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Original Research Article

Effect of Soil Type and Conditions on Field Efficiency of Selected Tractor-Hitched Farm Implements in South Eastern Nigeria

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ABSTRACT

The effect of soil type and conditions on the field efficiency of some selected tractor-hitched implements in south-east Nigeria was studied. This was to obtain data on the efficiencies of the implements based on soil types/conditions in the area for proper selection, to avoid unnecessary breakdown or wastage of energy during operation. The implements studied include plough, harrow, rotovator, ridger and planter using a Massey Ferguson tractor of model MF 430E and capacity of 55.2 kW. Results obtained revealed that the average performance efficiency of all the implements was highest on sandy-clay soil with plough recording average field efficiency of 88.07%, harrow 89.12%, ridger, rotovator and planter having average field efficiencies of 88.03%, 87.64% and 84.92%, respectively. The average moisture content of the soils before tillage operation was 17.74%, thereafter the moisture content reduced to 16.3% (w.b) after ploughing, 15.45% (w.b) after harrowing, 14.70% (w.b), 14.23% (w.b), and 14.13% (w.b) after ridging, pulverization with rotovator and planting operations, respectively. Furthermore, the average bulk density of the soil decreased from initial value of 1.62 gcm^{-3} obtained prior to the field operations to 1.48 gcm^{-3}, 1.40 gcm^{-3}, 1.33 gcm^{-3}, 1.29 gcm^{-3} and 1.35 gcm^{-3}, respectively after ploughing, harrowing, ridging, rotovator and planting operation.

1. INTRODUCTION

Soil type and condition are important factors that affect the field performance of machineries through their effects on the tractor traction and powered implements (Oduma et al., 2018). Smith (1993) observed that the performance of plough varies considerably according to the type of soil, its moisture content, weed growth, crop residues and shape of the field. John et al. (1987) posited that when soil condition such as the soil compaction increases, the bulk density also increases and consequently the soil penetration resistance became high. When soil conditions are poor for machine operations, the rate of operation is affected. This condition according to Alnahas, (2003) will improve field efficiency but it is not, of course, a desirable operating condition. An extreme time loss may occur in harvesting operation if the crop has been windblown to such a position that it can only be harvested from one direction.

Soil conditions that affect machine operations are mostly vegetative cover, topography and soil physical properties such as soil moisture, soil texture and structure, porosity and bulk density. Texture is described as the particle sizes of the sand, silt and clay that make up the soil (White et al., 2014). The measure of coarseness or fineness soil feels is dependent upon the size of the mineral particles. Sand, silt and clay, are the major composite mineral particles that make up the sizes and numbers of the soil's pore spaces. Soil structure is the systematic positioning or arrangement of different soil particles (sand, silt and clay) into larger aggregates called peds (Brandy, 2008). This decides how permeable a soil is, how well it holds water and nutrients, and how easily it permits plant roots to penetrate and grow. Soils that are ideal for plant growth cling/bind together and form moderately loose, granular aggregates that approximate the sizes of cookie crumbs and hold water and nutrients. According to Arshal et al. (1996), bulk density defines the soil's capacity to function for structural support, water and solute movement, and soil aeration. Bulk densities beyond thresholds show impaired function. The soil bulk density expresses the physical, biological and chemical features on volumetric basis of soil quality examination and comparisons between management systems (Murthy, 2012). Soil porosity is the ratio of volume of voids to the total volume of soil sample. Bulk density is a widely used indicator for determining porosity. It is a measure of the sizes of porous spaces present in the soil for water and air circulation in the soil (Cassel, 1982). High porosity (low bulk density) result to poor water retentions and low porosity (high bulk density) minimizes soil aeration and causes high soil penetration resistance, restricting root growth (Cassel, 1982).

