Draught and Soil Disturbance of Model Tillage Tines Under Varying Soil Parameters

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ABSTRACT

Soil bin investigations were carried out to study the influence of some soil parameters namely: moisture content and cone index, on draught force and soil disturbance of model tillage tools. The tools were tines in the groups of very narrow tines, narrow tines and wide tines. The soil under study was a sandy clay loam. It was observed that draught increased at a decreasing rate as the soil moisture content increased from 11 to 22.5% (db). Polynomial regression models best described the relationships with high R^2 (coefficient of determination) values. Soil disturbance parameters: ridge-to-ridge distance, width of crescent or width of furrow at the surface, total disturbed width, height of ridge, and furrow depth were determined. Tine draught increased at an increasing rate as compaction increased for a cone index in the range of 150 to 800 kPa with polynomial regression equations best describing the relationships. The models generated in this study were suitable for predictive purposes.

Keywords: Soil parameters, draught, regression models, tines, soil disturbance, soil moisture, bulk density.

1. INTRODUCTION

The specialized area of soil tillage dynamics research is taking a new positive dimension in Nigeria as researchers now develop soil bin facilities for model studies of soil engaging implements and tractive devices. This has become necessary in view of global trends, emerging technologies and ideas for curriculum modification of agricultural engineering programmes to produce better, more competent, and self-reliant graduates (Singh, 2000; Henry et al., 2000; Cortez et al., 2001; Senzanje, 2003; Setiawan et al., 2006).

It has also been reported that the intensity of mechanization of farming operations in Nigeria is still very low (Jekayinfa, 2006) and that the volume of tractors and implements in Nigeria is not commensurate with the work done by the machines on Nigerian farms due to frequent breakdown and lack of spare parts (Mijinyawa. and Kisaiku, 2006). These problems have been traced to lack of relevant data for the appropriate design of agricultural machines and implements and unsuitability of some imported machinery. It is hoped that through appropriate research in the specialized area of soil tillage dynamics some of the problems would be solved. This study is part of an attempt in the problem-solving scheme.

Draught is an important parameter for measuring and evaluating implement performance for energy requirements. It has been investigated by various researchers (Oni et al., 1992; Shirin et al., 1993; Fielke, 1996; Kushwaha and Linke, 1996; McKyes and Maswaure, 1997; Onwualu and Watts, 1998; Al-Suhaibani and Al-Janobi,1997; Manian et al., 2000; Shrestha et al., 2001; Gratton et al., 2003; McLaughlin and Campbell, 2004; Mamman and Oni, 2005). Natsis et al. (2002) used tillage force dynamometer to measure draught of mouldboard plough in a clay soil.

The specific draught of agricultural tools and implements varies widely under different conditions, being affected by such factors as the soil type and condition, ploughing speed, plough type, shape, friction characteristics of the soil-engaging surfaces, share sharpness, and shape, depth of ploughing, width of furrow slice, type of attachments, and adjustment of the tool and attachments. A great deal of work has been done in evaluating these various factors and investigating possible means for reducing draught. Mathematical methods and models have been developed by researchers for predicting draught (Reece, 1965; Stafford, 1984). Soil type and condition are by far the most important factors contributing to variations in specific draught.

Soil moisture content is an important factor in regard to both draught and quality of work. A dry soil requires an excessive power and also accelerates wear of the cutting edges. In USDA soil bin tests, an increase of moisture content from 9.1 to 11.7% (db) reduced the specific draught in a fine sandy loam by 15 to 35% (Gill and Vanden Berg, 1968). Other pertinent factors include the degree of soil compaction, the previous tillage treatments and the type, presence or absence of cover crop. For example, Gill and Van den Berg (1968) reported a 15 to 35% increase in draught when the bulk density of a fine sandy loam was changed from 1680 kg/m^3 to 1830 kg/m^3

Ademosun (1990) reported that draught decreased linearly with increasing soil moisture content within the range of 12 to 16% (wb) in a sandy loam soil. Gupta and Surendranath (1989) reported that draught increased with moisture content gradually at lower moisture contents of about 6.9%(db) until it reached 18.9%. Upon increasing the moisture content further, a steep rise in draught was observed in Bangkok clay. This according to them may be explained by the increased cohesion at higher moisture contents requiring greater force for failure.

Koolen and Kuipers (1983) reported a general formula for specific draught (D) as:

$$D = C_1 - C_2MC + C_3\,(MC)^2$$

where, MC is moisture Content. C_1, C_2, C_3 are positive constants. This is the formula of a parabola with its vertex being a minimum value. The soil moisture content at this minimum is called optimum moisture content.

Studies continue to be conducted to measure draught and energy requirements of tillage implements under various soil conditions in the developed nations of the world in Asia, America and Europe. Mathematical models have been developed to predict draught of some tillage tools. ASAE standards (1990) provide mathematical expressions of draught and power requirements for tillage tools in several soil types. Kydd et al. (1984) developed draught equations for tillage implements and found that variations in climatic conditions, soil moisture, soil hardness, and soil type made it difficult to obtain repeatable draught data. Bowers (1985) developed a computer programme using tillage data to calculate implement power requirements. He conceded that thorough reporting of soil conditions, implement description and draught requirement was necessary to obtain useful results. Boston and Rackham (1981) found no mathematical model that predicts draught of tillage tools accurately.

