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SOIL COMPACTION CAUSED BY TRAFFIC FREQUENCY OF RUBBER-TRACKED EXCAVATOR

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ABSTRACT

The project site described in this study was assumed to have been subjected to induced compaction of the excavator that was used to clear the land. It was therefore necessary to estimate the compaction so induced. The experimental soil was a sandy clay soil. The main objective of this study was to evaluate the soil compaction induced by traffic of rubber- tracked, medium size Excavator, 31.9 KW power and 36.4 KN weight in a sandy clay soil. The study was conducted at the Experimental site of the STEP B project of the Federal University of Technology, Akure (FUTA), Nigeria. The experimental soil was subjected to 1, 3, 5, 7, 9 and 11 passes of the Excavator. Variables measured include penetration resistance (PR), bulk density (BD), and rut depth (RD). The variables were monitored at the centre lines of the left (L) and right(R) tracks of the Excavator. Results showed that means of the L and R values were not significantly different at the 5% level of significance. Mean values of the PR in the depth range of 0 to 30 cm were 1102.85, 1363.65, 1163.5, 1269.60, 1315.05 and 1428.8 kPa for 1, 3, 5, 7, 9 and 11 passes respectively. PR increased with depth to a limit and then reduced in value in the range of depth considered. The maximum PR value occurred between 15 and 20 cm depth. The average PR value before the excavator passes (control) was 420 kPa which was significantly different from those after the passes. The range of rut depth corresponding to 11 passes was 4.6 and 14.8 cm. The moisture content during the experimentation ranged from 11.5 – 15.5% (db) in the depth range.

Key words: Induced compaction, Excavator, Penetration resistance, Rut depth

1. INTRODUCTION

Compaction is a process that brings about an increase in soil density or unit weight, accompanied by a decrease in air volume (Soane and van Ouwerkerk, 1994). Soil compaction *sensu stricto* results when the physical structure of the soil is unable to support an applied weight or mechanical stress leading to a coarsening or loss of soil structural units, decrease in soil volume, increase in bulk density, decrease in porosity (in particular macro porosity) and reduction in hydraulic conductivity of the soil. Soil compaction results from many human activities such as land clearing and development that normally precede agricultural production. In Nigeria, agriculture was the mainstay of the economy until the "oil boom" of the 1970s even till now. In- land- clearing is considered to have negative effects on agricultural production because it exposes the soil to forces of soil erosion, soil degradation and compaction. This is due to the use of land clearing machinery such as bulldozers, excavators, rake, tree pushers, root ploughs, shear blade, scraper and rotary mowers. However, most of the time, the 'danger' caused by the use of such machines have not been quantified in real terms.

Soil compaction of agricultural soil is a global concern (Soane and van Ouwerkerk, 1994), due to adverse effects on the environment: it is estimated to be responsible for the degradation of an area of

33 million ha in Europe and is one of the major problems facing modern agriculture. Soil compaction refers to the formation of dense layer of well packed soil, often at the bottom of the cultivated layer (Horn and Fleige, 2003). The underlying cause of compaction is the inability of soil to withstand external pressures applied to it. The most common causes of soil compaction are agricultural machines such as tractors: harvesting equipment and implement wheels travelling over moist, loose soils (Alakuku *et al.*, 2003). Soils tend to be more compacted deeper into the soil profile due to the weight of overlaying soil. Soil compaction occurs when soil particles are pressed together, reducing pore space between them. Heavily compacted soils contain few large pores, less total pore volume and consequently a greater density (Horn *et al.*, 2001). A compacted soil has a reduced rate of both water infiltration and drainage. This happens because large pores are more effective in moving water downward through the soil than smaller pores.

Compaction due to agricultural machinery or vehicular compaction is of two types: shallow compaction defined as any compaction occurring within the normal tillage zone. However, shallow compaction is usually temporary since it can be eliminated by normal tillage; deep compaction (or sub surface compaction) may be defined as compaction that occurs below the normal tillage zone. It is caused by weight of vehicle or force applied to the soil, and is mostly affected by the maximum axle weight. Wheel traffic is considered the main cause of soil compaction in agricultural production. With increasing farm size, the amount of time in which to get farming operations done in a timely manner is often limited. According to the University of Minnesota, the weight of tractors has increased from less than 3 tons in the 1940's to approximately 20 tons today. This is of special concern because spring planting is often done before the soil is dry enough to support the heavy planting equipment.

