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Performance Evaluation Of An Instrumentation System For Soil Draught Measurement

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***Abstract*—An instrumentation system was assembled to measure and record draught in soil-tool interaction in tillage study. The instrumentation system consists of a load cell, strain gauge amplifier, data logger and a computer system. The soil bin facility consists of the soil bin, soil leveling blade, smooth compaction roller, spiked roller, implement carriage system, sub implement carriage system, tool-bar and fixing device, drive system(45 kW-4 wheel drive tractor) and the instrumentation system. To evaluate the performance of the system, two experiments were conducted on the outdoor soil bin to determine the effects of speed and compaction (cone index) on draught and soil disturbance parameters. The soil in the bin was sandy clay loam. In the first experiment, speeds of tillage were 10, 15, and 20km/h at a constant degree of compaction of 3 passes of compaction roller. In the second experiment, 5, 10, 15 and 20 passes of compaction roller of respective mean values of cone index (compaction) of 1550, 2829, 3126 and 3775kN/m^2 at 8km/h constant tillage speed. The tillage depth was 120mm and the tool was a mouldboard plough for both experiments. The result of the soil bin experiments showed that the value of draught increased with increase in speed and later decreased with further increase in speed. A polynomial relationship was observed between the speed and the soil disturbance parameters except with the height of ridge and left soil throw in which inverse relationship was observed. It was also found that the value of draught increased with increase in the values of cone index and bulk density, whereas the values of the soil disturbance parameters decreased with increase in compaction.**

Keywords—Electronic measurement, soil draught, soil disturbance, tillage speed, compaction, soil bin instrumentation

1. INTRODUCTION

Soil bin is a generic term for a test facility for studying soil dynamics, specifically on soil-machine interaction research in agriculture. The application of soil bin for soil machine interaction research was initially established by several research institutes, like the National Tillage and Machinery Laboratory (NTML) in the United States, the U.S. Army Tank Automotive Centre, the Vicksburg Waterways experimental Station and Caterpillar Tractor Co. (Oni et al., 1992). Soil bins can be used for indoor and outdoor testing. But, many soil bins are intended for indoor testing. There are two broad divisions of soil-machine interaction studies. The first is on the applications of tools related to soil engaging and materials incorporation operations. While the second is on the applications related to tractive devices, such as wheels and tracks. Soil bins were used more often in the first division than in the second. For research purposes on the investigation into these important soil dynamic parameters, it is difficult to quantificationally analyse the dynamic mechanical behavior of soil directly because of the complex nature of the soil and the unstable nature of the mechanically disturbed soil. Soil bins can be classified into large scale soil bins and small scale soil bins and small scale soil bins; moveable (with stationary tools and stationary with movable tools); indoor and outdoor; straight (rectangular) and circular (Mardani, et al., 2010; Mamman and Oni, 2002).

Ideally, soil-machine interaction tests are conducted in fields for development of a prototype machine or evaluation of an existing machine, so that the tests could simulate the actual farm situation. Several problems often limit field-testing. The problems come from two sources, the weather condition and the soil condition. Testing can only be conducted when the weather is suitable for farming operations because weather condition and changes in climate affect farming operations. Soil moisture content, which influences the mechanical and dynamical properties of the soil, varies within one field. Bumpy and uneven fields that might affect the machine travelling speed and the working depth of a test-tool. Controlling these parameters is essential for valid comparisons of measurements of tools or traction devices. (Mahadi, 2005) but these field conditions are beyond the control of researchers. Hardpan due to subsoil compaction of agricultural soils is a global concern due to adverse effects on crop yield (Waseem, et al., 2007). Several factors affect compaction by machinery like soil water content, machinery weight, machinery tyres (width, type and inflation pressure) (Gemtos et al., 2015).

