Effects of soil moisture and tillage speeds on tractive force of disc ploughing in loamy sand soil

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Abstract

The effect of disc plough speeds and variations in soil moisture content on tractive force requirements was investigated using the trace-tractor technique. The results indicate that tractive forces decrease with increase in soil moisture content at constant tillage speeds of 1.94m/s, 2.22m/s and 2.5m/s respectively. The study further revealed that the optimum speed of operation for disc ploughing is 1.94m/s, while the optimum soil moisture content lies in the range of 2.5% to 25% wb. for the soil under consideration. Soil strength properties decreased with increase in soil moisture content and tillage speeds. This implies that there exists an optimum moisture content above or below which good soil tilth will not be realised. From the results, a linear relationship was established for predicting tractive force of disc plough under varying soil moisture content and plough speed of 1,94m/s, 2.22m/s and 2.5m/s.

Keywords: Tractive force, tillage speeds, soil moisture, disc ploughing, loamy sand soil.

1. Introduction

Land preparation is one of the major concerns in agricultural operations. Over the years, developments have taken place from the use of traditional methods of farm cultivations to the use of tractor drawn implements (Ahaneku et al., 2004). Disc plough in tropical zone is one of the most widely used tractor drawn tillage implements.

Ploughing is a primary tillage operation which is performed to shatter and achieve soil inversion. This operation is deep and leaves a rougher surface for secondary tillage operation(ASAE Standards 2002).

Tractive force in tillage operations is important in farming activities, in the sense that it is derived from contact between the tyre and a medium such as soil. A tractor pulling a tillage implement through the soil must overcome the draught force which is generated by the traction between the tyres and the soil surface in order to move forward. This becomes possible because modern tractors are designed to transmit large amounts of power to the soil. Transmitting the power requires large tractive force at the soil surface which converts the rotary motion of the tractor's crankshaft, into forward motion.

A tractor must ensure small wheel-slip but large tractive force to be efficiently utilized through implement draught (Baloch et al.,1991). Tractive force is influenced by various factors such as soil types, soil moisture content, tyre parameters, implement weights, etc. Dahab and Mohammed (2002) found in their studies that the differences between the effects of soil moisture content, tyre inflation pressure and implement type on the tractive force and power were highly significant. Tractive performance is affected by both the soils' normal strength and its shear strength. Generally normal strength has the most effect on motion resistance, while shear strength has most effect on travel reduction (slip) (Zoz and Grisso, 2003).

Performance evaluation of terrain-vehicle systems involves both the design parameters for the vehicle and evaluation of the physical environment within which the vehicle operates. The soil mechanical properties can be grouped as soil physical properties and soil strength parameters (Yu, 2006). Soil moisture content and soil texture affect mechanical behaviour and strength of soil.

Tyre diameter has a significant effect in the development of traction force. Increase in tyre width, increases the flexibility of the tyre and assists in the development of uniformity of pressure application. This in turn, increases traction capability and produces more motion resistance. The tyre inflation pressure contributes directly to the stiffness of the tyre. It controls tyre contact area and tyre-soil ground pressure distribution, both of which influence the traction capability of the tyre. There is need to improve on the efficiency of tillage operations to save time, money and increase productivity in mechanized agriculture. Research has shown that poor tractive performance in tillage operations is not cost effective.

The objective of this study, therefore, is to investigate the effect of soil moisture content and ploughing speeds on tractive force of a three- bottom disc plough on loamy sand soil.

2 Materials and methods

2.1 Experimental Site

All experiments were conducted in the field (in-situ),using trace tractor technique. It was conducted at the National Root Crops Research Institute (NRCRI) experimental farm in Umudike, Umuahia, Abia State of Nigeria. Umudike is under the derived tropical humid ecological zone of Nigeria, and is 122m above sea level and lies on latitude 05^0 29^1N and longitude 07^0 33^1E. Soil particle size distribution analysis indicated that the soil is loamy sand (clay-11.04%, silt-4% and sand-84.96%)