Domzal et al. (1991) reported that field traffic was the major factor causing soil compaction on soils developed from sand, loam and silt materials. They also mentioned that the soil response to compaction is especially affected by soil texture, moisture, structure and initial bulk density. Also it was reported that Agricultural traffic is the main cause of decreased structural soil macro porosity (Botta et al., 2002). According to them therefore, the challenge is to attain a suitable seedbed while minimizing traffic induced compaction, so that the physical properties of the soil do not diminish normal root growth. They also reported that among the several penalties that over compaction produce in agricultural soils Taylor and Burnett (1964) emphasized those due to soil impedance. They stated difficulty of developing normal root growth-habit when the dry bulk density is over 1.6 and 1.8 Mgm^{-3} in clayey and sandy soils respectively. Many other researchers have investigated surface and subsurface compaction (due to machinery traffic) and their effects on agricultural production (Botta et al., 2002; Horn et al., 2004; Botta et al., 2006; Botta et al., 2008; Botta et al., 2009; Becerra et al., 2010; Botta et al., 2010). The objective of this study therefore was to investigate the characteristics of the compaction caused under excavator tracks in an arable terrain.

2. MATERIALS AND METHODS

2.1 Site Characteristics

Research was conducted in August 2010 in the experimental plot located at The Federal University of Technology, Akure (FUTA) Step-B (Science and Technology Education Post –Basic) project site Akure, with geographical coordinate of 7° 10 North and 5° 05 East. The site is a two-hectare arable land and was manually cleared to avoid compaction due to machinery on the land. The experimental plot was of length and width 48.00 m by 12.00 m respectively, divided into three transects each of 16 m by 4 m. There was also a control plot of the same dimensions as transect. Soil samples were carefully collected from the test plots for textural and soil analysis.

2.2 Experimental Treatments and Layout

The machinery used was a medium Bobcat 430 Excavator of 31.9 kW power used to induce the necessary compaction on the experimental plots. The characteristics of the excavator are presented in Table 1. Seven treatments were imposed on plots 48m long x 4 m wide, where the experimental variable was traffic frequency of 0, 1, 3, 5, 7, 9 and 11 excavator passes in the same tracks, with 3 m wide buffer zones between plots to avoid interactions. Plots were completely randomized having three replications. Statistical analysis was performed utilizing Excel 2007. An analysis of variance was carried out on the data and means were analyzed by Duncan's multiple range test.

Table 1: Excavator Characteristics

Excavator.	**Bobcat 430**
Engine power at 2400rpm (DIN70020) (kW)	31.9
Rubber tracks width (mm)	320
Track length (mm)	1082
Dozer blade (mm)	1780
Travel speed (low range) (km/h)	2.4
Operating weight with ROPS canopy, rubber tracks, 610 mm bucket (SAE J732) (Kg)	3640
Ground pressure with standard diperstick and rubber tracks (kPa)	28.5

2.3 Soil Response Variables

Experimental variables related to soil compaction include the following:

Dry bulk density was measured by the cylinder core soil sampler method, soil moisture content measured with moisture meter model PMS- 714, TAIWAN with 0.1% resolution over the depth ranges of 0-10, 10-20, 20-30, 30-40 mm . Bulk density was the average of five measurements. Moisture content was verified by gravimetric method.

Soil penetration resistance PR, or cone index CI was determined using a Rimick CP20 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. Data were recorded at depth increments of 50 mm. Cone index was the average of 15 measurements per plot. The resistance of the soil was measured in the centre line of the foot print of the excavator tract. A photograph of the experimental track is shown in Figure 1.