Recently, there is rapid development in soil tool interaction, measuring instrument and electronic technology to some areas of agriculture, but scarcely adopted in Africa especially in the areas of soil tillage dynamic and research development. This is why instruments for use of soil bins have been adopted to replace the existing mechanical devices like the dynamometer. Therefore, a soil-tool interaction instrumentation system was developed and study was therefore on the performance of the instrumentation system for soil tillage study in a soil bin.

2. MATERIALS AND METHODS

2.1 Experiment Site

The research was conducted on the outdoor soil bin of the STEPB (Science and Technology Education Post Basic) Project Site of the Federal University of Technology, Akure, Nigeria, located on latitude 7°10' N and longitude5°05' E. The soil of the study area from which the the soil bin was filled is a sandy clay loam soil according to USDA textural classification of soil.

2.2. Soil Bin and its Components

The soil bin facility is equipped with a soil bin(Fig. 1) whose dimension is 48.0 x 1.5 x 1.2m of length, width and depth, respectively. The walls of the soil bin were constructed with concrete blocks; Soil leveling blade consists essentially of a plane steel board with light curvature, 1400mm wide and 350mm height, reinforced at the middle to provide sufficient strength and rigidity (Fig. 2); the soil compaction roller consists mainly of a cylindrical drum, the roller axle and bearing and ballast weights. Its major function is to compact the bin soil in layers as desired for testing; the spiked roller whose function is to ensure a satisfactory bond between successive soil layers is similar to the compaction roller.

a. Bin without Soil

b. Bin with Soil

Fig. 1: The Completed Soil Bin

2.3 Implement Carriage System

The implement carriage (Fig. 2) is made of rectangular hollow section steel and is supported on four wheels. The carriage dimension is 1.623 m x 0.70 m x 1.117 m of length, width and height, respectively. The main function of the carriage is to mount the implement sub-carriage system which in turn carries the toolbar for mounting any tillage or traction devices such as traction or towed wheels for testing or for transportation. The carriage can be coupled to the drive system (tractor) through the 3-point linkage.

2.4 The Drive System

The drive system(Fig. 3) is an MF 415 tractor with the following specifications: power, 45 kW; 4WD; Diesel engine; water cool; oil bath air cleaner with PTO drive shaft and 3-point linkage; a good range of forward speeds (2.59 – 34.21 km/h); a slow and fast reverse speeds of 3.5 and 14.2 km/h respectively.

Fig. 2: Implement Carrier and Drive System during the Trial Test of the Instrumentation System

2.5 Experimental Tillage Tool

A single bottom mouldboard plough was used as the tillage tool for this study.

2.6 Instrumentation and Data Acquisition Systems

Fig. 3, Fig. 4 and Fig. 5 show the different components of the instrumentation and data acquisition systems. A 10 tonne load cell (Fig. 5) of no. 100201022 and output 2.50mV/ TMAUTO INSTRUCO, LTD) was interfaced with a computer system and the sensor outputs. The data acquisition is made up a (load cell) outputs interfaced to a computer system (Fig. 3) (DELL, Poland) and a data logger (Grant Instruments Cambridge Ltd, U.K). The system can receive, monitor, display and store the measured signals from the load cell. It was calibrated using a dead load system at the Instrumentation laboratory of the Department of Physics, Federal University of Technology, Akure, Nigeria. The load cell was installed on the tool carriage system by the use of brackets. The software for the data logger as provided by the manufacturer was installed. The interfaced system was powered by a pair of 6volts batteries (12 volts). Fig. 4) shows the differential strain gauge amplifier (LM 358), while Fig. 5 is its circuit diagram.