Gill and Vanden Berg (1968) reported that draught requirements of a tillage implement depend on soil type and conditions, manner of tool's movement and tool shape. It is a function of implement width, operating depth and the operating speed at which it is pulled (Upadhyaya et al., 1984).

Harrigan and Rotz (1994) proposed a simple function for a range of soil conditions to model tillage draught under general conditions, where draught per unit width or cross-sectional area of the tilled zone is a function of soil type and the operating speed at which the implement is pulled. It has been reported that the draught force of a tillage implement increases with increasing bulk density (Mouazen and Ramon, 2002). This holds true because the soil strength usually increases with increasing bulk density (Horn, 1993).

All the draught data presented in the ASAE Standards (1994) and the data presented by Harrigan and Rotz (1994) were based mostly on USA soils. Presently there are very few published data available on draught requirements of agricultural implements operating in soils of Nigeria. It is not that Nigerian soils are different from soils of other countries but that research in this area of soil tillage dynamics is also necessary in order to advance the frontiers of knowledge.

The objectives of this study were to measure the draught requirements of three tillage tines under varying conditions of soil moisture content and penetration resistance (cone index) and to measure and evaluate soil disturbance parameters that arose from the experiments.

2. MATERIALS AND METHODS

The study was conducted in the Soil Tillage Dynamics Research Laboratory of the Department of Agricultural Engineering of the Federal University of Technology, Akure, Nigeria.

The soil studied was a sandy clay loam soil according to the USDA textural classification of soils. It was one of the prominent soils of Ondo State, Nigeria. The soil was taken from one of the fallow agricultural lands of the commercial farm of the Federal University of Technology, Akure, Nigeria, 7^0 15^1N, 5^0 15^1E, and elevation 210m. The soil was Oxic paleustalf (Alfisol) or ferric Luvisol (FAO). The site was recovered from three years of bush fallow. The soil was dug to expose the profile. Three layers EBS1, EBS2, EBS3, from top to bottom of the profile were recognized and sufficient quantities were taken from each layer for

the soil bin tests. The thickness of the three layers in the profile from top to bottom was 8, 15 and 15cm respectively.
Particle size analysis was determined by hydrometer method (Bouyoucos, 1962) in air-dried 2 mm sieved soil samples of the different layers. Chemical properties of the soil were determined following the description of Carter (1993). Soil organic C was determined using the dichromate wet oxidation method (Nelson and Sommers, 1982), total N was evaluated by the micro-Kjeldahl digestion method (Bremner, 1965), available P was extracted using Bray-1 solution and determined by molybdenum blue colorimetry (Bray and Kurtz, 1945). Exchangeable K, Ca and Mg were extracted using ammonium acetate. Potassium was determined using a flame photometer and Ca and Mg by the EDTA titration method (Jackson, 1962).

Preliminary tests conducted showed that the properties of the three layers of the soil were not significantly different from each other at 5% level of significance. A mixture of the three layers (equal proportions by weight) was used to determine the mechanical properties of the soil. The mechanical properties determined were cohesion, angle of internal friction, adhesion, angle of soil/metal friction and cone index. Angle of internal friction and cohesion were obtained using the direct shear method. Soil/metal friction angle and adhesion were measured using a metal slider and spring balance. Soil penetration resistance (cone index) was determined using a recording penetrometer (model CP 20 ultrasonic, AGRIDRY RIMIK PTY LTD, TOOWOOMBA), with a standard 30^0 cone of 322-mm^2 base area. The penetration rate was less than 10 mm/s. Core soil samplers were used to measuring soil bulk density and moisture content. All the above soil property determination tests were replicated three times.

The experimental soil was placed inside the bin according to the profile in the field. This arrangement was just to conform with the natural arrangement or profile of the soil from the field where it was dug and brought to the soil bin

The equipment consisted of an indoor soil bin of 9.0 m length, 0.85 m width and 0.45 m depth; a soil processing trolley with a compaction roller, a tool carriage, a power transmission system with a 3.1kW electric motor as prime mover, a tool mounting frame, a tool vertical and angle adjustment device, a profile meter for measuring soil disturbance parameters, and a spring dynamometer (load cell) for measuring draught. An overview of the soil tillage dynamic equipment is shown in Figure 1, with the full details presented in Manuwa (2002). The soil processing trolley with a compaction roller was used for leveling and compacting the soil to the required bulk density or penetration resistance (cone index) as desired for each test run. The soil was compacted in 50 mm deep layers by subjecting them to a given number (ranging from 3 to 7) of passes of the roller, similar to that reported by Godwin et al.(1980). To ensure satisfactory bond between successive layers, the surface of each freshly compacted layer was scored to a depth of 10 mm using narrow tines before placing the next layer.

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Following a test, the soil (according to the profile) was removed from the test section of the soil bin into the holding section, using a winched blade. It was possible to keep the soil profile arrangement because the different layers were quite distinct in colour to separate them. Bulk density was kept constant when the moisture content was varied. However, bulk density varied when cone index was varied.