Hunt (1979) asserts that measures of agricultural machine performance are the rate and quality at which the operations are being accomplished. Tillage operations are soil-related procedure. Soil type and condition are major factors that affect the field performance of tractor because of their impact on the tractor-hitched implement and traction force of the tractor in operation (Belel and Dahab, 1997). The field performance of plough differs extensively with the type of soil, water content, weed growth, crop residues and shape/pattern of the field (Smith, 1993). According to Alnahas (2003), soil physical characteristics which affect crop production and tillage requirements, are difficult to examine directly; these include size, shape, and arrangement of solids and volume of voids, and forces relevant to physical soil properties. Lal (1995) stated that structural stability is usually studied in terms of different soil features like total porosity, distribution of pore sizes, moisture content, and bulk density. The implements in the firm soils need a greater draft force to overcome a considerable amount of soil resistance, thus the draft force needed to drive/pull the hitched implement in firm soil condition is higher than that of loose condition (John *et al.*, 1987). High bulk density, higher slippage and increased fuel consumption, and decreased operating speed is be achieved in the firm soil. Belel and Dahab (1997) observed that, the implement in firm soil conditions gave better field efficiency than in loose ones. Osman (1964) added that many factors affect the draft of an implement. They include draft of blades, cohesion force in soil, soil type, moisture content etc. Salokhe and Shirn (1992) reported that increase in soil water content and disc angle, decreased the draft requirement. Similarly, Dahab and Mohamed (2002) observed that there are significant differences in traction performance between tested implements because of soil moisture content, and tire inflation pressure. Belel and Dahab (1997) observed that implement type also affects draft, and they attributed the lower draft force of disc plough to the effect of rotating disc elements. Riethmuller (1989) reported that all the implements tested in their study of the draft requirement of tillage implements showed linear increase in draft force with cutting depth and working speed. Bukhari *et al.* (1982) observed that wheel slip is increased in clay loamy soil, when the speed of ploughing increased and the energy consumption depends on many indicators/factors including soil type and strength, tilling depth, forward speed and quality of tillage. Shebi *et al*., (1988) and Kepner *et al*., (1982) described the effects of soil type as they reported that clay soil has a higher break up energy requirement than sandy loamy soils and for a given soil, fuel consumption (i.e energy requirements) increased with bulk density. Ahmed and Haffar (1992) noticed that variations in fuel consumption were attributed mainly to draft characteristics and depth of work. On the other hand, Bukhari *et al*., (1992) confirmed that disc harrow needed more fuel per hour because of high engine speed of operation. This shows that, as the plough width is increased, the energy efficiency to cut the soil is increased. Belel and Dahab (1997) observed that the waste of energy in tractors was minimized when wheel slippage was adjusted between 15% and 18%. Yassen et al. (1992) in contrast argued that, for a disc harrow, field efficiency increased in both states of soil (firm and loose) with the increase in soil texture coarseness and that disc plough has increasing field efficiency but at an increasing rate when working on coarser textured soils.

Data are not available under local conditions to quantify the effect of soil type and conditions on farm implement performances in South-east Nigeria which will enable farmers select appropriate machines/implements for their farm operations to avoid unnecessary breakdown/failures or wastage of energy during operation. Therefore, it is imperative to examine the effect of soil type and conditions on the performances of some selected agricultural field machineries under field conditions. This research on various agricultural operations with some tractor-hitched implements is aimed at obtaining data on the effect of soil type and conditions on the field efficiencies of the implements under field conditions in the study area.

2. MATERIALS AND METHODS

2.1. Materials

2.1.1. Description of experimental sites

The experimental sites were divided into four units of 45 x 45m each for random observations. Each unit was separated by a distance of 2.5m from the other to avoid interaction between the plot borders and to be equally used as head lands for the commencement of the experimental operations. The tests were conducted in May, through June, July and August, 2016 which coincide with planting season of the year; and which also offer the tractor and the hitched implements an exposure to a wide range of soil conditions.

2.1.2. Description of machine used for the test

A Massey Ferguson of model MF430E and capacity of 55.2 kW (74 hp) was used for the study. The same operator was used for the operation of the machine throughout the test to ensure minimal variations in operation skill/style throughout the study. The hitched implements that were studied include ploughs, harrows, rotovators, ridgers, and planters.

2.2. Methods

2.2.1. Determination of soil physical properties

Soil samples freshly tilled and free of organic matter, stones, stumps or plant roots was collected from different parts of the experimental site, to a depth of 0-20cm and were bulked together to form a composite sample (Okeke et al, 2016), for laboratory test. The core- cutter apparatus was used specifically to collect soil sample for bulk density measurement (Oduma et al., 2018).

