TRACTABILITY CONDITIONS FOR DISC PLOUGHING ON A LOAMY SAND SOIL IN THE ILORIN AGRO-ECOLOGICAL ZONE

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ABSTRACT
For agricultural field operations such as tillage and planting, an agricultural soil is considered tractable if it can develop adequate shear resistance to minimize tyre slip and soil damage and can produce required soil tilth without undue soil pulverization or the formation of large clods. Furthermore, the soil must be devoid of physical obstructions like stones, stumps, ant-hills, etc and be of a light vegetative cover. Tractability conditions for disc ploughing on a loamy sand soil based on soil moisture have been determined for Ilorin agro-ecological zone, which fall within the Guinea Savannah zone of Nigeria. This was achieved by carrying out disc ploughing on an experimental plot at thirteen different soil moisture levels ranging from 8.90 to 91.74% *of field capacity. The tyre slip and wheel sinkage measured at each soil moisture level, were used to judge whether the soil was tractable or not. Soil is adjudged tractable if the observed tyre slip is either 15% or less. The corresponding soil moisture range was selected as the soil moisture condition at which the soil is tractable. It was found that the loamy sand soil of Ilorin agro- ecological zone was tractable between soil moisture levels of 8.90 and 60.08% of field capacity. Results showed that differences in soil moisture distribution along the slope of the land had no significant (P< 0.05) effect on the towing force and the drawbar pull of the tractor. However, differences in soil moisture levels had significant effect on them. Furthermore, data such as towing force, drawbar pull, soil cone index and tyre slip generated and analyzed using regression analysis, were used to establish empirical trafficability prediction equations; which are useful in studies of soil-machine interactions*

1 INTRODUCTION

In the recent time, agricultural engineering research in the area of tillage has been tending towards conservation tillage. Tillage is the mechanical manipulation of the soil for any purpose, but in agriculture the term is usually restricted to the changing of soil conditions for crop production [1]. According to Anazodo [2], the general objectives of tillage in agriculture may be summarized as follows: to develop a desirable soil structure for a seedbed or a rootbed; to control weeds; to facilitate the placement of surface residues; to minimize soil erosion; to prepare land for irrigation, to incorporate and mix fertilizers or soil amendments Into the soil; and to destroy insects as well as their eggs, larvae and breeding places. Conservation tillage on the other hand is a system that involves less or no mechanical manipulation of soil and any form of vehicle traffic over the soil in the course of agricultural production, which is targeted at optimum soil and energy conservation. However, from the definition and objectives of tillage aforementioned, especially in tropical agriculture in a country like Nigeria; it is obvious, even from experience that tillage can never be ruled out completely. In Nigeria, agricultural land preparation and maintenance is a major, and perhaps the most difficult and the costliest factor that any person venturing into crop production must have to consider and tackle.

In every tillage operation, there are three factors that should be considered for the achievement of desired results: the personnel (operator), the tillage tool and the soil. The most important of these is the soil, followed by the tool [3]. As the most important factor in tillage, soil conservation is very essential for the continuation of agricultural productivity [4].

Due to frequent traffic of tractor and other farm vehicles over agricultural lands and natural soil settling, the soil is constantly subjected to a process of compaction [5]. Agricultural soils generally lack enough strength to absorb pressures, and this, results in a continuous compaction of the soil [4]. Adeoti and

Olarewaju [6] stated that soil compaction due to vehicular traffic or climatic changes on agricultural land results in low infiltration rate, soil erosion, restricted root growth and reduced crop yield. Manipulating the soil using tools is what is referred to by Makanjuola [7] as primary tillage. Ploughing is a primary tillage operation which is performed to shatter soil with partial or complete soil inversion [1].

For operations that involve machinery traffic and soil engaging tools, such as tillage and planting, an agricultural soil is considered tractable if it can develop adequate: shear resistance to minimize tyre slip and soil damage and can produce soil tilth without the formation of large clods. Furthermore, the soil must be devoid of physical obstructions like stones, stumps, ant-hills, etc. and be of a light vegetative cover, 15 to 30 cm height [5]. Soil damage, poor and uneconomical machine (tractor) performance are always experienced when soil physical and mechanical properties necessary for adequate plant growth and machine performance respectively are significantly altered by inadequate level of soil moisture. This research work was therefore conceived, towards enhancing soil conservation, efficient and economical performance of agricultural tractors and other farm vehicles. Earlier works by Ahaneku et al.[8], Hassan and Broughton [9] and Babeir et al.[10], had shown that soil is not tractable above 95% of field capacity. However all these conclusions were reached based on works done outside Nigeria. The objectives of the work are to determine the tractability condition based on soil moisture for disc ploughing on a loamy sand soil of Ilorin agro- ecological zone, and to apply a trafficability prediction equation initially developed by Wismer and Luth [12] to the Ilorin environment. Ilorin is located on longitude 4° 35=F. and Latitude 8° 31 =N in the Guinea savanna zone of Nigeria

