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SLOPE POSITION AND DEPTH EFFECTS ON SELECTED SOIL PHYSICAL PROPERTIES UNDER OIL PALM (*Elaeis guineensis*) PLANTATION

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ABSTRACT
A study was conducted to examine the influence of slope position and depth on soil physical properties in an oil palm (*Elaeis guineensis*) plantation established on a gently sloping terrain in NIFOR Benin, Nigeria. A line transect was delineated along the slope of the selected plantation. The line transect was 45 m long and 45 m wide. It was divided into three equal slope segments namely; Summit, Mid and Bottom slopes respectively. Each slope was further sub-divided into three (3) quadrants measuring 15 m x 15 m making a total of nine (9) plots. Random sampling covering four depths (0-15 cm, 15- 30 cm, 30-45 cm and 45-60 cm) for soil physical properties determination was done. A Garmin 12 GPS was used to geo-reference each sampled point in the field. The soil physical properties considered in this study were bulk density, soil moisture, porosity, saturated hydraulic conductivity and particle size distribution using standard methods. The result of the statistical analysis revealed a significant difference ($P<0.05$) among the soil properties in different slope positions and depths. Major factors accounting for the variations in the soil properties studied were the slope position and soil depth. Slope position had a significant effect ($p<0.05$) bulk density and porosity. Soil depth significantly affected ($p<0.05$) all soil properties studied. The highest clay content occurred at the bottom slope position and depth. The more clayey sites are characterized with higher effective Cation exchange capacity and thus plantations cultivated on such sites would be more productive and sustainable. The findings strengthen the fact that slope position and depth have a strong relationship with soil physical properties.

Key words: Slope position, depth, Oil palm, soil physical properties, GPS

INTRODUCTION

Soil is composed mainly of mineral particles, organic matter, organisms, air pores and water all which relate to one another and with plants and microbes to form an ecosystem. The suitability of a soil for sustaining plant growth and biological activity is a function of its physical and chemical properties (Mulumba and Lal, 2008). The spatial variability of soil properties depends mainly on the soil position and depth in the local topography. Certain landscapes have significant differences in soil physical properties due to spatial variability and can be a major reason for variability in crop yields (Terra *et al.,* 2005). In development of soils the slope aspect plays an important role but the position of a soil on a slope has been also found to affect the properties of soil.

Soil depth gives an indication of the soil volume which can be utilized by the plant and which is conducive to moisture retention. Soil physical properties affect water and chemical movement in the soil and can have significant impact on crop productivity and the environment. Plantation agriculture features the production of crops in monoculture in large commercial estates and has become a vital part of the agricultural economy of tropical Africa (Aweto and Enaruvbe, 2010).

The oil palm which is a plantation crop provides one of the leading vegetable oils produced globally, accounting for one- quarter of global consumption and approximately 60% of international trade in vegetable oil (World Bank, 2010).

Several studies relate soil properties to landscape position. Brubakar *et al.* (1993), studied the soil properties in relation with landforms position found significant differences among soil properties of sand and silt. Other studies were carried out by Wysocki *et al.* 2001; Ogunkunle, 1993).

Due to marginal agricultural crop return, steep land research had not been extensively explored. An understanding of the interrelationship between soil properties and slope position is of pivotal importance to the management of soils in different topographic position in the land scape.

The study was undertaken to examine the characteristics of soil physical properties as influenced by slope position and depth.

MATERIALS AND METHODS

Study Area

This study was conducted at the Nigerian Institute for Oil palm Research (NIFOR) Main Station Benin, Edo State. It has an altitude of 149.4 m above sea level and lies on latitude $06^0$33'N and longitude $05^0$37'E in the rainforest ecological zone of Nigeria. It has a tropical rainforest climate with a bi-modal rainfall regime. The Annual rainfall is between 1500 mm- 2500 mm with a mean annual rainfall of about 1700 mm. Most of the rains are concentrated in the wet season lasting from March to October. Two periods of peak rainfall occur in June – July and September – October, the two peaks being separated by a relatively dry period in August. Temperatures are relatively uniform throughout out the year, with an annual average of 31ºC and no marked seasonal or monthly departure from the annual average. The soils are classified into four soil series namely; Alagba, Orlu, Ahiara and Kulfo soil series which are Rhodic Paleudult and Typic Dystropet according to U.S. Taxonomy (Ogunkunle, 1982).