2.2.2. Determination of soil moisture contents

The oven-dry method of moisture content determination was used to determine the moisture content of the soil. In the process, the weight of initial samples of soil (wet soils) collected from the site and the weight of oven-dry samples of the same soils (dry soils) was determined in the laboratory and the moisture content was evaluated from Equation 1 (Murthy, 2012)

$$M_C = \frac{Ws - Ds}{Ds} \times 100\% \quad (1)$$

Where M_C = moisture content of the soil (%), W_S = weight of wet soil (initial soil sample) (kg) and D_S = Wight of oven-dry soil (kg)

2.2.3. Determination of soil textural class (soil type)

The mechanical soil analysis method was adopted from Oduma et al. (2018) in which a freshly tilled soil free from gravel, stones, plant roots/stumps and organic matters was collected with an air tight container for a quantitative determination of the particle sizes (sand, silt and clay) in the laboratory. The soil sample was properly oven-dried and finely ground, to free all the separate particles. The total weight of the soil sample was accurately measured; and was passed through a series of mechanical sieve with mesh of different sizes ranging from 2.0 to 0.002 mm in diameter. The weight of the contents of each sieve after mechanical shaking was determined separately and expressed as a percentage of the initial weight of the fine sample; and the textural class of the soil was finally determined using the textural triangle (USDA, 2010).

2.2.4. Determination of soil bulk density

The cylindrical core-cutter method was used to determine the soil bulk density and evaluated from the expression suggested by Murthy (2012)

$$\rho = \frac{Ws}{Vs} \quad (2)$$

Where ρ = bulk density (g cm^{-3}) W_S = weight of dry soil sample (g) and V_S = volume of dry sample of soil (cm^3) (equal to the volume of the cylindrical cutter)

2.2.5. Determination of soil structure

The disruptive method for assessing soil structure according to Diaz-Zorita (2002) was used to determine the soil structure of the area; by drop shatter technique in which the bulk sample of the soil is broken into smaller natural units/fragments of peds along planes of weakness by dropping the soil sample from various heights into a hard surface (Hadas and Wolf, 1984); and the shape of peds formed was observed and recorded as adopted by Oduma et al. (2018).

2.2.6. Determination of soil porosity

The soil porosity was evaluated from Equation (3) suggested by Danielson and Sutherland, (1986).

$$\text{Porosity} = 1 - \frac{\text{Bulkdensity}}{\text{average density of soil particles}} \times 100\% \quad (3)$$

Density of soil particles was determined from the expression adopted by Murthy (2012) as:

$$\gamma_w = \frac{Wt}{Vt} \quad (4)$$

Where γ_w = unit weight of soil sample (kN m^{-2}), Wt = wet weight of soil sample (kN) and Vt = total volume of soil sample (m^3)

2.2.7. Field performance characteristics test

The field operations such as ploughing, harrowing, ridging, pulverization and sowing were generally performed longitudinally with the implement full width at selected forward speeds and cutting depth, the distance travelled and the corresponding time taken to complete the working distance were noted; and the total productive and delay time were recorded (Afzalina et al., 2006). Furthermore, in the evaluation of the performances of planter, 50 kg of maize grains were planted on the prepared seed bed on each site of the study area (Oduma et al., 2019).

2.7.8. Measurement of productive and delay (idle) time

The total time spent on the entire row length operation and the delay or idle time encountered in the operation which include, time for refilling the tank, time for repair of breakdown/adjustments, turning time, and any other idle time observed was noted and the actual time (productive time) used in the operation was evaluated from the relationship;

$$T_e = T_t - T_d \quad (5)$$

Where T_e = actual (productive) time (hr), T_t = total time spent on the entire row length operation (hr) and T_d = delay (idle) time (hr)

Measurement of turning time commences immediately the implement is raised on the completion of a row length, to initiate a turn until it turns completely to continue the operation. An average of three replications was taken as the working time.