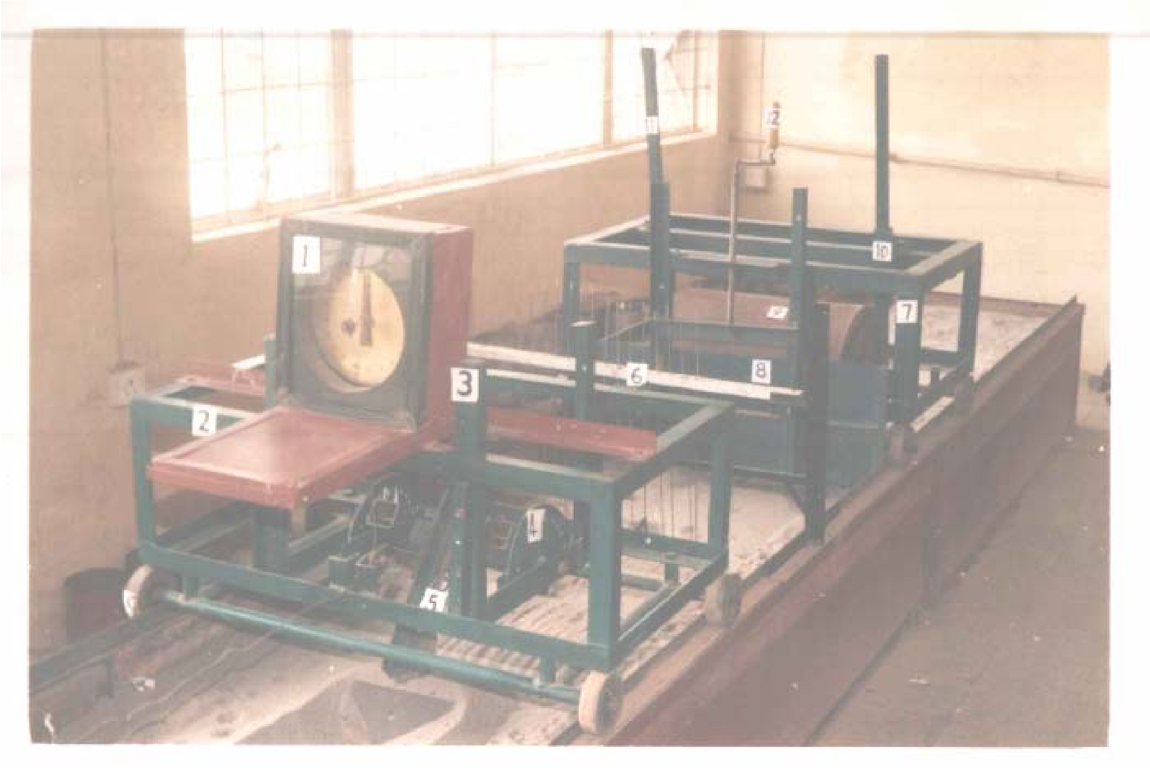

Figure 1. An overview of the soil tillage dynamics equipment used in the study
1, load meter; 2, tool carriage; 3, tool vertical adjustment device; 4, tool angle measuring plate; 5, tool bar; 6,profilemeter; 7, soil processing trolley frame; 8, soil leveler; 9, compaction roller; 10, roller vertical adjustment device; 11 vertical adjustment pipe; 12, winding handle.

Other items of equipment that were used in this study include three different model tillage tines. The tines were rectangular in cross-section and the widths were 1.0 cm (T1), 5.1 cm (T5) and 20.0 cm (T20). They were classified as very narrow tine, narrow tine and wide tine respectively. The thickness of the tines was 8 mm. They were made from mild steel, each with a bevel angle of 15^0.

2.1 Effect of Variation in Moisture Content on Draught
2.2

Under this experiment, there were two treatments with three replications, while mean values of draft were recorded. First, the rake angle and depth were held constant at 45^0 and 150 mm respectively and speed at 1.0m/s. In the second treatment, rake angle, depth and speed were held constant at 90^0, 150 mm and 1.0 m/s respectively, and the cone index was held constant at a mean of 400 kPa. Moisture content varied from 6.0 to 17.5% (db). This range of moisture content was in the moist or friable consistency, typical of when tillage operations in loamy soils are undertaken in Nigeria. Soil uniformity throughout the tests was monitored using the cone penetrometer and direct soil sampling.

2.3 Effect of Variation in Cone Index on Draught
2.4

Under this set of experiments, there were two treatments also with three replications: when rake angle, speed and depth were fixed at 45^0, 1.0 m/s and 150 mm respectively. The other treatment when the rake angle, speed and depth were fixed as 90^0, 1.0 m/s and 150mm respectively. Here the moisture content was maintained constant at about 11.5 % (d.b).

2.3 Measurement of Soil Disturbance

The tine was stopped while still engaging with the soil to examine soil failure pattern and soil disturbance ahead of the tine and also behind it. In some cases the cross-section of the disturbed soil was carefully excavated, leaving undisturbed boundary. The disturbance was recorded by laying a steel rule across the disturbance and measuring the vertical distances from the rule to the disturbed boundary. Alternatively a profile meter was used.