Field Study

An existing twenty eight (28) years old Oil palm plantation on a gently sloping land in the study area was used for this research work. A line transect was delineated along the slope of the selected plantation. The line transect was 45 m long and 45 m wide. It was divided into three equal slope segments namely; Summit, Mid and Foot slopes respectively. Each slope was further sub-divided into three (3) quadrants measuring 15 m x 15 m making a total of nine (9) plots.

Land Slope Determination

On the marked field an automatic level instrument mounted on a tripod stand and a graduated leveling staff was used to obtain the elevation of four different points along the drainage of the slope line at intervals of 15 meters. In total, sixteen (16) elevation points were obtained. A Garmin Global positioning system (GPS) 12 was used to obtain the co-ordinates of each point. The data obtained from the field survey was used to generate a topographic map. Graphical plots of elevation against drainage were used in determining the slope of the study area

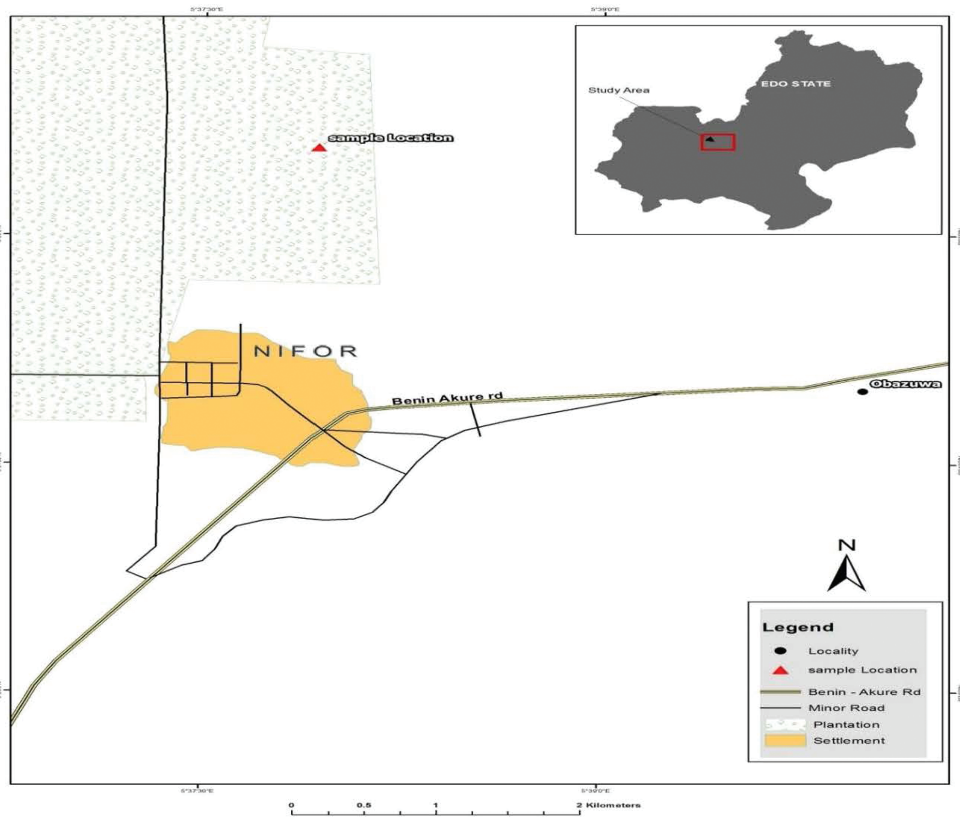

Figure 1: Map of the study area.

based on the information from the topographic map. Auto-CAD software version 10.0 was used. The slope direction also known as aspect was determined with a compass in the northern and eastern direction.

Soil sampling and analysis

A systematic design was employed in sampling for soil physical properties determination. Four depths were chosen in the soil sampling. The depths were 0-15 cm, 15-30 cm, 30-45 cm and 45-60 cm using a core sampler and soil auger. The sampling depths were chosen because the roots of oil palm are concentrated in the 0-60 cm depth of the soil (Ogeh and Osiomwan, 2012). A single sampling point was randomly selected in each quadrant for the soil physical properties determination. Each sampling point was geo- referenced using a Garmin GPS 12.