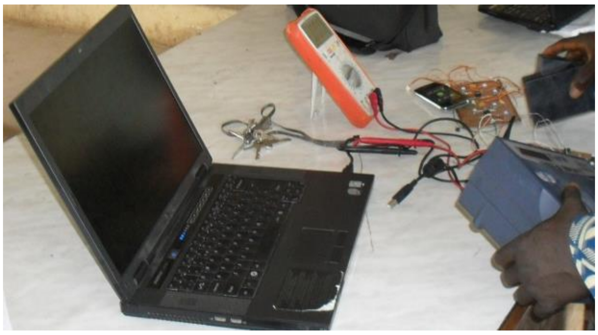

Fig. 3: Aspect of the Instrumentation System showing the Computer System, Data Logger, Circuited Amplifier and the Voltage Meter during the Calibration Process

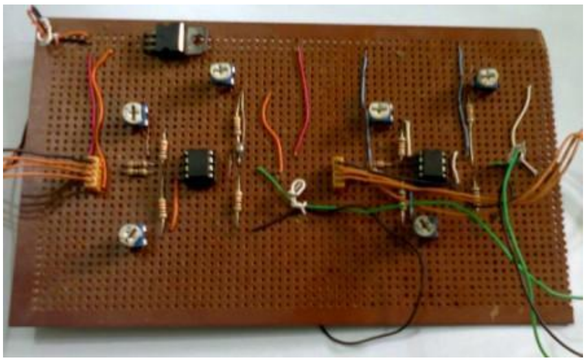

Fig. 4: Differential Strain Gauge Amplifier (LM 358).

Fig. 5: Load cell

2.7 Performance Evaluation

2.7.1 Variable Speed Experiment

In this experiment, after the soil bin has been filled, the soil was compacted by driving of the 20kg-compaction roller on the soil bin three times (three passes). Soil samples were taken for both moisture content and bulk density determination at 60, 120 and 180mm depth. The tillage tool (single bottom mouldboard plough) was mounted on the tool bar of the carriage system for the experiment. The rake angle was kept constant at 60° and the tool carriage was towed for each of the three treatments at operating speeds of 10, 15 and 20 km/hr respectively and at operating depth of 150mm. The soil disturbance measurement was taken. The draught data as recorded and stored by the data logger was downloaded to the computer system (lab-top) for analysis.

2.7.2 Constant Speed Experiment

In constant speed experiment, the soil in the soil bin was hipped and divided into four equal blocks. Each block was subjected to compaction by driving the compaction roller through each of the block according the desired number of passes (degree of compaction); 5, 10, 15 and 20 passes respectively. The compaction value of each of the treatments was taken from two points of reasonable distance by the use of a hand-held penetrometer graduated in psi, but converted to kN/m^2 Soil samples were collected for moisture content and bulk density determinations at 60, 120, 180mm soil depth. The mould board plough was attached and towed at constant operating speed of 8km/hr, operating depth of 150mm and rake angle of 60°. The soil disturbance measurement was also taken and the data downloaded for analysis.

2.8 Soil Measurements

Soil Disturbance: The soil failure parameters; maximum width of soil throw(TDW), maximum width of cut(Wfs), ridge to ridge distance(RRD), small height of ridge(h_{rs}) , large height of ridge(h_{rl}) and after plough depth(d_f) were measured with the use of a profile meter.

Soil Bulk Density: Soil samples were collected from the depth of 0-6, 6-12, 12-18 and 18-24cm by the use of core sampler of 5.8cm diameter and 6cm height. The core sampler was driven into each depth of the soil and the collected soil was kept in an air tight polythene bag to avoid moisture loss. The sample was oven dried and weighted. The oven dried soil was allowed to cool for one hour. The bulk density was determined using standard equation 1;

$$\text{Bulk-Density}=\frac{Mass}{Volume} \qquad (1)$$

Soil Moisture Content: Soil moisturemeter was used to determine the moisture content at 0-6, 6-12 12-18 and 18-24cm soil depths.

Compaction (Cone Index): The compaction (cone index) of two points in each block(of varied number of passes of the compaction roller) was taken by the use of a soil cone penetrometer by continuous hand pushing of the cone tipped shank of the penetrometer into each depth (6,12,18,24 and 30cm) and maximum reading at each depth taken and recorded. This was repeated for every treatment.