2.3.1 Soil Disturbance Parameters

The soil disturbance generated from the operation of the model tillage tines was observed, assessed and analyzed. From knowledge of the soil disturbance and the draught, the specific draught was also determined.

For the purpose of analysis, the general form of soil disturbance was quantified by the parameters shown in Figure 2. The parameters of the soil disturbance include: maximum width of soil throw (TDW); maximum width of soil cut (Wfs); this is also known as width of crescent; the ridge – to – ridge distance (RRD); the height of the ridge (h_r); after plough furrow depth (d_f) and the tool width (W).

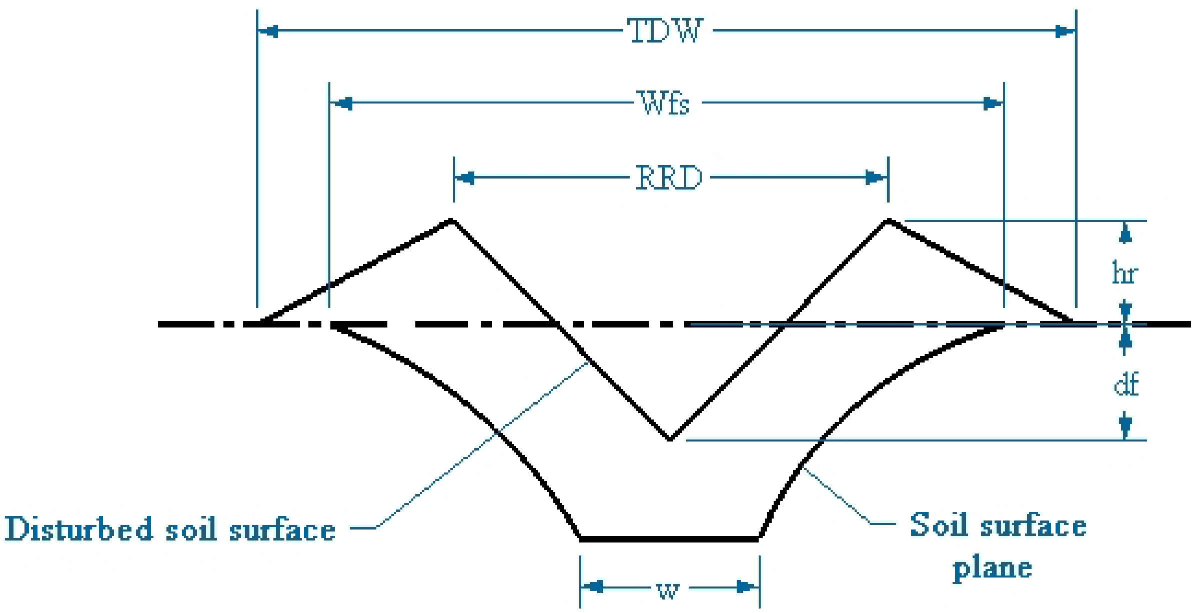

Figure 2. Parameters used to define soil disturbance of a single tine

Another parameter of the soil disturbance measured but not shown in the Figure 2 is rupture distance, (f), defined as the distance ahead of the tine at which the distinct shear plane broke the surface (Godwin and Spoor, 1977). These parameters have been used to assess soil disturbance of tillage implements by researchers (Willat and Willis, 1965; Godwin and Spoor, 1977; Spoor and Godwin, 1978; Spoor and Fry, 1983; Wheeler and Godwin, 1996; Taniguchi et al., 1999).

2.5 Data Analysis

2.6

After the soil bin experiments were carried out, a statistical analysis based on a completely randomized design (CRD) with a factorial treatment design of 2x3x3 to investigate the interactions between rake angles and tool types was carried out in Excel programme. Analysis of Variance (ANOVA) tests were carried to investigate the interaction between tools and rake angles to study their significant effect. In this analysis, the soils were assumed to be the same since they were carried from the same pit and have the same texture.

Regression analysis was also carried out to fit appropriate models for the relationships between draft, moisture content and cone index.

3. RESULTS AND DISCUSSION

Tables 1 (a), 1 (b) and 1(c) show the physical, chemical and mechanical properties of the soils. Soil samples EBS1 and EBS2 seem to be very much the same but yet they are different physically especially in colour which may be due to the more presence of dead organic material in the EBS1 than in the EBS2.

Table 1(a) Physical properties of the experimental soils

Soil Type	Texture Sand %	silt %	clay %	Bulk density Mg/m^3	Sat hyd cond mm/min	Clay ratio	Clay + silt	LOI	Colour
Sandy clay loam (EBS1)	54	21	25	1.43	1.21	33.3	46	3.98	dark brown
Sandy clay loam (EBS2)	54	21	25	1.55	1.22	33.3	46	3.12	brown
Sandy clay loam (EBS3)	52	17	31	1.39	0.85	44.9	48	3.58	brownish red