2.2.9. Determination field efficiency

The field efficiency was determined from the expression suggested by Kepner et al (1982)

$$\mathcal{E} = \frac{100Te}{Tt} \quad (6)$$

Where $\mathcal{E}$ = field efficiency (%), T_e = actual working (productive) time (hr), T_t = total working time = (T_e +T_d) (hr) and T_d = delay or idle time (hr)

O. Oduma et al. / Nigerian Research Journal of Engineering and Environmental Sciences
5(1) 2020 pp. 306-318

3. RESULTS AND DISCUSSION

The results of this research work are presented in Table 1 – 5. Table 1 presents the physical characteristics of the soils. Results of the soil analysis conducted to determine the soil textural class of the soil showed that the dominant soil types in south-east agricultural zone are clay – loam, loamy – sandy and sandy – clay soil as stipulated by Obinna et al. (2004). The average moisture contents of the soils in the study areas before the experiment ranges from 15.7 to 20.4% with clay – loam and sandy – clay soil having the highest moisture contents of 18.9% and 20.4% respectively. The area had bulk density and porosity ranges of 1.47 – 1.68g/cm^3 and 37.40 -50.8% respectively; with granular structure which is a very good soil characteristics for crop production.

Table 1 Physical characteristic of soils in South-East Nigeria

Location	Percentage of soil content/type				Moisture content (%) w.b	Bulk density (g/cm^3)	Porosity (%)	Structure type
	Sand (%)	Silt (%)	Clay (%)	Textural class				
Abia	34.5	36	65	Clay-loam	18.9	1.68	37.40	Granular
Ebonyi	35.2	34	70	Clay-loam	16.3	1.68	37.40	Granular
Anambra	79.5	18	15	Loamy-sand	17.8	1.47	50.80	Granular
Enugu	54	9	45	Sandy-clay	15.7	1.64	48.30	Granular
Imo	54	10	46	Sandy-clay	20.4	1.64	48.30	Granular

Table 2: Effect of soil type on field efficiency of the machines

Soil type	Plough		Harrow		Ridger		Rotovator		Planter	
	Field efficiency (%)	Mc (%) wb	Field efficiency (%)	Mc (%) wb	Field efficiency (%)	Mc (%) wb	Field efficiency (%)	Mc (%) wb	Field efficiency (%)	Mc (%) wb
Clay-loam	87.41	17.12	82.06	16.22	84.41	14.24	87.13	14.20	86.18	13.23
Loamy-sandy	87.47	16.20	85.83	15.43	87.51	14.48	84.91	13.53	85.31	14.48
Sandy-clay	88.07	18.63	89.12	17.32	88.03	17.09	87.64	16.33	87.92	16.21
Mean	87.65	17.32	85.67	16.32	86.65	15.27	86.56	14.69	86.47	14.64

Table 2 shows the result of the effect of soil type on implement performance. The average performance efficiency for all the implements was highest on sandy-clay soil with plough recording 88.07% average efficiency, harrow (89.12%, ridger, rotovator and planter having average field efficiencies of 88.03%, 87.64% and 87.92% respectively; followed by clay-loam that gave average efficiency of 87.41 for plough, 82.06% for harrow, 84.41, 87.13 and 86.18% for ridger, rotovator and planter respectively. The least field efficiency was obtained on loamy-sandy soil in which plough, harrow, ridger, rotovator and planter, respectively had 87.47, 85.83, 87.51, 84.91 and 85.31%. The highest field efficiency observed in sandy-clay could be due to low aggregation stability, high moisture content and low decomposed organic matter found in sandy-clay soil than other soil type as observed by Alnahas (2003).

Table 3: Effect of moisture content (%) on field efficiency (%) of the machines

Soil type	Before tillage	Plough		Harrow		Ridger		Rotovator		Planter	
		MC (%) wb	Field efficiency (%)	MC (%) wb	Field efficiency (%)	MC (%) wb	Field efficiency (%)	MC (%) wb	Field efficie ncy (%)	MC (%) wb	Field Efficiency (%)
Clay – loam	18.9	17.12	87.41	16.22	82.06	14.24	84.41	14.20	87.13	13.23	86.18
Loamy-sandy	17.4	16.20	87.47	15.43	85.83	14.48	87.51	13.53	84.91	14.48	85.31
Sandy - clay	20.4	18.63	88.07	19.32	89.12	17.09	88.03	16.33	87.64	16.21	87.92
Average	17.74	16.30	87.11	15.45	86.32	14.70	86.78	14.23	87.14	14.12	86.81

Results of soil moisture content before and after field operations are shown in Table 3. The highest average moisture content of 17.7% was recorded before tillage. After tillage, ploughing recorded 16.3% moisture content, harrowing, ridging, pulverization and planting in that order recorded 15.45%, 14.70%, 14.23% and 14.125 respectively. The decrease in the moisture content obtained during the field operation was as a result of the break-up of the initial compacted virgin soil which exposed it to direct effect of sun rays thereby inducing evaporation of moisture on the soil. However, the highest moisture content recorded for the plough operation as compared to other implements may be attributed to high compaction (which decelerates infiltration rate) associated with ploughing operation. More so, it may be due to the soil inversion and high penetration in ploughing operation as noticed by Omer et al. (2015). From the result it was noticed that the efficiency of the machine generally increased with the increase in moisture content.

