10	35.35	34.84	540.00
e. Speed of ploughing at 2.78 m/s			
1	13.80	14.00	450.00
2	14.10	14.52	460.00
3	14.98	15.10	470.00
4	15.21	15.43	480.00
5	15.97	16.11	490.00
6	16.70	16.36	500.00
7	16.84	16.97	510.00
8	17.42	17.42	520.00
9	17.90	18.00	530.00
10	18.23	18.88	540.00

respectively. This point to the fact that optimum speed of operation for disc plaguing is 1.94 per ms while the optimum soil moisture content is between 8.0 and 9.4% for the soil under consideration. From the model derived the observed trend in Table 3a, b, and c can be explained by the fact that at higher soil moisture contents, the degree of shearing and shattering of clods is reduced leading to a lower impact force Thormas and Singh, (2002).

This further corroborates the findings of Singh and Pedersen (1979). Manian *et al*. (2000) that when moisture contents exceed the plastic limit value, the draught per unit area decreases. The draught increased linearly with the depth of cut as predicted from the model. The draught speed relationship can be used to estimate the tractor horse power required to pull the tillage implement for a given ground speed and operating depth. Table 4 shows the result of ANOVA on the effect of soil moisture content and tool speed on drought. The plaguing speed and soil moisture content had no significant effect on draught. The interaction between the plaguing speed and soil moisture content was not significant.

The effect of weight on the depth of cut: The results from Table 5a-c, as predicted from the model show that the depth of cut varied with a change in the weight of the implement. Also from the model, an increase in the weight of the implement at a constant speed, showed an appreciable increase in the depth of cut. This is in agreement with the findings of Singh and Pedersen (1979).

From the model at speed, 1.39 and 2.5 m/s it was discovered that the ploughing efficiency was lower compared with the speed of 1.94 m/s. at 1.94 m/s speed, with added weights the implement was able to penetrate deeper to the soil which help to remove some buried root and hard pan in the soil.

CONCLUSION

The field work was carried out to investigate the evaluation of disc plough performance on sandy loam soil at different soil moisture levels. The model validation and analysis of variance on the data collected showed that with an increased soil moisture content, the draught for disc plough increased at a higher tool speed, which also cause an increase in the depth of cut. An increase constant speed showed an appreciable increase in the depth of cut of ploughing. This is in agreement with the findings of Singh and Pedersen (1979), Summer *et al*. (1986). The analysis further revealed that at tool speed of 7.0 km/h and soil moisture levels 5.7 and 9.6%d.b, the drawbar pull required to produced a good soil till was minimal. The application of the model derived will aid planning in tillage operations.

ACKNOWLEDGMENT

Engr. Barnabas Bassuo, Mr. Iyoyo and Tractor operator of NCAM Ilorin, Nigeria and workshop staff of soil lab Department of Agricultural and Environmental Engineering Rivers State University of Science and Technology, Port Harcourt, Nigeria.

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