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Determination of the Effect of Tillage on Soil Resistance to Penetration. A Study of South-East Agricultural Soils

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ABSTRACT: *The effect of tillage on soil resistance to penetration was determined on three agricultural soil types (clay-loam, sandy-loam, and sandy-clay) in south-east Nigeria. Four tillage treatments namely: plough, harrow ridger and zero tillage were used for the study under twelve (12) arbitrary depth ranges (0 to 600mm). Results obtained showed that clay-loam had its highest penetration resistance at depth range of 350-400mm with average resistance of 14.3kg/mm^2 for plough, 10.4kg/mm^2 for harrow, 7.9kg/mm^2 for ridger and 13.3kg/mm^2 for zero tillage. However, at the end of 600mm depth, the overall average penetration resistance was found to had improved from 9.84kg/mm^2 of zero tilled soil to 8.08kg/mm^2, 6.48kg/mm^2 and 4.23kg/mm^2 with plough, harrow and ridger respectively.Sandy-loam gave its highest penetration resistance of 12.3kg/mm^2, 10.5kg/mm^2, 7.2kg/mm^2 and 12.8kg/mm^2 for plough, harrow, ridger and zero tillage respectively at depth range of 250-350mm. But at the end of 600mm depth, the overall mean penetration resistance reduced from 8.43kg/mm^2 of zero tilled soil to 7.22kg/mm^2 for plough, 5.26kg/mm^2 for harrow and 3.33kg/mm^2 for ridger. Finally, sandy-clay showed its highest resistanceto penetration at depth of 300-400mm with average resistance of 13.3kg/mm^{2}for plough, 11.5kg/mm^2 for harrow, 7.4kg/mm^2 for ridger and 13.8kg/mm^2 for zero tillage. At the end of 600mm depth, the overall mean penetration resistance was brought down from 8.46kg/mm2 of zero tilled soil to 7.22kg/mm^2, 5.26kg/mm^2 and 3.83kg/mm^2 for plough, harrow, and ridger respectively.*

Keywords:*Implements, tillage, penetration, resistance, agricultural soils, south east Nigeria.*

I. INTRODUCTION

Tillage is the first agricultural operation upon which depends the success or failure of the agricultural season, it is the preparatory stage of seedbed which is the critical stage in plant life[1]. At the same time soil tillage is one of the main energy inputs for agricultural production [2]. It consumes about half of the entire seasonal energy budget before the seed is planted [3] Tillageaccording to [4] is the change of the soil condition for the purpose of crop production. It includes all operations leading to seedbed preparation that optimizes both soil and environmental conditions for good seed germination, seedling establishment, and crop growth[5].

[6] maintained thattillage is the agricultural preparation of soil by mechanical agitation of various types, such as digging, stirring, and overturning. According to [7], tillage operation changes the soil surface in a number of ways, such as roughing or smoothing of the surface. [8] argued that, undisturbed soil seems to be harder and more resistant to root penetration than tilled soil. [9] observed that high soil strength reduces and even stops root growth or penetration to the soil. He stipulated that one of the aims of tillage is to reduce soil bulk density (increase soil porosity), and that the large pores in the soil generally favor high infiltration rates, good tilth, and adequate aeration for plant growth. [10] defined soil penetrability as a measure of the ease with which an object can be pushed or driven into the soil. According to [11] it is one method of measuring soil strength. Themost common variables used to assess the soil strength in tillage studies are bulk density and penetration resistance because they are interrelated and the use of only one of the variables will not give a perfect result[8]. According to[12], Cone indices, computed from static penetrometer data, is used to characterize available soil compaction, resistance to root growth, and tillage effects, wheel traffic effects and hard pan resistance into the soil. The cone indices values depend on cone properties such as diameter, height, and included angle; as well as soil properties such as bulk density, shear strength, soil water content, texture, organic matter, particles surface roughness[13]. Mechanical impedance of soil increases as bulk density increases and water content decreases [14]. [10] noted that the strength in some horizons of soil can restrict root growth even when water content is at field capacity, and strength increases as the soil dries. As a consequence