Table 1(b) Chemical properties of the experimental soils

Soil Type	pH	Chemical composition				O/C % w/w	N % w/w	P (ppm)	CEC Mg/100g
		Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}				
Sandy clay loam (EBS1)	6.12	1.90	0.80	0.11	0.08	1.41	0.14	2.54	3.98
Sandy clay loam (EBS2)	6.13	1.30	1.00	0.08	0.07	1.22	0.15	1.70	3.12
Sandy clay loam (EBS3)	6.56	1.00	1.00	0.05	0.07	0.87	0.13	0.85	3.53

Table 1(c) Mechanical properties of the experimental soils

MC %(db)	BD Kg/m^3	Cohesion (kPa)	Angle of internal friction (degree)	Adhesion (kPa)	Angle of soil/metal friction (degree)	Cone index kPa	
						75 mm depth	150 depth
6.0	1500	12.1	30.2	0.18	22.3	575	580
11.5	1520	13.3	29.6	O.21	23.6	690	725
17.5	1560	24.5	36.5	0.29	24.7	785	800
20.0	1530	22.6	34.5	0.35	23.1	720	745
22.5	1490	20.5	32.2	0.31	24.0	630	650

MC = moisture content BD = bulk density

3.1 Effect of Moisture Content on Draught of Tillage Tines

The variation of draught force, D with increase in moisture content, MC of the tillage tines is presented in Figures 3 and 4. A quadratic regression model best fitted the relationships. These agree with Koolen and Kuipers (1983) quadratic model.

$$D = a_1MC^2 + b_1MC + k_1 \qquad (1)$$

where,
a_1, b_1 and k_1 are regression coefficients and a constant, respectively.

Figures 3 and 4 show that the draught force increased with increasing moisture content. This is in agreement with the findings of Gupta and Surendranath (1989) for a clay soil. However the rate of increase decreased as the moisture content increased. This could be explained by the cohesion of the soil that was weakened by increased moisture content. The decrease in draught with moisture content reported by Ademosun (1990) for a sandy loam soil, occurred in the region where the maximum cohesion of the soil had been overcome by water molecules.

The quadratic models that described the relationship shown in Figure 3 for a 45° rake angle are:

D_{T1} = $- 0.3300MC^2 + 24.82MC - 142.05$ ($R^2 = 0.991$) (2)

D_{T5} = $- 0.9444MC^2 + 49.15MC - 157.35$ ($R^2 = 0.9986$) (3)

D_{T20} = $- 1.1376MC^2 + 56.27MC - 37.61$ ($R^2 = 0.9909$) (4)

Where, D_{T1}, D_{T5}, D_{T20} are draughts of the corresponding tines T1, T5, T20 and R^2 is coefficients of determination.

It was observed that draught was higher for the 90^0 rake angle than for 45^0 rake angle. This is in agreement with the observation reported by Spoor (1969). The quadratic models that describe the relationships shown in Figure 4 for the 90°rake angle are:

DT1 = $- 1.605MC^2 + 63.71MC + 342.61$ ($R^2 = 0.9853$) (5)

DT5 = $-.2.175MC^2 + 85.64MC - 221.19$ ($R^2 = 0.9883$) (6)

DT20 = $- 2.221MC^2 + 89.29MC + 21.76$ ($R^2 = 0.9912$) (7)

The high R^2 values would make the models suitable for prediction under similar soil conditions.