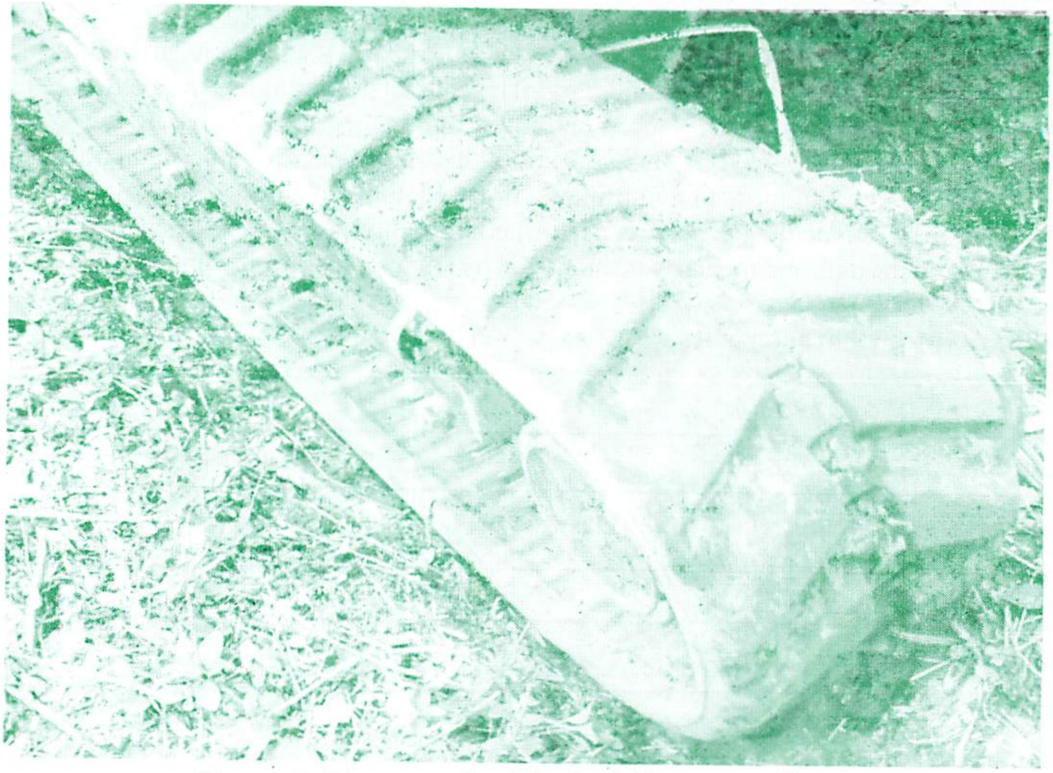

Figure 1: Photograph of the Left Excavator Track

Rut depth of the excavator foot print was measured using a profile meter similar to that reported (Botta et al., 2006; Manuwa, 2009). The bar was placed across the wheel tracks, perpendicular to the direction of travel and rods position to conform to the shape of the depression. Rut depth was calculated as the average depth of 40 readings on the 1 metre bar.

The estimated rut depth at any traffic frequency was calculated as the mean of the total number of sections' ruts at that frequency. A typical excavator track footprint is shown in Figure 2. For each traffic treatment, cone index, bulk density and rut depth were measured at 2 m intervals along a 48 m transect within the excavator tracks (left and right). All measurements were made in the centerlines of the tracks because this is where the compressive effects tend to concentrate (Sohne, 1958). Cone index and bulk density were also measured in the control treatment where no tracks had passed.

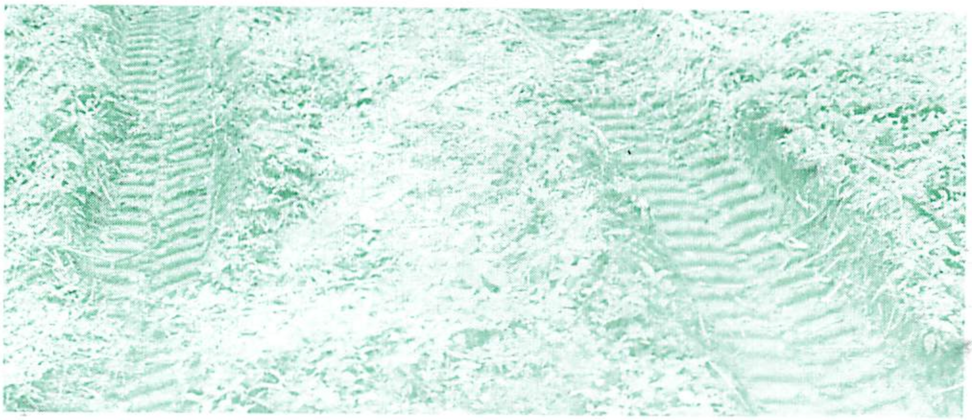

Figure 2: Plan View of the Rut Produced the Excavator Tracks during Experimentation

3. RESULTS AND DISCUSSION

The most common causes of soil compaction are agricultural machines such as tractors: harvesting equipment and implement wheels travelling over moist. lose soils (Alakuku *et al*.. 2003). Soils tend to be more compacted deeper into the soil profile due to the weight of overlaying soil. Heavily compacted soils contain few large pores. less total pore volume and consequently a greater density (Horn *et al*.. 2001). The characteristics of the excavator used to induce compaction as a result of its traffic frequency is presented in Table 1. It can be categorized as light machinery in agreement with the report (Botta et al.. 2006). Similarly. the characteristics of the experimental soil are shown in Table 2. This soil texture is one of the dominant textures in the locality and even the state in general. Table 3 shows the rut that was produced as a result of the traffic frequency. This is considered to be high for the moisture content range (11 to 15% (db)) at which the experiment was carried out.