2.2 Experimental Procedure:

The instruments and implements used in measuring the tractive forces and other parameters are two tractors of the Massey Ferguson 435 model and 72 horse power, dynamometer, measuring tape, disc ploughs, auger, stop watch and instrument for measuring weight of tractor (static hydraulic press). Before the field experiment started, experimental layout area of 90m by 90m was designed with three different blocks of 90m by 27m each. Each block was divided into 9 strips of 90m by 2m wide with a space of 3m between each strip. Ploughing operations were carried out on each of the blocks 24hours after each rainfall event. Three replications of ploughing operations were conducted after every rainfall event. There were altogether twenty (20) rainfall events. Hence, the total treatments were 9 x 20 rainfall events. The sequence of tillage operations was: Rainfall event 1, ploughing on block 1, strip 1; block 2, strip 1; and block 3 strip1. Rainfall event 2, ploughing on block1, strip 2; block 2, strip 2; and block 3 strip 2. Rainfall event 3, ploughing on block 1, strip 3; block 2, strip 3; and block 3 strip 3. This pattern was followed for the remaining number of rainfall events up to the last day when minimum moisture content was achieved.

2.3 Determination of Soil Moisture Content

Soil moisture was replenished only through rainfall. The soil moisture content on each rainfall event was determined gravimetrically (oven dry method). In order to define the relevant soil conditions, soil samples were collected from various soil depths before any tillage operation to determine soil parameters including soil moisture content. The soil samples were collected at depths of 0 - 50mm, 50 - 150mm and 150 - 200mm, using soil auger at three replications per sample point. Different spots in the test plot were randomly selected for the soil sample collections for determination of soil moisture content levels. The beginning of tillage operation was a function of rainfall i.e. tillage operation started only after each rainfall event.

2.4 Determination of Machine Parameters

The machine parameters that were determined included tractor speeds, towing force and drawbar – pull forces. The implement used was a 3- bottom disc plough. Ploughing speeds used were 1.94m/s, 2.22m/s and 2.5m/s. The speeds of operations were obtained by setting the tractor at suitable gears of a gear reduction unit for the targeted speeds. Simultaneously, the time taken to cover a fixed distance of 90m was recorded using a stopwatch. The operating speed of the tractor and implement combination was then calculated. The towing force and drawbar-pull forces were determined using trace- tractor technique. Two 72- horse power (hp) tractors were used. The tractor carrying the implement with its engine disengaged (neutral gear) was coupled to another tractor which towed it with the dynamometer between the two tractors. The first tractor pulled the second tractor coupled to the implement(3 bottoms disc plough).The dynamometer reading was taken to determine the towing force. The drawbar-pull force was the difference between the towing force in neutral gear without implements in tillage operation and towing force when the implement was in tillage operations. Ploughing depths and widths were measured with rule (steel tape). Plate 1, shows the tractors –dynamometer- tractor-implement in action.

2.5 Data Analysis

Analysis of variance was carried out to determine the effect of soil moisture contents(%,wb) on depths and blocks. Multiple regression analysis was also carried out in order to establish a prediction equation for tractive force of disc plough under varying soil moisture contents and tillage speeds.

3. Results and discussion

3.1 Rainfall amounts and mean values of moisture content.

Table 1 presents the mean soil moisture content obtained after each rainfall event, the amount of rainfall per rainfall event, and the sequence and dates of field operations. The amount of rainfall ranged between 0mm and 149.3mm. The highest amount of rainfall (149.3mm) was obtained on 06/10/10.

3.2 Effects of moisture content (%) wb on tractive force during ploughing

Figures 1, 2 and 3 illustrate the relationships between soil moisture contents and tractive forces at the various tillage speeds of 1.94m/s, 2.22m/s and 2/5m/s, for the ploughing operations. These relationships are expressed by the linear regression equations outlined below.

$Y = -128.1x + 15556$, with coefficient of determinations R^2 = 0.884 for ploughing at 1.94m/s.

$Y = -127.6x + 16582$, with coefficient of determination R^2 = 0.882 for ploughing at 2.22m/s.

$Y = -127.1x + 17672$, with coefficient of determination R^2 = 0.883 for ploughing at 2.5m/s.

where : Y = Tractive force requirement (N) and X =Soil moisture content (%)

These linear regressions analyses equations can be used to predict tractive force requirements as function of soil moisture content.