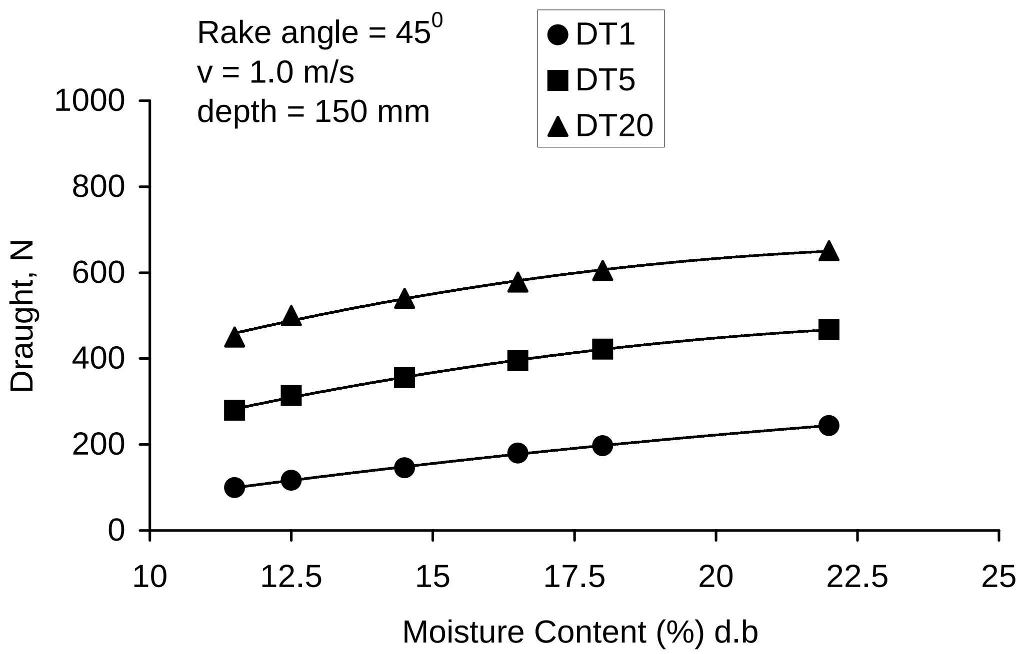

Figure 3. Effect of moisture content on draught

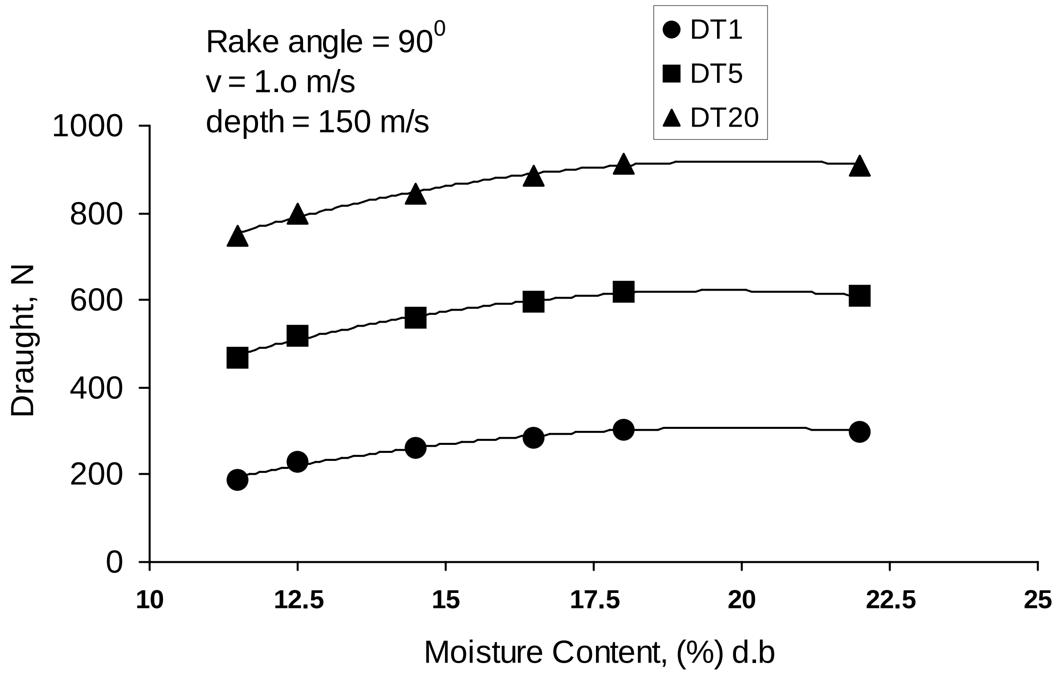

Figure 4. Effect of moisture content on draught

3.2 Effect of Moisture Content on Soil Disturbance

The effect of soil moisture content on soil disturbance is presented in Table 2 for a 90^0 rake angle tool, 150 mm operating depth and 1.0 m/s forward speed. There was no general common trend between the parameters. Certain parameters; after plough furrow depth, height of ridge and soil rupture distance increased with increase in moisture content. However, the maximum width of soil cut, maximum width of soil throw, and ridge-to-ridge distance decreased with increase in moisture content. With all the tines and different rake angles, the undisturbed soil face was roughly trapezoidal, similar to findings reported by Willat and Willis (1965) compare Figure 2.Observation of the shape of the loose surface after the passage of a tine showed that loose soil is thrown further to the side. The maximum width of soil throw decreased with increase in moisture content but increased with tine width. The explanation being that the soil particles or aggregates were heavier and tightly held by cohesive forces within and therefore would not flow or move like when they had lesser water content.

Draught increased with increase in moisture content as the cohesion of the soil increased with moisture content (Gupta and Surendranath, 1989). Draught also increased with tine width but less than proportionately, similar to the findings of McKyes and Maswaure (1997).

Table 2:Effect of moisture content on soil disturbance parameters for 90^0 rake angle, 150 mm depth and 1.0 m/s speed

Parameters of Soil Disturbance (cm)	**T1**			**T5**			**T20**		
	Moisture Content (%)			Moisture Content (%)			Moisture Content (%)		
	6.0	11.5	17.5	6.0	11.5	17.5	6.0	11.5	17.5
RRD	11.4	9	8	19	16.5	15.5	30.5	30	29
Wfs	12	10.5	9.5	22.5	19.5	18	32.5	31.5	30.5
TDW	14.5	12	10.5	25.5	23	20.5	35	33.5	32
d_f	5.5	6.5	7.0	6.5	7.2	7.8	4.0	4.5	5.5
h_r	2.0	3.5	4.4	3.5	5.5	6.5	5.0	6.0	6.5
f	8	9	10	16.5	18.5	20	18.5	20	22
Draught, N	150	180	210	450	510	563	1005	1160	1125
*Specific Draught, N/cm	12.5	17.1	22.1	20	26.8	31.3	36.2	36.8	36.9
$\alpha = 90^0$ depth =150 mm				v = 1.0 m/s			CI = 400 kPa		

∗ Specific draught = Draught / disturbed width

3.3 Effect of Soil Compaction on Draught of Tillage Tines

The range of cone index (200-800 kPa) in this study compared favourably with that reported by Isaac et al. (2002), that is 560-1360kPa and a mean of 940 kPa observed in the field.