Table 2: Soil Properties

Properties	Values
Sand (%)	51
Silt (%)	10
Clay(%)	39
Texture (%)	Sandy clay
Organic carbon (g/kg)	1.5
Organic matter (%)	2.58
C/N ratio	7.89
Total nitrogen g/kg)	0.19
pH in H_2O (1:2)	6.75
Ca^{2+} (cmol/kg)	3.30
Mg^{2+}(cmol/kg)	2.20
Na^{+}(cmol/kg)	0.14
K (cmol/kg)	0.26
P (mg/kg)	17.54

Table 3: Effect of Excavator Traffic Frequency on Rut Depth

Traffic Treatments (No of Passes)	Mean Rut Depth (mm)
1	27^a
3	45^b
5	70^c
7	99^d
9	132^e
11	148^f

Different letters within each traffic treatments show significant difference at 1% level of significance, Duncan's Multiple Range Test)

Cone penetration index without excavator traffic (control) increased with depth due to shaft friction, and overburden pressure of the weight of soil above the depth (Figure 3). Also, lateral forces on the penetrometer cone increase with increasing depth so that more force was needed for the cone to displace soil (Becerra et al., 2010). Resistance can also increase with depth because of changes in soil texture, gravel content, structure and agricultural traffic if it had occurred.

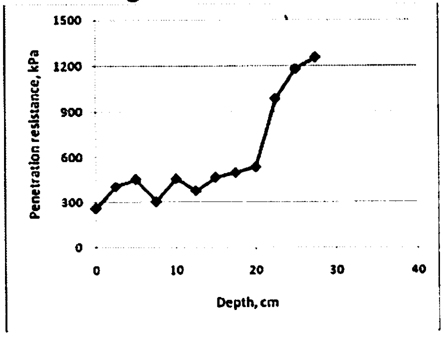

Figure 3: Variation of Cone Penetration Resistance with Depth at Control Plot

The variation of penetration resistance with depth along the excavator foot print as a result of machinery traffic is presented in Figure 4.