The negative slopes of the lines in ploughing operations at these various tillage speeds indicate decrease in tractive forces as the soil moisture contents increased. At about moisture contents of 2.5% to 25%, tractive force values decreased from 15,500N to 12,500N, 16,500N to 13,500N and 17,500N to 14,500N at the respective tillage speeds. The results show, that at the three ploughing speeds of 1.94m/s, 2.22m/s and 2.5m/s, coefficient of determinations $R^2 = 0.884$, $R^2 = 0.882$ and $R^2 = 0.883$ are closely related. This may be due to soil strength as at the time of ploughing operations, smaller contact area and implement weight. This agrees with the finding of Sun et al., (1986) that cone index are useful in assessing the strength status of soil before and after tillage operations. A comparative analysis of Figures 1, 2 and 3 show that at tillage speeds of 1.94m/s tractive force requirements were virtually the same and relatively high when compared to the higher speeds of 2.22m/s and 2.5m/s respectively. This points to the fact that the optimum speed of operation for disc ploughing is 1.94m/s, while the optimum soil moisture content for disc ploughing lies in the range of 2.5% - 25% for the soil under consideration. The observed result can be explained by the fact that at higher soil moisture contents, the degree of shearing and shattering of clods is reduced leading to lower draught force and motion resistance force. This agrees with the finding of Ahaneku, at el., (2004).

The analysis of variance(ANOVA) was used to determine the significant effect among the days of tillage operations with different tillage speeds on tractive force. The ANOVA (Table 2) shows that the effect of samples (different tillage speeds) on tractive force was not significant ($P \geq 0.05$), while the interactions between the samples and columns on tractive force was significant ($P \leq 0.05$). The columns were highly significant, indicating that the differences in soil moisture contents from the 1st day to 20th day of field operations, caused significant changes in traction forces. This same trend was observed for drawbar pull and motion resistance forces.

Table 3 shows the mean tractive force and motion resistance force values determined during disc ploughing operations at 1.94m/s, 2.22m/s and 2.5m/s tillage speeds. It therefore follows that tractive force increases with increase in tillage speeds, while it decreases with increase in moisture content.

The obtained mean tractive forces ranged from 12908.33N to 15603.33N, 13,928.33N to 16,628.33N and 15,028.33N to 17,728.33 N for ploughing, at their respective tillage speeds and days of field operations.

It was observed that ploughing operation recorded the highest tractive force of 17,728.33N at 2.5m/s tillage speed.

4. Conclusion

All the graphs of moisture content vs tractive force at the various tillage speeds are negatively sloping, indicating a decrease in tractive force as moisture content increases. The results further show that at the three ploughing speeds of 1.94m/s, 2.22m/s and 2.5m/s, the coefficient of determinations $R^2 = 0.884$, $R^2 = 0.882$ and $R^2 = 0.883$ for the respective speeds are closely related. This points to the fact that the optimum speed of operation for disc ploughing is 1.94m/s, while the optimum soil moisture content for disc ploughing lies in the range of 2.5% - 25% for the soil under consideration. The analysis of variance on data collected show that the effect of different tillage speeds on tractive force was not significant ($P \geq 0.05$), while the interactions between the speeds and tillage operations on tractive force was significant ($P \leq 0.05$). An empirical equation to predict tractive force from soil moisture content at different speeds during operation was established. The application of this equation will assist farmers and tractor operators in planning tillage operations

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Plate 1. A photograph depicting tractor- dynamometer, implement mounted position during disc ploughing operations.

Table 1 : Mean Soil Moisture Content Determined On Each Day Of Field Operations

Dates	Operations and sequence	Amount of rainfall, mm	Soil moisture content (0-200mm depth) (% db)
06/09/10	1	50.7	15.50
15/09/10	2	66.9	16.04
20/09/10	3	48.2	15.44
26/09/10	4	15.3	17.71
30/09/10	5	42.2	14.42
06/10/10	6	149.3	24.14
12/10/10	7	11.6	13.92
16/10/10	8	3.8	11.58
23/10/10	9	93.7	17.66
01/11/10	10	90.6	17.62
06/11/10	11	30.1	14.83
11/11/10	12	23.1	14.44
17/11/10	13	23.3	14.48
22/11/10	14	1.3	6.31
28/11/10	15	0	1.53
05/12/10	16	0	2.24
11/12/10	17	0	2.01
18/12/10	18	2.1	6.86
25/12/10	19	0	2.70
04/01/11	20	4.6	11.94