3. RESULTS AND DISCUSSION

The results of the experiments were respectively presented by the figures below;

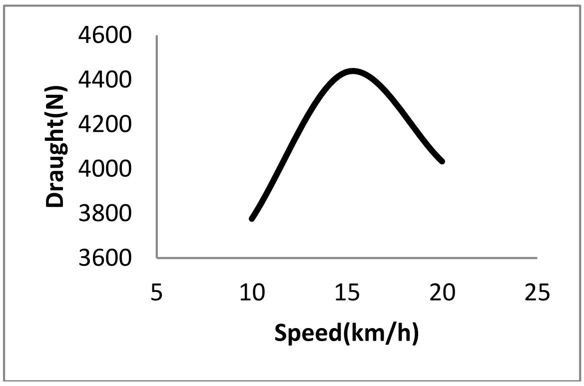

Fig. 6: Variation of Draught with Speed

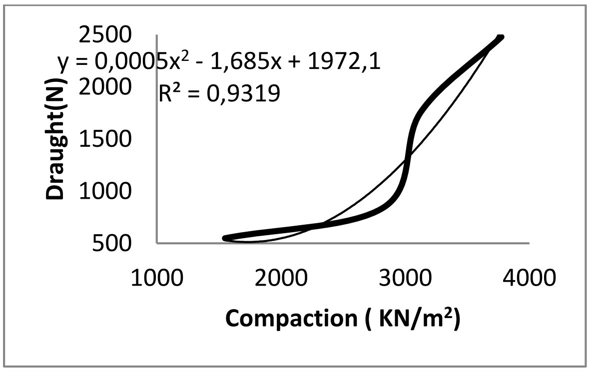

Fig. 7: Variation of Draught with Compaction

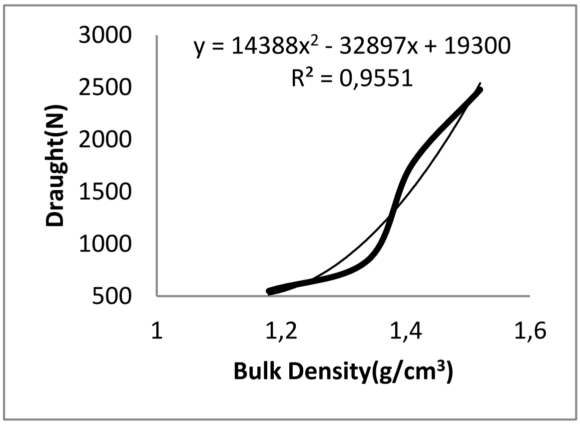

Fig. 8: Variation of Draught with Bulk Density

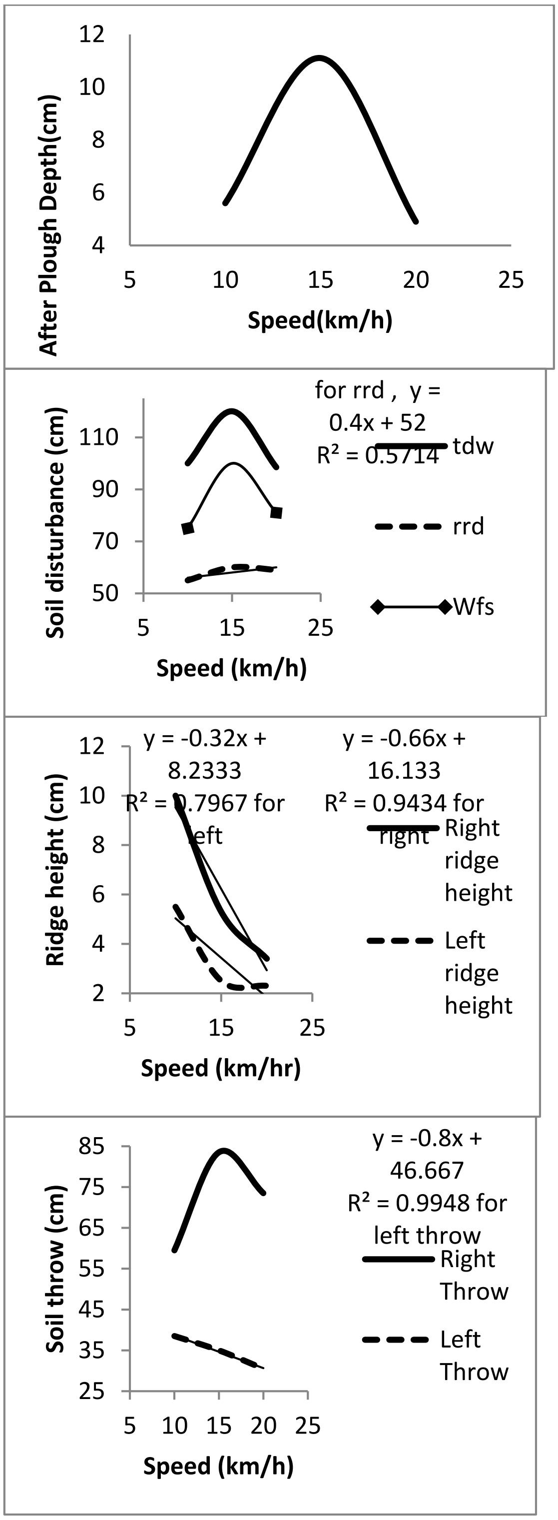

Fig. 9: Variation of Soil Disturbance Parameters with Speed

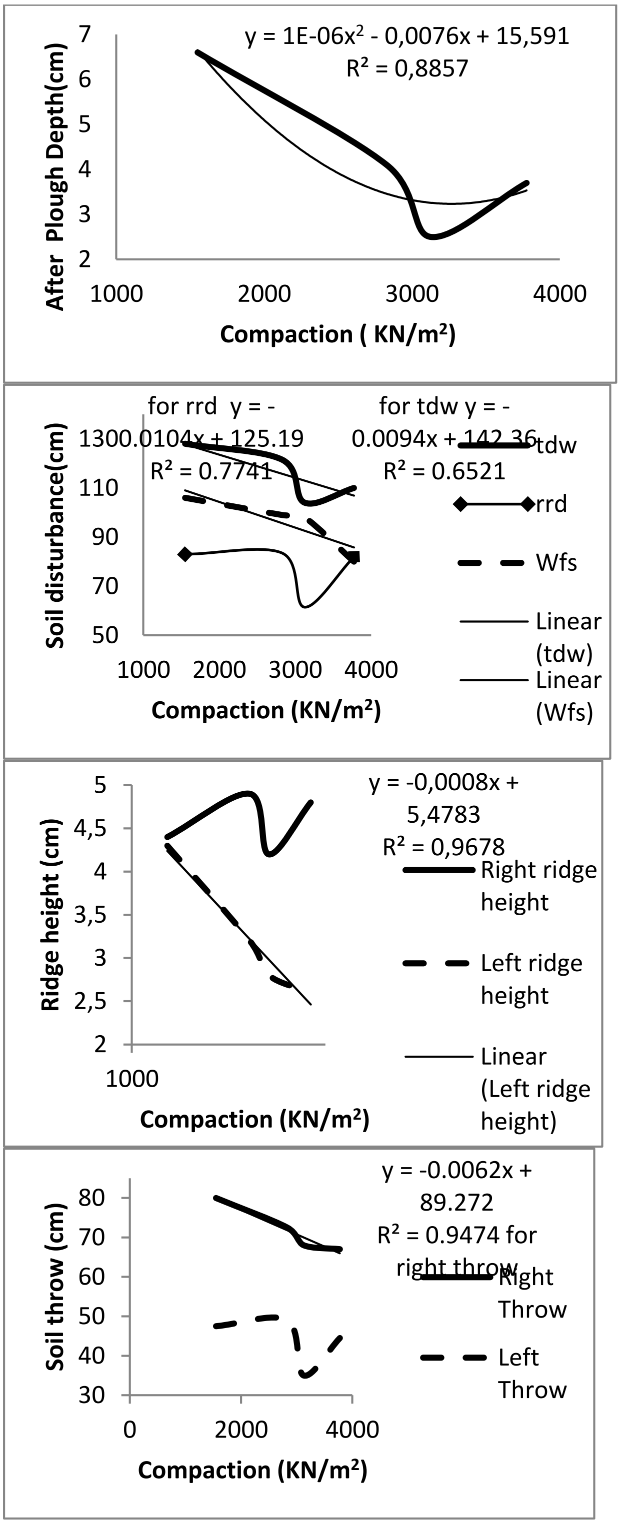

Fig. 10: Variation of Soil Disturbance Parameters with Compaction

4. DISCUSSION

4.1 Effect of Speed on Draught and Soil Disturbance

The results showed that draught increased with increase in forward speed of the tractor and later decreased with increase in forward speed at average moisture content of 9%. The experiment of 15km/h had the highest mean value of 4,435.40 N while speed of 10km/h had the lowest mean value of 3775.67N. This polynomial relationship is in good agreement with Mamman and Oni (2005) who reported that beyond a certain speed level, the draught decreased or remained constant. Variations of the soil disturbance parameters with speed are presented in Fig. 9. The results showed a polynomial relationship between the speed and the soil disturbance parameters except with height of the large ridge and the small soil throw which