the roots exert a vertical pressure ranging from 0.7 to 2.5 Mpa, depending on the crop species [15]. [10] also found different penetration resistance produced in different soils or in different layers in the same soil. Generally penetration resistance increases with depth due to the increase in shaft friction [16]. The applied force required to press the cone penetrometer into a soil is an index of the shear resistance of the soil and was called the “cone index”, usually reported in kilopascals [10]. [12] explained the soil penetration resistance as the force applied to the dynamic penetrometer by the soil causing the penetrometer to decelerate from its initial velocity, resulting from the hammer blow, to zero velocity. They showed that, resistance can be calculated as the work done by the soil to stop the movement of the penetrometer divided by the distance the penetrometer travels. They explained that, when the penetrometer is driven into the soil by the hammer, the kinetic energy of the hammer is transferred to the penetrometer cone. Its kinetic energy is zero. Therefore, the work done by the soil equals the kinetic energy transferred to the cone from the penetrometer when the hammer contacts the strike plate (Its drop points), if there are large number of blows needed to cause the cone to penetrate a short distance, the soil/material is well compacted, and if the cone penetrates easily with few blows the soil/material is poorly compacted or "unsuitable" [17]. The penetration distance depends on the kinetic energy applied to the penetrometer, the geometry of the penetrometer tip, and the soil penetration resistance [12].

Soil strength tends to increase with depth of soil[18]. According to [19], the maximum bulk density and soil strength was found in the upper 30 cm in zero-tilled plots than deep tilled ones. [20] compared the timing effects of deep tillage with surface tillage on penetration resistance and wheat and soybean yield and they observed that, disking compacted the soil more than it loosened it, it developed 60- kPa higher mean profile soil cone indices than non-disked treatments, generally it never reduced mean profile cone index. It loosened the top 5 to 15 cm of the profile, and compacted soil below the disked zone to produce mean profile cone indices that were equivalent to or higher than none disked treatments for the deep tillage treatments. They also found that the cone indices were generally lowest in deep-tilled plots averaged over all dates of measurement, spring deep tillage maintained lower mean cone indices than the fall deep tillage. The probable reason for this according to [9] was the lower evapotranspiration in the winter. Study of [21] revealedthat in areas where rainfall is on the average and fairly uniform throughout the year at about 10 cm per month, more water will percolate through the soil reconsolidating the tilled subsoil more during the winter than during the summer.

Studies from different researchers indicated that machinery traffic and use of different tillage systems greatly affected several soil properties under different plant growth systems [9].From physical point of view, tillage exert pressure on soil profile, which differ in magnitude and direction and the soil tends to react differently to that pressure through compaction, deformation, cutting, crumbling, pulverization, or transportation [22]; [9].The degree of compaction relates to the soil compressibility, its moisture content, axel load and how often equipment is driven on the soil [23]. Heavy equipment, especially when operated under moderately wet soils, also tends to reduce soil air content and increase the physical resistance to penetration of the soil by roots. The effects of soil compaction include restriction of root development, nutrient and water movement, and oxygen availability which often results in reduced yields of both agronomic and horticultural crops [24]. [5] confirmed that collapsed soil structure results in loss of inter and intra aggregate voids which significantly contribute the declination of soil productivity. Crusted and sealed soil surfaces reduce infiltration through blocked upper most pores; the final result is root aeration impedance and water logging. Tillage, especially when including moldboard ploughing, can be one of the dominant causes of soil organic carbon reductions [25]. With the adoption of sustainable management practices, such as conservation tillage, agricultural soils can increase the amount of soil organic carbon and contribute to mitigate carbon dioxide (CO2) emissions [26]. However, the magnitude of conservation tillage response can considerably vary depending on soil and climate conditions. In addition,[3] reported that, tillage operations can contribute significantly to soil compaction and dust emissions, resulting in reduced yield and degradation of the environment. [27] stated that the wind and water erosion hazard is one of "clean-tilled" system outputs. [28] confirmed that the improvement of hydraulic characteristics of soils as due to increased porosity and decreased bulk density resulting from tillage, were temporary and will last soon after the first irrigation when the recently tilled soil particles settle back to its former conditions of bulk density, and thus block water pores. For all that, when energy, time and impact of tillage on soil are to be reduced, the working depth, intensity and action of tillage should be kept at the minimum level [29]. The objective of this study is to determine the effect of tillage on the penetration resistance of different agriculturalsoiltypes inSouth-East region of Nigeria.

II. MATERIALS AND METHOD

2.1 Experimental Area: The experiment was conducted at different locations in south-east agricultural areas. Namely:Abia, Anambra, Ebonyi, Enugu and Imo State. South-east zone lies approximately latitudes 4° 47′ 35"N and 7° 7′ 44"N, and longitudes 7° 54′ 26"E and 8° 27′ 10"E [30], with a land area of approximately28, 873km$^{2.}$ They have fertile and well drained soils; and the people are essentially farmers. The soil map of south-east agricultural region of Nigeria is shown below (figure 1).