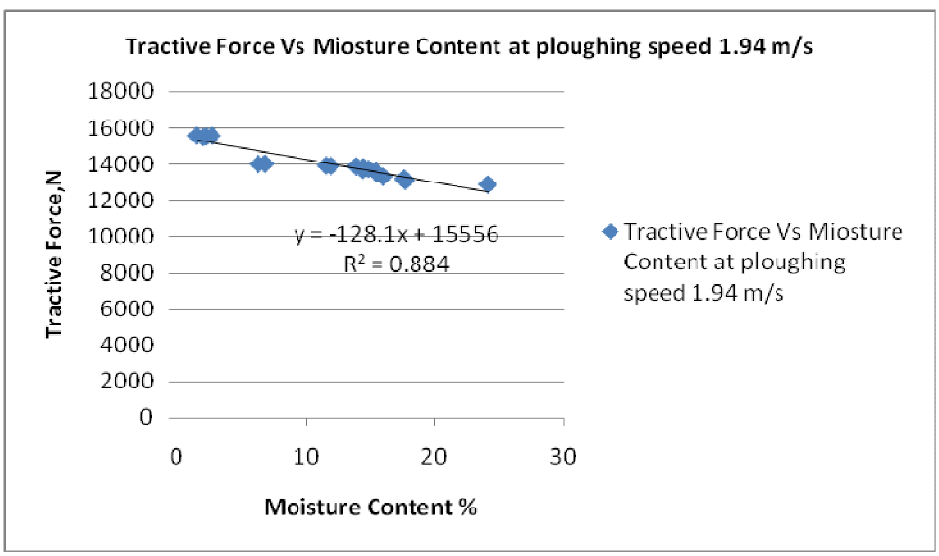

Figure 1 : Effect of moisture content on tractive force at 1.94m/s tillage speed for ploughing.

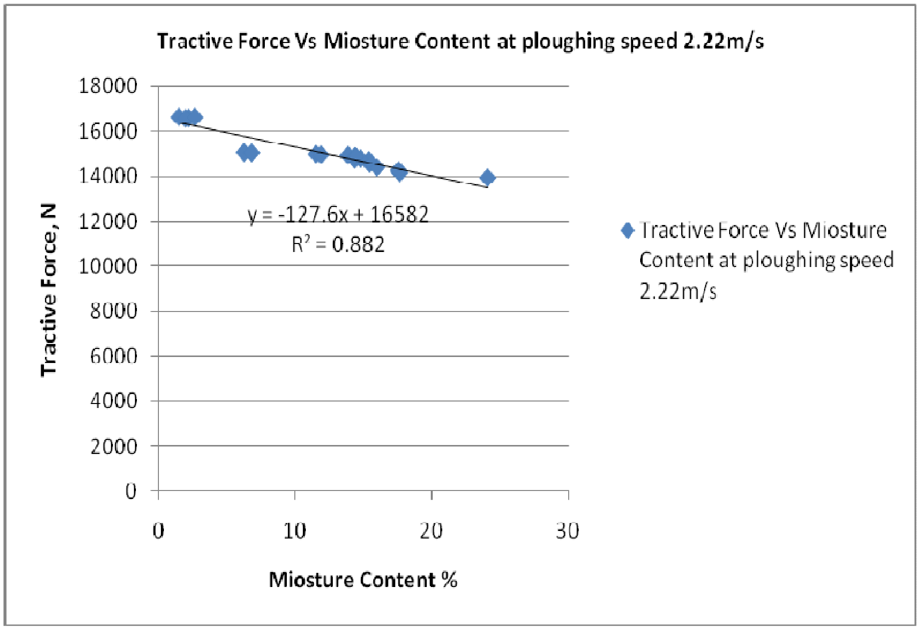

Figure 2 : Effect of moisture content on tractive force at 2.22 m/s tillage speed for ploughing.