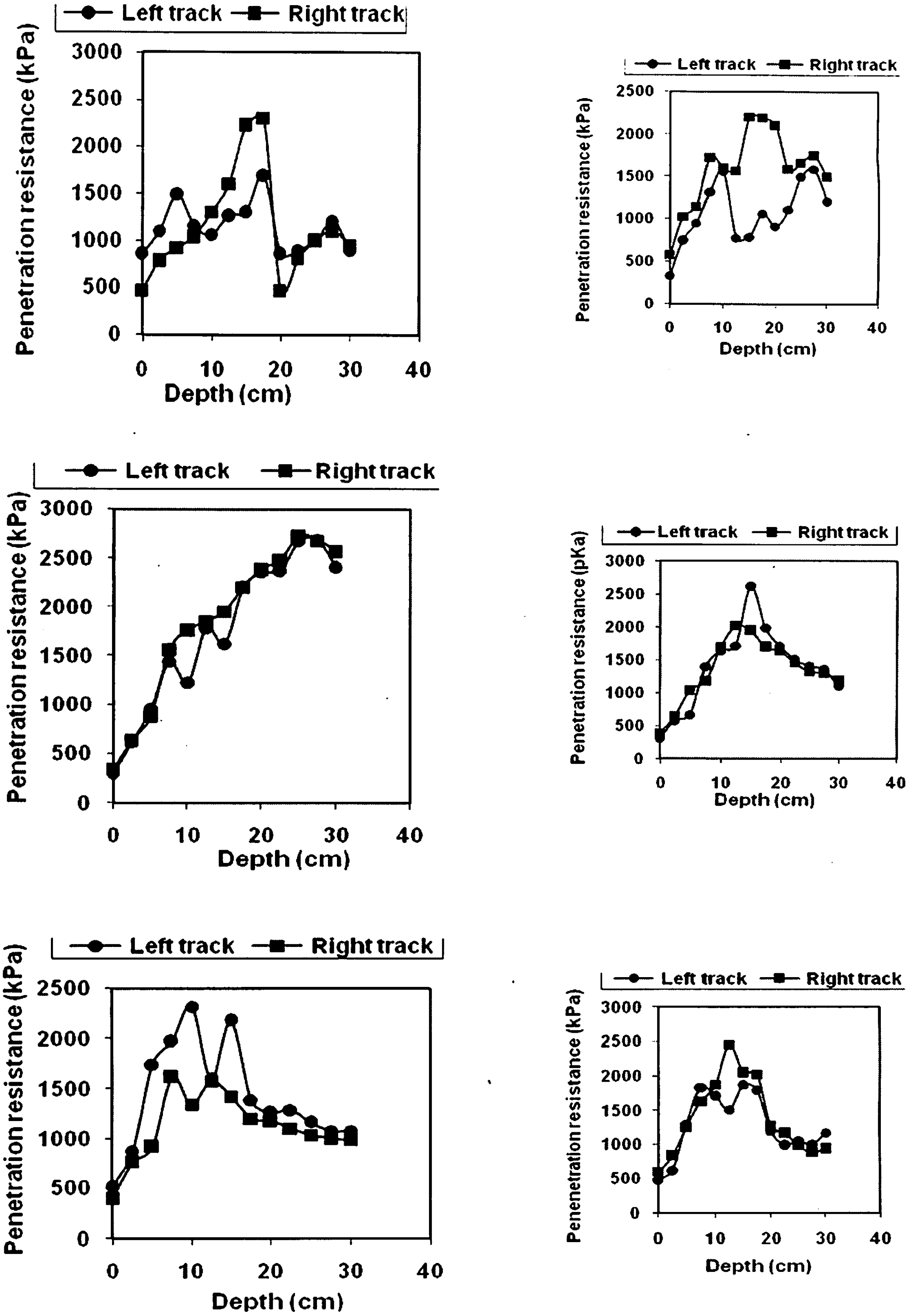

Figure 4: Cone Penetration Resistance in the Centre Lines of the Excavator Tracks: (a) 1 pass (b) 3 passes (c) 5 passes (d) 7 passes (e) 9 passes (f) 11 passes

Generally, penetration resistance increased with depth up to a point and then decreased. This trend is consistent with the findings of many researchers. It was observed that the mean values of penetration resistance along the left and right foot prints of the excavator for each treatment were not significantly different from each other at 5% level of significance. It was reported that bulk density and penetration resistance always increase with the number of passes but bulk density tended to be less responsive than penetration resistance (Becerra et al., 2010). Despite this, the measured changes in bulk density agreed with soil behavior suggested by changes in penetration resistance. The result of this study agreed with this assertion. Examination of soil responses to traffic in deeper layers revealed that soil compaction increased as the traffic intensity increased. This also agreed with the findings of other researchers (Botta et al., 2002; Becerra et al., 2010). Effect of traffic on bulk density is presented in Table 4 at two depths. This was due to the limitation imposed by the short (35 cm) shank of the penetrometer used in this study. At 9 and 11 passes, soil bulk density became significantly different than at lower traffic frequency.

Table 4: Bulk Density (Mg m^{-3}) at Two Depths under different Degrees of Excavator Traffic (1, 3, 5, 7, 9, 11)

Depth	Control	Excavator Traffic Frequency (No of Passes)					
(mm)	Plot	1	3	5	7	9	11
0-150	1.242	1.251^a	1.259^a	1.301^a	1.319^a	1.435^b	1.442^b
150-300	1.407^a	1.422^a	1.427^a	1.431^a	1.439^a	1.506^b	1.534^b

Values with different letters (horizontally Bulk) are significantly different at each depth (P less than 0.001; Duncan's Multiple Range Test).

4 CONCLUSIONS

The following conclusions follow from this study:

(i) Cone penetration resistance under left and right centre lines of excavator tracks was not significantly different from one another.

(ii) There were significant differences in the mean rut of traffic frequencies at 5% level of significance.

(iii)There were also significant differences in the mean bulk density due to traffic frequencies at two depths, at 5% level of significance

(iv)The maximum penetration resistance (2.5 MPa and above) observed were not all due to traffic frequency.

Depth	Control	Excavator Traffic Frequency (No of Passes)					
(mm)	Plot	1	3	5	7	9	11
0-150	1.242	1.251^a	1.259^a	1.301^a	1.319^a	1.435^b	1.442^b
150-300	1.407^a	1.422^a	1.427^a	1.431^a	1.439^a	1.506^b	1.534^b

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