SOIL BIN INVESTIGATIONS OF THE EFFECTS OF TILLAGE TOOL WIDTH ON DRAUGHT AND SOIL DISTURBANCE PARAMETERS IN SANDY CLAY LOAM SOIL

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ABSTRACT Published data are scarce on soil bin investigations of tillage tools in the design of soil engaging implements in Nigeria. The major objective of this study was to investigate the effects of tool width on draught and soil disturbance of tillage tools (tines), with a view to generating relevant data in the design of soil engaging implements and soil/tool interaction. Experiments were conducted in an indoor soil bin filled with sandy clay loam soil at average moisture content of 11.5 % (dry basis). The implements used in these tests were tillage tines. Tests were carried out to study the effect of variation in tool width on soil disturbance and draught. In each of the two sets of tests, depth was held constant at 35 mm and then at 70 mm. Speed was varied at three levels, V1, V2 and V3, corresponding to 1.0, 3.6 and 9.0 km/h respectively. The widths of the tines tested were 10, 20, 31, 40, 51, 88, 126, 163 and 200 mm. The penetration resistance (cone index) of the experimental soil varied from 400 to 600 kPa. Tools draught was measured with a load cell while soil disturbance was also observed and measured by means of a profile meter and meter rule. Draught increased at a decreasing rate with tine width Quadratic models best fit the data points with very high R² values. The increase in draught was also affected by the forward speed since higher draught values were obtained at higher speed. Soil disturbance was evaluated by the parameters: maximum width of cut (Wfs), maximum width of soil throw (TDW), rupture distance (f), ridge-to-ridge distance (RRD), height of ridge (hr), and after plough depth (df), and width of tool (w). The results show that the parameter of soil disturbance increased with increase in tine width, except height of ridge (hr), which did not show any specific trend. The specific draught was highest with tine T20 (10.63 N/cm), followed by tine T10, and then T5. Tine T1 has the least specific draught of 5.2 N/cm. The limit and nature of soil disturbance at the incipient of failure (length and width of crescent) was also evaluated and reported.

Keywords: Soil bin, tillage tines, draught, soil disturbance parameters, rake angle, forward speed, regression analysis
INTRODUCTION
Draught is an important parameter for measuring and evaluating implement performance for energy requirements. Some researchers investigated draught of tillage tools (Fielke, 1996; Kushwaha and Linke, 1996; McKyes and Maswaure, 1997; Onwualu and Watts, 1998; Al-Suhaibani and Al-Janobi, 1997; McLaughlin and Campbell, 2004). 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.

Soil profile or soil redistribution after tillage operation is important in several aspects such as incorporating manure and crop residues and protecting soil from wind and water erosion (Liu and Kushwaha, 2006). They also reported that the study of soil profile and soil redistribution by tillage has progressed slowly due to complexity, which involves many factors such as soil types and properties, types of tillage tools and their operational parameters. It was reported Dowell et al (1988) in a study with sweeps that the ridge height and the lateral distance, increased with increasing travel speed. Hanna et al. (1993) reported that higher speed and larger rate angle of sweep resulted in more soil movement creating higher ridges. Also, Sharifat and Kushwaha (1999) studied soil lateral movement under different soil conditions with a sweep and a furrow opener at speeds of 5 to 8 km/h and they concluded that different tools created different geometries of soil profiles; the parameters of soil profile were also affected by tillage speed, soil bulk density, and soil moisture content (Liu and Kushwaha, 2006). Soil disturbance parameters have been evaluated (Manuwa and Ademosun, 2007; Manuwa, 2009) in sandy clay loam soil in a soil bin experiment.

The objectives of this study were:
(i) to evaluate the effect of width on draught requirements of tillage tines and the soil disturbance parameters of the soil profile generated.
(ii) to model the parameters of soil disturbance.

2. MATERIALS AND METHODS

2.1 Experimental tines The tines were made from flat 8 mm plain carbon steel. They all have rectangular cross-section. The widths of the tines were 10, 20, 31, 40, 51, 88, 126, 163 and 200 mm. The bottom edge of each blade was beveled at an angle of 15° to provide a sharp cutting edge

2.2 Soil bin facility Experiments were conducted in the Soil Dynamics Laboratory of the Department of Agricultural Engineering, The Federal University of Technology, Akure, Nigeria. The equipment consists of an indoor soil bin as reported (Manuwa, 2002, Manuwa and Ademosun, 2007).