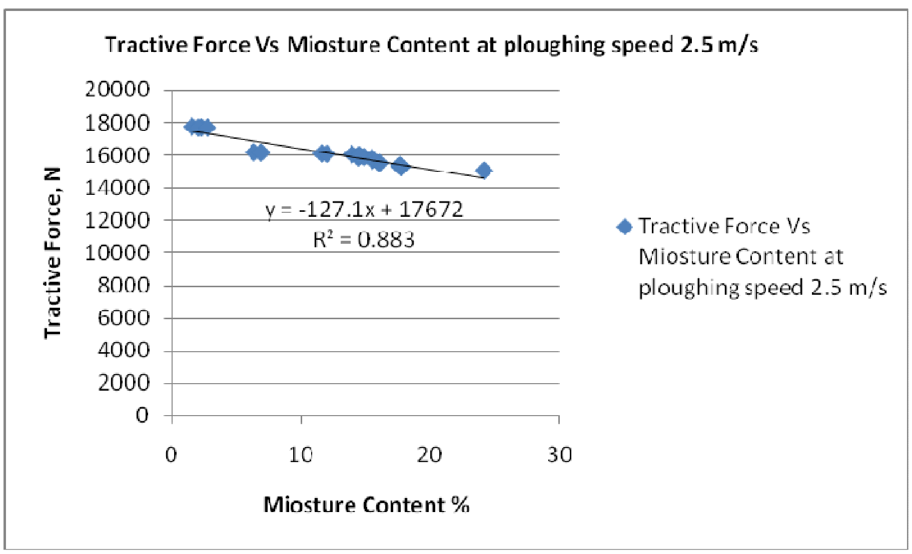

Figure 3: Effect of moisture content on tractive force at 2.5 m/s tillage speed for ploughing.

Table 2 : ANOVA Effect Of Different Tillage Speeds On Tractive Force

Sources of Variation	SS	df	MS	F	P-Value	F crit
Sample	1977071	2	988535.7	0.328814	0.719923	3.0126NS
columns	2.49E+08	2	1.24E+08	41.37151	2.01E-17	3.013SS*
interaction	95747651	4	23936913	7.962067	3.08E-06	2.3887SS
within	1.6E+09	531	3006369			
Total	1.94E+09	539				

NS: No significant different ($P \geq 0.05$)

SS*: Highly Significantly different($P \leq 0.05$)

SS: Significant different ($P \leq 0.05$)

Table 3 : Determined Mean Tractive Force And Motion Resistance Force During Ploughing, at 1.94m/s,2,22m/s and 2.5m/s

Date	Moisture content% (db)	Implement engaged N (F)	Implement disengaged (motion resistance)N (FR)	Implement engaged N (F)	Implement disengaged (motion resistance) N (FR)	Implement engaged N (F)	Implement disengaged (motion resistance) N (FR)
		Ploughing at 1.94m/s		Ploughing at 2.22 m/s		Ploughing at 2.5 m/s	
06/09/10	15.50	13,505.00	9,925	14,561.66	9,975	15,661.66	10,025
15/09/10	16.04	13,331.66	9,925	14,395.00	9,975	15,495.00	10,025
20/09/10	15.44	13,650.00	9,925	14,705.00	9,960	15,805.00	10,010
26/09/10	17.71	13,101.66	9,900	14,141.66	9,920	15,725.00	9,970
30/09/10	14.42	13,696.66	9,920	14,736.66	9,920	15,836.66	9,970
06/09/10	24.14	12,908.33	9,900	13,928.33	9,910	15,028.33	9,960
12/10/10	13.92	13,910.00	9,905	14,930.00	9,915	16,030.00	9,965
16/10/10	11.58	13,950.00	9,900	14,985.00	9,925	16,085.00	9,975
23/10/10	17.66	13,153.33	9,900	14,183.33	9,910	15,283.33	9,960
01/11/10	17.62	13,226.66	9,910	14,266.66	9,920	15,356.66	9,970
06/11/10	14.83	13,761.66	9,920	14,776.66	9,915	15,876.66	9,965
11/11/10	14.44	13,855.33	9,915	14,880.00	9,920	15,980.00	9,970
17/11/10	14.48	13,845.00	9,915	14,870.00	9,920	15970.00	9,970
22/11/10	6.31	14,033.33	9,950	15,058.33	9,955	16,158.33	10,005
28/11/10	1.53	15,603.33	10,915	16,628.33	10,920	17,728.33	10,970
05/12/10	2.24	15,553.33	10,910	16,578.33	10,915	17,678.33	10,965
11/12/10	2.01	15,516.66	10,900	16,566.66	10,930	17,666.66	10,980
18/12/10	6.86	14,050.00	9,950	15,043.33	9,960	16,143.33	10,010
25/12/10	2.70	15,600.00	10,950	16.625.00	10,955	17,675.00	10,955
04/01/11	11.94	13,930.00	9,900	14,960.00	9,910	16,060.00	9,960