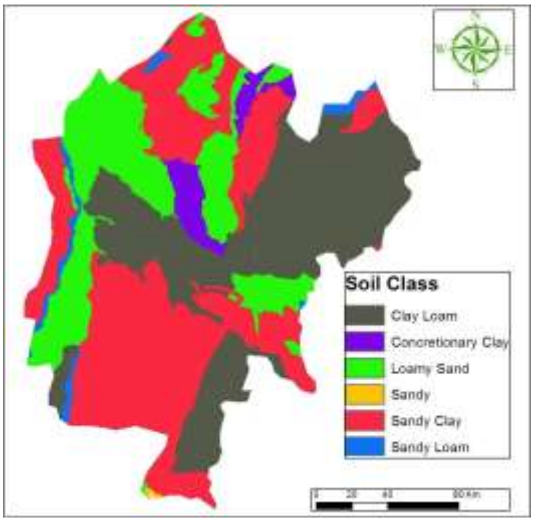

Figure 1. Soil map of south east zone. source: [30]

2.2 Machine, implements and apparatus used: Three tillage implements namely: plough, harrow and ridger were used for the study. A Massey Fagunson tractor of model MF375E and capacity of 58.8 kW with three points hitch was used to power the implements. Other apparatus used are slider hammer and metre rule for soil compaction and measurements of soil depths, respectively.

2.3 Experimental methods/procedure: The experiment was conducted on the tilled and untilled (zero tilled) soils. The tillage operation was conducted using the plough, harrow and the ridger; and measurements of soil resistance to penetration were taken under different soil depths using a cone penetrometer.

Prior to the test, the soil physical characteristics such as soil type, texture, structure, moisture contents, bulk density and porosity were determinedas adopted by [31].

2.3.1 Measurement of soil resistance to penetration: A hand operated cone penetrometer was used. Five points on the tilled and untilled areas located randomly at various study sites were taken for the study.The cone of the penetrometer was placed on the soil surface with the shaft oriented vertically [9]. The cone remained in this position constantly to reduce variations that may likely occur at the initial depth. The cone while in position was pressed into the soil until it is completely buried. The initial penetration is regarded as zero (0) blow. The slider hammer is raised and released one, two or more times depending on the soil strength. The depth of penetration after each blow and the total blows to achieve the required depth werenoted. The process was repeated until the requireddepth for the experiment is achieved. The researcher used 600mm as the required depth for the experiment as adopted by [12]and also used by [9].

III. RESULTS AND DISCUSSION

3.1 Results:Results obtained from the research work are presented in tables 1 to 6

Table 1. Effect of tillage with depthon soil penetration resistance (kg/mm^2) for clay- loam soil

Soil Depths (mm)	Tillage implements			
	Plough	Harrow	Ridger	Untilled
0 – 50	2.9	0.8	0.5	3.4
50 – 100	3.3	1.6	1.03	5.7
100 – 150	4.6	2.9	1.5	7.3
150 – 200	5.8	3.7	1.9	7.8
200 – 250	6.1	4.8	2.8	9.4
250 – 300	7.8	6.5	4.2	9.8
300 – 350	8.2	12.5	5.7	13.8
350 – 400	14.3	10.4	7.9	13.5
400 – 450	12.1	8.3	5.1	13.0
450 – 500	11.6	7.9	6.0	10.5
500 – 550	9.4	8.7	6.8	11.2
550 – 600	10.9	9.6	7.3	12.7
Mean	**8.08**	**6.48**	**4.23**	**9.84**

Table 2. Effect of tillage with depth on soil penetration resistance (kg/mm^2) for sandy- loam soil

Soil Depths (mm)	Tillage implements			
	Plough	Harrow	Ridger	Untilled
0 – 50	2.0	0.5	0.3	2.5
50 – 100	2.6	1.1	0.7	4.6
100 – 150	3.8	1.8	1.3	6.3
150 – 200	5.3	2.7	1.8	6.5
200 – 250	5.9	3.2	2.2	8.0
250 – 300	12.3	4.5	3.8	12.8
300 – 350	10.8	5.9	4.9	11.5
350 – 400	10.6	10.5	7.2	11.3
400 – 450	6.2	9.4	5.1	10.7
450 – 500	7.8	7.6	5.8	8.2
500 – 550	9.4	7.3	6.2	9.5
550 – 600	9.9	8.6	6.7	9.3
Mean	**7.22**	**5.26**	**3.83**	**8.43**