2.3 Soil description and properties The soil studied was a sandy clay loam soil (54 % sand, 21 % silt and 25 % clay) according to the USDA textural classification of soils. It was one of the prominent agricultural soils of the State. The soil was taken from the first 35 cm of the topsoil. Particle size analysis and other physical and chemical properties
were determined by standard methods. Dynamic properties including cohesion, adhesion, internal and external friction angles were determined through laboratory tests. Direct shear test method was used to measure these values of soil shear strength under same moisture and density conditions as applied in the soil bin experiments. These properties were reported in Manuwa (2009). Soil penetration resistance (cone index) was measured by using a Rimik penetrometer (model CP 20 ultrasonic, Agridy Rimik pty Ltd, Toowoomba, Australia). The penetrometer was comprised of an in-built data logger, an 500-mm long shank, a cone with a base area of 129 mm² and an apex angle of 30°. The penetrometer was pushed into the soil by hand at a speed of approximately 0-2 mm/s according to the ASAE standards.

2.4 Experimental procedure

2.4.1 Soil preparation and measurements The soil condition in the soil bin was maintained constant (11.5 % db) in a set of experiments and varied (6.0 to 17.5 % db) in another set of experiments. The cone index indicating the soil strength was kept constant at 400 kPa in the first set of experiments and varied 200 to 800 kPa in the other set of experiments. A compaction roller of the soil processing carriage and a penetrometer for random testing were used to ensure uniform soil condition throughout the test runs. In between runs, the soil bin was leveled and compacted using the soil processing carriage.

2.4.2 Test Procedure The tool, in each case, was attached to the tool bar on the tool mounted on the carriage and adjustment made to give the required rake angle and depth of operation. The carriage was then winched from the starting point end at specific speeds by operating the starting switch from the power unit. Data were collected and mean values of three replicates were used for computation and analysis. A profile meter similar to that described by Spoor and Godwin (1978) and meter scale were used to measure the soil-disturbed surface after each test. Soil disturbance parameters as defined (Manuwa and Ademosun, 2007; Manuwa, 2009) were observed and evaluated.

2.4.3 Soil Disturbance Data – Immediately after each run, the profilometer was placed in position and the vertical members adjusted to acquire the shape of the surface profile of the soil resulting from the tillage. Care was taken to ensure the two extreme points coincides with undisturbed soil surface, from this a datum from which measurements are taken was established. When the rods corresponding to the transect to be measured have been adjusted, the instrument is then carefully lifted from its stand and place on its side on a large graph sheet. The rod tip was then located on the graph sheet thus, tracing surface profile of the resulting soil disturbance. The soil disturbance parameters are illustrated in Fig. 1
2.4.4 Analysis of Data Experimental observation in each case was replicated thrice and the mean value was used in the analysis. Regression analysis using Excel 2003 package was used to perform the regression analysis (simple and multiple regression, including analysis of variance-ANOVA) and to draw the necessary charts and line plots.

3. RESULTS AND DISCUSSION The results and discussion are hereby presented in this section

3.1 Effect of width of tine on draught. Effect of dimension (width) of tool on draught is shown in figures 1 and 2. In figure 1, it was draught versus width of tine at constant depth, 35 mm while in figure 2, it was draught versus width of tine at constant depth, 70 mm. In these two figures (1 and 2), draught increased at a decreasing rate with tine width. The increase is also affected by the forward speed since higher draught values were obtained at higher speed. The forward speed V1, V2 and V3 were 0.28 m/s (1.0 km/h), 1.0 m/s (3.6 km/h), and 2.5 m/s (9.0 km/h). Quadratic model was best fit model to fit the data points with very high $R^2$ values (> 0.996). These relationship agree well with the work reported by Hettiaratchi and Reece (1974), O’ Callaghan and Farrelly (1964).
3.2 Effect of width of tine on soil disturbance parameters