Figures 1 – 3 present the bar chart of the variation of field efficiency of the implements with moisture content of the soils. From the bar charts it was observed that the efficiency of the implements increases with the increase in the moisture contents. The bar chart showed that the sandy-clay soil with the highest moisture content gave the highest field efficiency, followed by the clay-loam soil and least was the loamy- sandy soil for all the field operations. These results corroborate with the findings of Olatunji (2011). It therefore shows that for well-drained and granular structured soils, tractor-hitched implements attain maximum field efficiency at moisture content level range of 18-20% (wb).

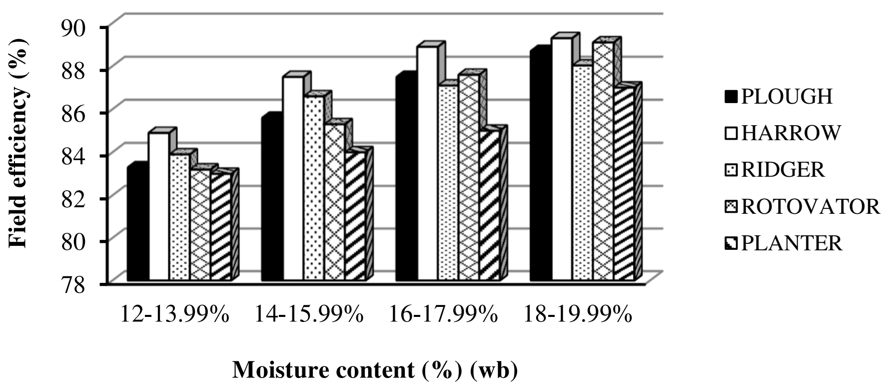

Figure 1: Variation of field efficiency of the implements with moisture content on clay-loam soil

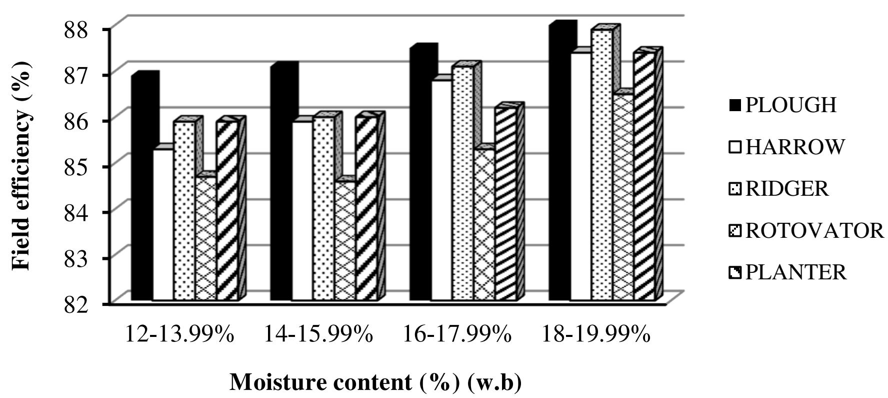

Figure 2: Variation of field efficiency of the implements with moisture content on loamy-sandy soil

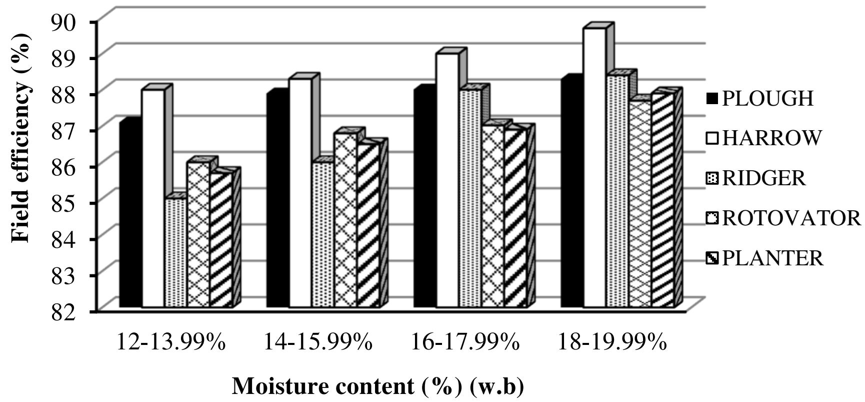

Figure 3: Variation of field efficiency of the implements with moisture content on sandy-clay soil