2. MATERIALS AND METHODS

Disc ploughing was carried out at one of the experimental plots in the National Centre for Agricultural Mechanization, llorin, Nigeria; under thirteen different soil moisture levels. The experimental plot was prepared in a Randomized Complete Block Design, with the thirteen soil moisture levels ranging from low to high (8.90 to 91.74% of field capacity), as the treatments and three physical blocks against the gentle slope of the land. Two FIAT 640 model tractors were used in conjunction with a strain gauge dynamometer, adopting the trace-tractor technique to measure the towing force and drawbar pull. Speeds of tractor while implement was engaged and disengaged, were measured and used to determine the tyre slip at each soil moisture level. Soil moisture was determined by gravimetric method, soil resistance to penetration (CI) was measured using a cone penetrometer, and average ploughing depth was measured from the furrow to the level of the unploughed soil surface using a rule. Laboratory experiments carried out included calibration or penetrometer and dynamometer using the Testometric Universal Testing Machine, as well as determination of soil type by textural classification. The machine performance in terms of wheel sinkage and drawbar pull were measured while soil tilth was observed at each soil moisture level to establish the range of soil moisture at which the soil is tractable. Regression analysis of the soil and machine parameters generated were used to establish the soil moisture range at which the soil is tractable as well as the trafficability prediction equations.

3. RESULTS AND DISCUSSION

Analysis of Results

Textural classification of soil revealed that the soil type is loamy sand soil; consisting of 56% sand, 32% silt and 12% clay. The data collected were analyzed using regression analysis (both linear and non-linear) for the establishment of the tractability condition and the prediction equation for field trafficability. Also, analysis of variance (ANOVA) was used to determine the block and treatment effect on disc ploughing.

Analysis of Tractability Condition

In order to determine tractability condition, tyre slip was determined as given in equation1.

$$\text{Tyre Slip} = -\frac{Va}{Vt} \qquad (1)$$

Where

V_a = speed of tractor when implement is engage (under load)

V_t = speed of tractor when

implement is disengaged (no load)

Tractability condition (Table 1) based on soil moisture was established by finding out the soil moisture condition at which tyre slip was beyond acceptable level i.e. about 15% [113,141]. This was achieved through regression analysis, considering soil moisture as the independent variable while tyre slip is dependent. The following prediction equation was obtained from the regression analysis.

$$x = \frac{y - 7.19}{0.13} \qquad (2)$$

x = soil moisture, and
y = tyre slip

Equation 2 was used to determine tractability condition based on soil moisture. It was found that at 60.08% soil moisture the corresponding tyre slip is 15%, therefore, It can be concluded that soil is not tractable as from 60.08% soil moisture and above for Ilorin soil. It was also observed that wheel sinkage increased with the soil moisture. Other factors that could affect soil tractability include vegetative cover and physical obstructions like stones, stumps, ant-hills, etc.

Analysis of variance (Tables 2, and 3) showed that differences in soil moisture distribution along the slope of the land had no significant ($P < 0.05$) effect on the towing force and the drawbar pull of the tractor. However, differences in soil moisture levels had significant effect on both.

Application of Trafficability Prediction Equations

In order to apply the trafficability prediction equations, the parameters: towing force (TF), tyre load (W), cone index (CI), soil-wheel numeric (Cn), tyre width (b), tyre diameter (d), tyre slip (S) and drawbar pull contained in the equations were computed as shown in Table 4; which is the summary of average values for days 1 to 13, of machine and soil parameters determined. The tyre width (b), diameter (d) and load (w) were measured and their values given as constants in Table 4 as follows:

Tyre width	b = 0.43m
Tyre diameter	d = 1.48
Tyre load	w = 2725

From Table 4, the regression analyses for TF/W vs 1/Cn and (P/W+TF/W) vs.CnS were carried out and equations 3 and 4 were established i.e. the constants in the equations were established for the soil under consideration.