The effect of width of tine on soil disturbance parameters at different moisture content, 90 degrees rake angle, 70 mm operating depth and 5.4 km/h forward speed is shown in Figure 3. All soil disturbance parameters decreased in values for all the tines as the moisture content increased from 6.0% to 17.5% (db), except height of ridge that did not show any specific trend. This trend agrees well with the result reported by Liu and Kushwaha (2006).
Similarly, the effect of width of tine and moisture content on the maximum width of cut of tool (Wfs), rupture distance (f), and specific draught (SDR), is presented in Figure 4. The rupture distance (f) and specific draught (SDR) all increased for all the tines as the moisture content increased in the range. However, the maximum width of cut increased for narrow tines (T1, T5) but decreased for wide tine (T20) in the moisture content range.
3.3 Regression analysis of soil disturbance parameters Statistical analysis was carried out using Excel 2003 software to regress the maximum width of soil throw (TDW) as dependent variable on the other soil disturbance parameters (as independent variables) including, the maximum width of soil cut (Wfs) and specific draught (SDR) for the three selected of tines (T1, T5, T20).

The multiple regression equation obtained is presented in Eq. 1

\[
TDW = 0.68w + 0.017hr - 0.4mc + 0.12Wfs + 3.55df + 0.92RRD + 0.31SDR - 15.22
\]

\[R^2=0.9999\] \hspace{1cm} (1)

The value of the coefficient of determination implies that changes in the independent variables explain 99.99% of the variation in the TDW. The regression equation is quite significant at 5% level of significance, the p-value is just 0.005. The depth of furrow has the highest partial coefficient of all the other independent variables.

Line plots were generated from the multiple regression analysis. The plots of TDW versus each of the other soil disturbance parameters (independent variables) were analysed and the simple regression equations are presented in Table 1.
Table 1. Models of line plots of the multiple regression analysis of soil profile and tool parameters under different moisture contents (MC)

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Independent Variable</th>
<th>Model</th>
<th>Equation</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>TDW</td>
<td>hr</td>
<td>Polynomial</td>
<td>$y = -4.64x^2 + 33.77x - 25.06$</td>
<td>0.7592</td>
</tr>
<tr>
<td>TDW</td>
<td>df</td>
<td>Polynomial</td>
<td>$y = 5.18x^2 - 46.06x + 120.7$</td>
<td>0.6232</td>
</tr>
<tr>
<td>TDW</td>
<td>Wfs</td>
<td>Polynomial</td>
<td>$y = -0.037x^2 + 2.71x - 9.35$</td>
<td>0.9814</td>
</tr>
<tr>
<td>TDW</td>
<td>MC</td>
<td>Linear</td>
<td>$y = -0.202x + 28.64$</td>
<td>0.0065</td>
</tr>
<tr>
<td>TDW</td>
<td>SDR</td>
<td>Polynomial</td>
<td>$y = -0.085x^2 + 4.47x + 27.89$</td>
<td>0.3186</td>
</tr>
<tr>
<td>TDW</td>
<td>RRD</td>
<td>Polynomial</td>
<td>$y = -0.04x^2 + 3.03x - 10.3$</td>
<td>0.9761</td>
</tr>
<tr>
<td>TDW</td>
<td>w</td>
<td>Polynomial</td>
<td>$y = -0.169x^2 + 5.05x + 6.45$</td>
<td>0.9930</td>
</tr>
</tbody>
</table>

4. CONCLUSION The following conclusions can be drawn from this study:

- Draught increased at a decreasing rate with tine width, with quadratic model as best fit model. The increase is also affected by the forward speed since higher draught values were obtained at higher speeds.
- Soil disturbance parameters decreased in values for all the tines as the moisture content increased from 6.0 % to 17.5 % (db), except height of ridge that did not show any specific trend.
  - Soil disturbance parameters were modeled by multiple regression equation. The regression equation is quite significant at 5 % level of significance.
  - Line plots from multiple regression analysis showed that polynomial function was the best-fit model when the maximum width of soil-throw (TDW) was regressed on all other independent variables separately.

5. REFERENCES
  - Agricultural Handbook 316, Washington D. C.; USDA Agricultural Research service