Table 3. Effect of tillage with depth on soil penetration resistance (kg/mm^2) for sandy-clay soil

Soil Depths (mm)	Tillage implements			
	Plough	Harrow	Ridger	Untilled
0 – 50	2.0	1.2	0.7	3.2
50 – 100	3.1	1.7	1.2	5.4
100 – 150	4.3	2.9	1.4	7.2
150 – 200	5.6	3.5	1.6	7.6
200 – 250	6.3	4.8	2.4	9.0
250 – 300	8.0	6.5	4.0	9.3
300 – 350	7.8	8.4	5.1	13.8
350 – 400	13.3	7.9	5.1	13.2
400 – 450	12.1	11.5	7.4	12.7
450 – 500	11.1	10.4	6.2	12.0
500 – 550	9.4	8.3	6.5	10.5
550 – 600	10.4	8.6	7.0	11.2
Mean	**7.22**	**5.26**	**3.83**	**8.46**

3.2 Discussion

Table 1 presents the effect of tillage with depth on soil penetration resistance in kg/mm^2 for clay- loam soil. Results of these table revealed that the clay- loam soil has its highest strength or resistance to penetration within the upper layer of the soil (depth range of 350-400mm). Within this depth the soil registered a penetration resistance of 14,3kg/mm^2 for plough, 10.4kg/mm^2 for harrow, 7.9kg/mm^2 for ridger and 13,3kg/mm^2 for zero tillage. This is in agreement with [9]. The tillage implement was capable of improving the average penetration resistance of the entire soil from 9.84kg/mm^2 of zero tilled soil to 8.08kg/mm^2, 6.48kg/mm^2 and 4.23kg/mm^2 with plough, harrow and ridger respectively.

Table 2 reveals the effect of tillage with depth on soil resistance to penetration in kg/mm^2 for sandy- loam soil. From this result it is observable that sandy- loam soil has its penetration resistance at depth range of 250-350mm; with resistance to penetration of 12.3kg/mm^2, 10.5kg/mm^2, 7.2kg/mm^2 and 12.8kg/mm^2 for plough, harrow, ridger and zero tillage respectively. The engagement of tillage implement enhanced the overall average penetration resistance and brought it down from 8.43kg/mm^2 of zero tilled soil to 7.22kg/mm^2 for plough, 5.26kg/mm^2 for harrow and 3.33kg/mm^2 for ridger. This is also in consonance with the findings of [9] for top soil.

Table 3 show the result of the effect of tillage with depth on soil resistance to penetration for sandy- clay soil. From the table the highest resistance to penetration was within the depth range of 300-400mm. the average penetration resistance at this depth range was 13.3kg/mm^2 for plough, 11.5kg/mm^2 for harrow, 7.4kg/mm^2 for ridger and 13.8kg/mm^2 for zero tillage. With the adoption of the tillage implements, the overall average penetration to resistance was improved from 8.46kg/mm^2 of zero tilled soil to 7.22kg/mm^2, 5.26kg/mm^{2}and 3.83kg/mm^2 for plough, harrow and ridger respectively.

IV. CONCLUSION

The highest soil resistance to penetration was recorded in the upper layer of zero tilled soil than the deep tilled soils as observed by [9] and [19]. This upper layer was found to fall within the mean depth range of 250 - 400mm. However, the adoption of tillage implement reduced the penetration resistance of soils; thereby creating large stable aggregates which will permit root penetration to the soil.In all the soils studied, the zero tilled soil gave the highest mean penetration resistance followed by the ploughed soil; while the harrow and the ridger decreased the average penetration resistance of the soils.

V. RECOMMENDATION

Tillage operation improves soil aggregation stability and tends to reduce the bulk density and compaction effect of the soil.Thefollowingrecommendation can be made based on the findings from the study:

1. Agriculturalsoils should by well tilled during seed bed preparation to improve soil aeration, aggregation, root penetration, tilth and create good and enabling environment for root growth and development.
2. Knowledge of soil physical properties is necessary for timing of tillage operations.
3. Primary tillage should be adopted on agricultural soils to alleviate compaction caused by field activities.
4. Tillage should be adopted in farming system to incorporate soil nutrients.

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