Table 4: Effect of bulk density (g/cm^3) on field efficiency (%) of the machines

Soil type	Before tillage	Plough		Harrow		Ridger		Rotovator		Planter	
		BD (g/cm^3)	Field efficiency (%)	BD (g/cm)	Field efficiency (%)	BD (g/cm^3)	Field efficiency (%)	BD (g/cm^3)	Field efficiency (%)	BD (g/cm^3)	Field efficiency (%)
Clay – loam	1.68	1.54	87.41	1.49	82.06	1.40	84.41	1.35	87.13	1.38	86.18
Loamy–sandy	1.47	1.39	87.47	1.28	85.83	1.21	87.51	1.18	84.91	1.22	85.31
Sandy –clay	1.64	1.49	88.07	1.40	89.12	1.32	88.03	1.29	87.64	1.40	87.92
Average	1.62	1.49	87.11	1.40	86.32	1.33	86.78	1.29	87.14	1.35	86.81

Results of Table 4 revealed that the bulk density reduces with the application of tillage implements. Prior to the field operation, the average bulk density of the soil was 1.62 g/cm^3 but when the implements were applied, there was reduction or improvement in the bulk densities in which ploughing gave 1.48 g/cm^3, harrowing recorded 1.40 g/cm^3, ridging (1.33 g/cm^3), rotovator (1.29 g/cm^3) and planter recorded 1.35 g/cm^3. The bulk densities obtained during the operations were within the range defined by Chi *et al.* (1993) for usual agricultural soils. The reduction or lower bulk densities recorded when the implements were applied as compared to the initial bulk density (i.e. when the implements have not been applied) was evidence of the improvement on the soil for crop growth, root development and better yield. Finally, the field efficiency of the machines was higher at low bulk density soil as compared to soil with higher bulk densities.

Figure 4 - 6 present the relationship between the bulk density of the soil and the field efficiency of the various implements studied. According to the curves, the field efficiency of the implements decreases with the increase in bulk density of the soil, showing that the bulk density of the soil is inversely proportional to the field efficiency of the implements. The decrease in the field efficiency with the increase in the bulk density of the soils showed that more energy will be required to break up the compacted soil than loosed ones. Clay-loam recorded the highest initial bulk density and therefore requires more draft force (high energy) to break up as compared to other soil types. The higher bulk density recorded at the location of clay-loam soil as compared to the other soils may be as a result of the variation in the structural conditions of the soil as described by (Chen et al, 1998)

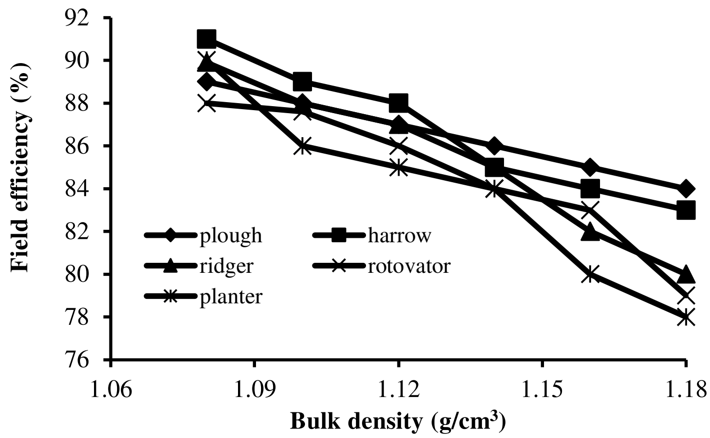

Figure 4: Variation of bulk density on field efficiency of the implements in clay-loam soil