The variation of draught force, D with increase in cone index (CI) of the model tillage tines is presented in Figures 5 and 6. The regression model that best described the relationships was a quadratic model of the form:

$$D = a_2CI^2 + b_2CI + k_2 \quad (8)$$

where

A_2, b_2 and k_2 are regression coefficients and constants respectively.

Figures 5 and 6 show that draught increased at an increasing rate as the cone index increased from about 200 to 850 kPa.This is in agreement with the findings (Horn, 1993; Mouazen, and Ramon, 2002). This is because the soil strength (cohesion) increased with increased cone index.

It was also evident that draught was substantially greater for 90^0 rake angle than a 45^0 for the same conditions of cone index, depth and speed of operation. The models developed for the relationship in Figure 5 where rake angle, speed and depth are 45^0, 1.0 m/s and 150 mm respectively were:

$$D_{T1} = 0.0012CI^2 - 0.791CI + 157.5 \quad (R^2 = 0.9987) \quad (9)$$

$$D_{T5} = 0.0011CI^2 - 0{:}616CI + 253.8 \quad (R^2 = 0.9982) \quad (10)$$

$$D_{T20} = 0.0013CI^2 - 0.586CI + 379.1 \quad (R^2 = 0.9985) \quad (11)$$

Similarly the quadratic models representing the relationship in Figure 6 when rake angle, speed and depth were 90^0, 1.0 m/s and 150 mm respectively were:

$$D_{T1} = 0.0008CI^2 - 0.477CI + 211.7 \quad (R^2 = 0.9989) \quad (12)$$

$$D_{T5} = 0.0009CI^2 - 0.505CI + 487.8 \quad (R^2 = 0.9991) \quad (13)$$

$$D_{T20} = 0.0013C1^2 - 0.753CI + 763.6 \quad (R^2 = 0.9996) \quad (14)$$

The very high values of R^2 would make these models suitable for predictive purposes, in the range of soil conditions considered. It was also observed that specific draught increased with an increase in cone index. The range was 13.4 to 24.4 N/cm for T1, 28.5 to 30.57 N/cm for T5 and 33.20 to 36.3 N/cm for T20 when the cone index varied from 200 to 800 kPa, and moisture content, 11.5% (db); depth, 150 mm; rake angle, 90^0 and speed, 1.0 m/s.