decreased with increase in speed with coefficient of determination r^2 of 0.9434 for large ridge height (h_{rl}) and 0.9948 for small soil throw. This is in good agreement with Morris et al (2007). This may be due to higher speed and the type of tool used for the experiment.

4.2 Effect of Compaction on Draught and Soil Disturbance

The result (Fig. 7) of this study indicated that draught increased with increase in compaction from mean value of 1550 to 3775KN/m^2 with a coefficient of determination r^2 of 0.807. This is in conformity with Manuwa and Ademosun (2007). A quadratic relationship was observed from 1500KN/m^2 (compaction)/549.28N (draught) to 3126KN/m^2 (compaction)/1757.13(draught) while perfect linearity was observed from from 3126KN/m^2 (compaction) to 3775N (draught). This is due to the normal increase of soil strength with compaction. The Variation of bulk density (1.18g/cm3 to 1.52g/cm3) was observed to have a polynomial relationship with tillage draught with coefficient of determination r^2 of 0.9551(Fig. 8). The draught increased with increase in bulk density at average moisture content of 10%. This result is in conformity with Seidi et al (2010).

In the constant speed experiment, it was also observed as presented in Fig. 9 that the values of soil disturbance decreased with increase in cone index. Except the height of the small ridge which increased with increase in compaction. Soil disturbance parameters (Fig. 10) with the linear relationship are of the coefficient of determination r^2 ranging from 0.6521 to 0.9678. This is due to the increase in the bond between the soil grains. This can be attributed to increase in soil weight of the sheared soil segments as bulk density increases with cone index of the soil and the tillage tool used.

5. CONCLUSIONS

The following conclusions can be drawn from this study:

1. The instrumentation system was calibrated and found suitable for measurement of soil forces in tillage studies.
2. A polynomial relationship between speed and draught that showed that draught increased with increase in speed and later decreased with further increase in speed was observed.
3. A polynomial relationship was also observed between the soil disturbance parameters and the speed except the height of the ridge and small soil throw in which a good inverse relationship was found.
4. There was a good correlation between draught and compaction as well as between draught and bulk density of the soil.
5. Good correlation was also observed between compaction and soil disturbance parameters as they decreased with increase in compaction except with the height of ridge which increased with increase in compaction.

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