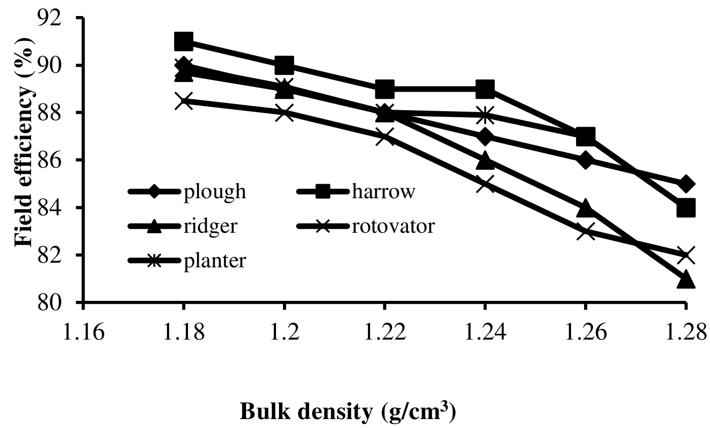

Figure 5: Variation of bulk density on field efficiency of the implements in loamy-sandy soil

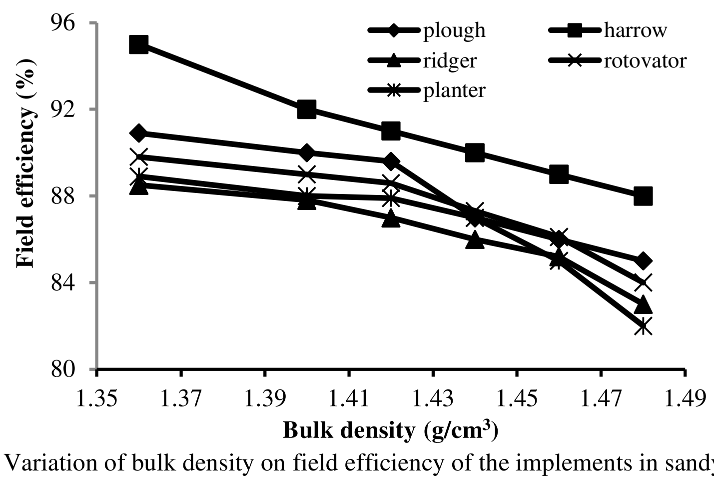

Figure 6: Variation of bulk density on field efficiency of the implements in sandy-clay soil

Table 5 shows the effect of porosity on implement performances. It is observable from the results that the effects of porosity on the performance of the implements follow the same trend as bulk density. The lowest porosity values were observed in zero tilled soil (before tillage) with average porosity value of 48.30%. The highest porosity was recorded on the loamy-sandy soil followed by sandy-clay and least was obtained on the clay-loam soil. Results obtained showed that the higher the bulk density, the lower the porosity; according to Chen et al (1998), this is due to the variation in the structural conditions of the soil. During the field operation ridger gave the highest average porosity value of 54.14%. The plough, harrow, rotovator and planter in that other gave average porosities of 49.68%, 53.43%, 54.11% and 53.67% respectively. Finally, the field efficiency of the machine increases with the increase in porosity of the soil.

Table 5: Effect of porosity (%) on field efficiency of the machine

Soil type	Before tillage	Plough		Harrow		Ridger		Rotovator		Planter	
		Porosity (%)	Field efficiency (%)	Porosity (%)	Field efficiency (%)	Porosity (%)	Field efficiency (%)	Porosity (%)	Field efficiency (%)	Porosity (%)	Field efficiency (%)
Clay – loam	37.40	45.22	87.41	48.18	82.06	48.20	84.41	45.82	87.13	48.13	86.18
Loamy–sandy	50.80	55.25	87.47	57.25	85.83	50.28	87.51	53.25	84.91	58.22	85.31
Sandy – clay	48.30	51.38	88.07	57.52	89.12	55.20	88.03	52.55	87.64	52.53	87.95
Average	48.30	49.68	89.11	53.43	86.32	54.14	86.78	54.11	87.14	53.67	86.81

Figure 7 – 9 show the relationship between the porosity and the implement performances; the figures indicate that the field efficiency of the implement increase with increase in soil porosity (i.e., field efficiency of the implement is directly proportional to the soil porosity). The soil porosity has a reverse trend with the bulk density as per field efficiency. It implies therefore that the application of the implements enhances the porosity of the soil thereby making way for proper air and water circulation in the soil.