$$\frac{TF}{W} = 1.21 - \frac{5.23}{Cn} \qquad (3)$$

$$\frac{P}{W} = 2.24(1 - \ell^{-0.02CnS}) \qquad (4)$$

$$Cn = \frac{CIbd}{W} \qquad (5)$$

Discussion of Results

As already stated, results of this experimental work reveal that the loamy sand soil of Ilorin agro-ecological zone is tractable when the soil moisture content is 60.08% of field capacity or below. This implies that it is unsafe and uneconomical to embark on disc-ploughing operation on this type of soil when the soil moisture is already above the level stated. High soil moisture will lead to high loss of input or available energy from the tractor engine due to slip at the interface of tractive element (tyre in this case) and the soil. This may result in reduction of output energy (i.e. work available or drawbar pull) which makes it difficult or impossible to successfully carry out the desired field operation. In this case high tyre sinkage will be experienced; there will be high fuel consumption, given that other conditions such as depth of cut and speed of operation are constant. It will be discovered that more energy and time will be used to do less work which will eventually lead to overall low profit margin or total loss in a given farm business. This argument is in line with what Young et al.[15] had already stated, that output energy (work available or drawbar pull) is equal to input energy minus slip energy minus motion resistance. Culpin [16] had earlier reported that 15% slip on pneumatic tyres is hardly noticeable, and on heavy draft work (such as disc ploughing), this level often has to be accepted. Furthermore Onwualu [14] stated that tyre slip of about 10% can be accepted on our local soils, explaining that energy loss at such slip levels are always of negligible consequence. It is based on these, that tractability condition based on soil moisture vis- a vis tyre slip was established in this work. It was discovered through this experiment that acceptable slip limit which is fifteen percent occurs at 60.08% soil moisture. This means

that the soil is tractable at 60.08% of field capacity or below.
From Table 5, it can also be seen that the draught requirement during the peak dry season (days 8 - 12, all in the month of December), i.e. towards the end of dry season (when the soil moisture was very low) and the on set of rainy season (days 10 - 13 in the months of December, January and February), was appreciable. This implies that ploughing can be done on the particular soil even at the lowest soil moisture levels possible.

This finding is contrary to what was reported by other researchers such Hassan and Broughton [9], Babeir et al.[10]; stating that soil is not tractable above 80% soil moisture. Simalenga and Have [11] as well as Ahaneku and Onwualu [8] also reported that soil is not tractable above 95% of field capacity. This result is not surprising because field tractability is a function of soil type and soil moisture. Given the same soil type, experience has shown that soil properties still vary from one geographical zone to another, due to climate and other ecological factors; also the type of vegetative cover affects the reaction of the soil to tractive elements while carrying out any field operation. Therefore such variation is expected, and indeed justifies the essence of this work. Researchers can now predict with higher degree of certainty and assurance the tractability or non- tractability of similar types of soil in this agro-ecological zone for each day in the year using the soil moisture budget. This eventually will help in determining with higher level of accuracy, the suitable field workdays (SFW) within each year. As stated earlier, this, kind of information will be useful to Ministries of Agriculture, Equipment and Tractor Hiring Units- government and private, individual private farmers and other workers who depend on weather for successful execution of their jobs.
Also, after applying the prediction equations earlier developed by Wismer and Luth [12] for clay soil to suit the loamy sand soil of Ilorin agro-ecological zone; the constants established in the new equations obtained were found to vary significantly. This also is not surprising, owing to the same reasons as stated earlier, such as different soil-type in a different agro-ecological zone, different vegetative cover and others. Such empirical equations for analysis of off- road vehicle traction or trafficability is known to be site specific, hence the justification of this kind of work for our own zone here. Other factors that might have contributed to the difference are machine type and specifications, type of tillage operation and soil condition at the time of the operation.

4.CONCLUSION

This work has tried to establish tractability condition based on soil moisture for disc ploughing on the loamy sand soil of Ilorin agro-ecological zone.
Results of the field and laboratory work have shown that the soil is considered not tractable above 60.08% soil moisture level. This result can be used to predict suitable field workdays (SFW) using the soil moisture balance equation. Subsequently, such data can be useful in machinery management and planning as well as to other weather dependent workers.

5.RECOMMENDATION

This work could be expanded to include other types of tillage operations such as harrowing, ridging etc and perhaps using more than one type of tractor for pulling the implement and for different soil types.
If this is achieved, such results and data could now be collated and compared, and tractability conditions for tillage operations for different agro-ecological zones could now be compiled as a standard reference, as it is done in developed countries like United States of America.