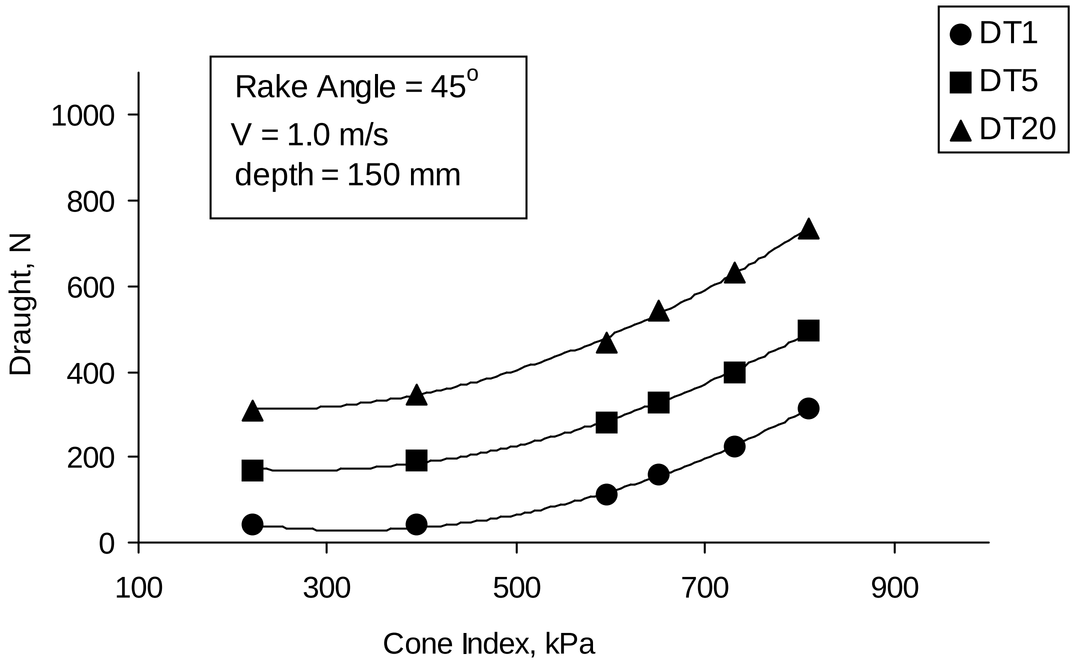

Figure 5 : Effect of cone index on draught

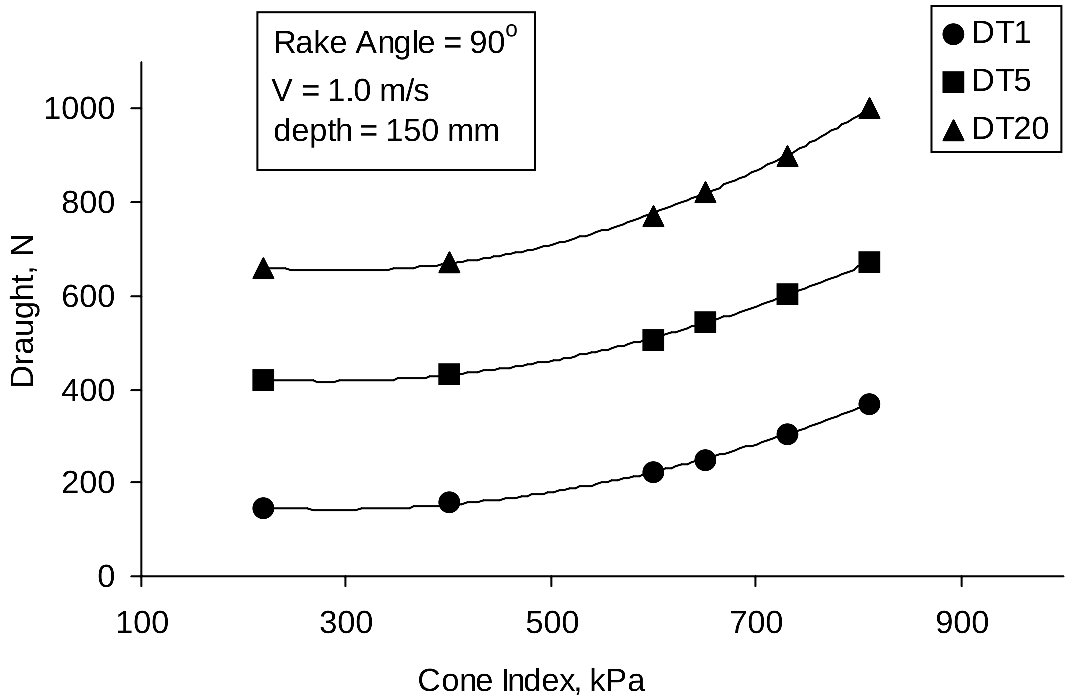

Figure 6 : Effect of cone index on draught

3.4 Effect of Compaction on Soil Disturbance

Effect of soil compaction on soil disturbance for 90^0 rake angle is presented in Table 3. As the cone index increased in value the soil disturbance parameters values also increased.
All the soil disturbance parameters identified in this study, except height of ridge increased as cone index increased, for all the tines. This is because the strength or mechanical properties of the soil such as cohesion, angle of internal friction, bulk density increased as the cone index. The increase however was less proportionate. On the average, the rate of increase decreased with increase in tine width.

Table 3: Effect of cone index on soil disturbance parameters for 90^0 rake angle, 150 mm depth and 1.0 m/s speed

Parameters of Soil Disturbance (cm)	T1			T5			T20		
	Cone index (kPa)			Cone index (kPa)			Cone index (kPa)		
	200	400	800	200	400	800	200	400	800
RRD	9	9.5	11	11.5	13.5	18	24	29	32
Wfs	9.5	10	12	18	20	21	25	32	33
TDW	11	12.5	14	22	27.5	29	30	43.5	46
d_f	6	7.5	8	4	5.5	7	2	3.5	5
h_r	2	1.5	0.5	4	3.5	2.0	3.5	3.0	2.0
f	9	11	12	17	18	19.5	21	23	27
Draught, N	127	160	290	515	580	640	825	1100	1200
Specific Draught, N/cm	13.4	16.0	24.5	28.5	29.0	30.5	33.2	34.5	36.3
$\alpha = 90^0$	V = 1.0 m/s								
d = 150 mm	mc = 11.5 (% db)			f = rupture distance					

3.5. Analysis of variance tests

The results of analysis of variance tests are presented in Table 4.The sources of variation were tool, rake angle of tool and interaction. Results showed that tool type and rake affected the draught of the tines significantly at 5 % level of probability ($p< 0.05$). The interaction between the two factors was also statistically significant at 5 % level of probability ($p< 0.05$).

Table 4. Analysis of variance for model tines draught

Source of variation	SS	DF	MS	F-ratio	F crit	P-value
Tool	681213	2	340606.5	843.31	3.88	< 0.001
Rake angle	172872	1	172872	428.02	4.74	< 0.001
Interaction	28102.33	2	14051.2	34.78	3.88	< 0.001
Error	8846.67	12	403.88			
Total	887034	17				

SS = Sum of squares; MS = Mean square; DF = Degree of freedom

4. CONCLUSIONS

In all the treatments, a significant increase in draught force was observed for all the three tillage tines. Draught force was significantly affected by moisture content and penetration resistance of the soil (or cone index). Draught force increased quadratically with a decreasing rate with moisture content. On the other hand draught force increased quadratically at an increasing rate with cone index. Analysis of variance (ANOVA) of the data collected showed that tool type and rake angle have significant effect ($p < 0.05$) on draught. Similarly the interaction between tool type and rake angle was significant ($p< 0.05$). The very high values of coefficient of determination would make the models suitable for predictive purposes.

5. ACKNOWLEDGEMENT

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