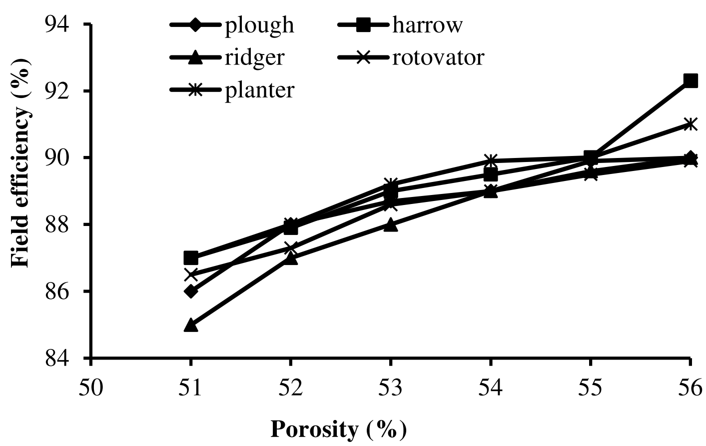

Figure 7: Variation of porosity on field efficiency of the implements in clay-loam soil

O. Oduma et al. / Nigerian Research Journal of Engineering and Environmental Sciences
5(1) 2020 pp. 306-318

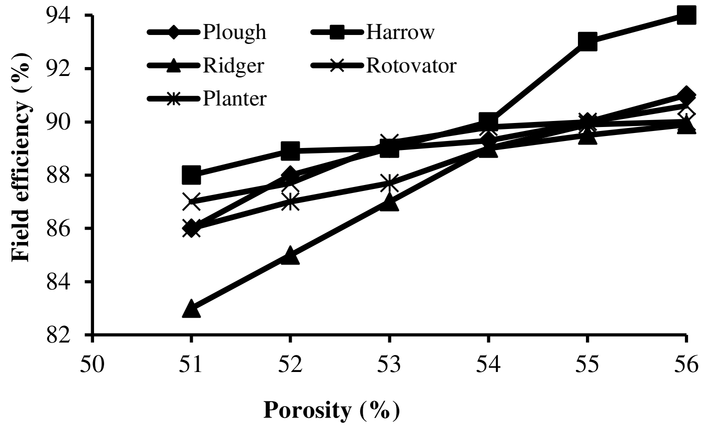

Figure 8: Variation of porosity on field efficiency of the implements in loamy-sandy soil

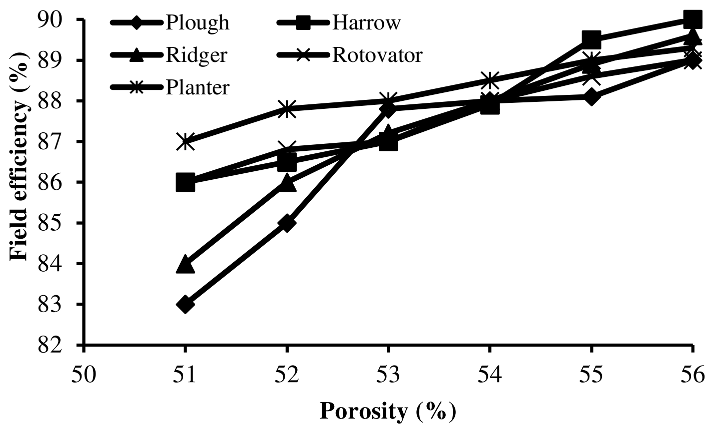

Figure 9: Variation of porosity with field efficiency of the implements in sandy-clay soil

4. CONCLUSION

Based on the findings made from this work, the following conclusions can be drawn about the study:

i. Sandy-clay soil with the highest moisture content gave the highest field efficiency followed by the followed by the clay-loam and least was the loamy-sandy soil for all the operations.

ii. The field efficiency decreases with the increase in the bulk density of the soils while the soil porosity recorded a reverse trend with the bulk density as per field efficiency. On the other hand, the field efficiency increases with the increase in moisture content of the soil.

iii. The reduction in the bulk density of the soil after the operation was an evidence of soil improvement associated with tillage operation which enhances proper air and water circulation in the soil for crop growth and development.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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