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APPENDIX

Table 1: Average Values for Tractability Condition

Day	Soil Moisture (% of Field Capacity)	Slip (%)
1	91.74	21.32
2	88.13	18.90
3	68.04	17.55
4	87.99	18.18
5	67.25	16.70
6	35.12	9.78
7	22.77	9.54
8	18.26	9.52
9	10.66	9.46
10	10.89	9.46
11	20.46	9.53
12	16.25	9.49
13	8.90	9.31

Table 2: ANOVA Table for Drawbar Pull

Source of variation	d.f	s.s	m.s	f.cal	f.tab(5%)
CFM		411.81			
Block effect	2	0.4975	0.2488	1.1653	3.74$^{N.S}$
Treatment effect	7	7.3395	1.0485	4.9110	2.85*
Error	14	2.9892	0.2135		
Total	23	10.8262			

N.S. = Not significant at the chosen alpha level (i.e.5% alpha level).
* = Significant at the chosen alpha level

Table 3: ANOVA Table for Towing Force

Source of variation	d.f	s.s	m.s	f.cal	f.tab(5%)
CFM		117.0417			
Block effect	2	0.0258	0.0129	1.50	3.74$^{N.S}$
Treatment effect	7	14.0916	2.0131	234.08	2.85*
Error	14	0.1209	0.0086		
Total	23	14.2383			

N.s = Not significant at the chosen alpha level (i.e.5% alpha level).
* = Significant at the chosen alpha level.

Table 4: Summary of Average Values of Machine and Soil Parameters Determined for Days of Field Operation

Day	TF (N)	TF/W	CI(N)	$Cn=\frac{CIbd}{W}$	$\frac{I}{Cn}$	S	CnS	P	$\frac{P}{W}$	$\frac{P}{W}+\frac{H}{W}$
1	2768.7627	1.0161	228.2209	0.0533	18.7617	21.32	1.1364	3207.9107	1/1772	2.1933
2	2700.8114	0.9911	220.2521	0.0514	19.4552	18.90	0.9715	3208.9249	1.1776	2.1687
3	2802.2312	1.0283	272.0491	0.0635	15.7480	17.55	1.1144	3411.7647	1.2520	2.2803
4	2633.8742	0.9666	205.3771	0.0480	20.8333	18.18	0.8726	3410.7505	1.2516	2.2182
5	2363.0832	0.8672	150.0854	0.0350	28.5714	16.70	0.6363	3952.3327	1.4504	2.3176
6	1146.0446	0.4206	517.7526	0.1209	8.2713	9.78	1.1824	4256.3923	1.5620	1.9826
7	1078.0933	0.3956	541.6600	0.1265	7.9051	9.54	1.2068	4594,3205	1.6860	2.0816
8	1078.0933	0.3956	697.0497	0.1628	6.1425	9.52	1.5500	4695.7404	1.7232	2.1188
9	1011.1562	0.3711	697.0497	0.1628	6.1425	9.46	1.5401	4965.5172	1.8222	2.1933
10	1011.1562	0.3711	697.0497	0.1628	6.1425	9.46	1.5401	5000.0000	1.8349	2.2060
11	1044.6247	0.3833	697.0497	0.1628	6.1425	9.53	1.5515	4932.0487	1.8099	2.1932
12	1044.6247	0.3833	697.0497	0.1628	6.1425	9.49	1.5450	5202.8398	1.9093	2.2926
13	1044.6247	0.3833	697.0497	0.1628	6.1425	9.31	1.5157	5030.6122	1.8461	2.2294

Table 5: Drawbar-pull Determined During Ploughing for each Day of Field Operation

Average Dynamometer Readings (kN)				
Day	Implement Disengaged	Implement Engaged	Difference (Drawbar-pull)	Drawbar-pull Force (N)
1 (25-09-2003)	0.2900	0.6233	0.3333	3207.9107
2 (30-09-2003)	0.2833	0.6167	0.3334	3208.9249
3 (07-10-2003)	0.2933	0.6467	0.3534	3411.7647
4 (09-10-2003)	0.2767	0.6300	0.3533	3410.7505
5 (15-10-2003)	0.2500	0.6567	0.4067	3952.3327
6 (6-11-2003)	0.1300	0.5667	0.4367	4256.5923
7 (27-11-2003)	0.1233	0.5933	0.4700	4594.3205
8 (04-12-2003)	0.1233	0.6033	0.4800	4695.7404
9 (11-12-2003)	0.1167	0.6233	0.5066	4965.5172
10 (18-12-2003)	0.1167	0.6267	0.5100	5000.0000
11 (29-12-2003)	0.1200	0.6233	0.5033	4932.0487
12 (15-01-2004)	0.1200	0.6500	0.5300	5202.8398
13 (09-02-2004)	0.1200	0.6300	0.5100	5000.0000