Soil cores were used to obtain undisturbed soil samples used in the determination of bulk density and hydraulic conductivity. Soil particle size distribution was determined by the hydrometer method (Bouyoucos, 1951). Bulk density was determined for undisturbed soil using core sampler. Saturated hydraulic conductivity was determined using the constant-head method. Moisture content was determined with an automated moisture analyser

Soil porosity was determined from the relationship between bulk density and particle density.

$$\text{Soil porosity} = \left(1 - \left\{\frac{BD}{PD}\right\}\right) \times 100\%$$

Data Analysis

A two way analysis of variance (ANOVA) was used to test for significant differences in

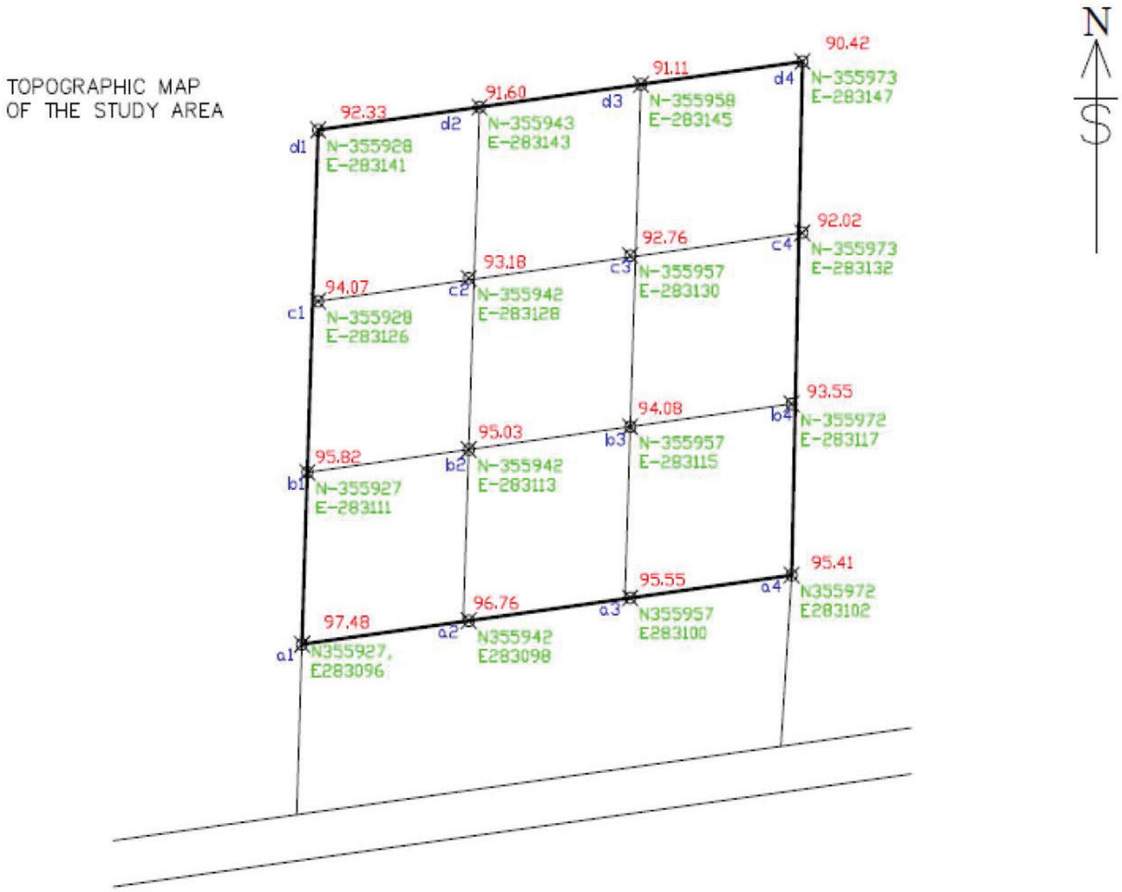

Figure 2: Topographic map of the study area

soil physical properties at different slope positions and depths. For statistical comparison, the means were separated by the least significant difference (LSD) test at 5% confidence level. Relationships among the variables were determined using Pearson's correlation. The statistical package for social sciences (SPSS) version 20.0 was used in the analysis of the data.

RESULTS AND DISCUSSION

Land Slope determination

The slope of the study area was determined from the topographic map (figure. 2) using a graphical plot of elevation against the measured distance (figure 3 and 4) shown below.

The map shows the layout of the field. The elevations observed at each point in the various quadrants at a line distance of 15 meters are also shown in the map. The GPS co-ordinate points at each chainage were captured. The slope was determined along each slope line distance 15 meters apart. The final slope was obtained by taking the average of the various slope lines. The slope was determined in the Northern aspect and Eastern Aspect.

In the Eastern aspect, the first slope line a1-b1-c1-d1 gave three (3) values of 11.11%, 11.50 % and 11.63 % with the average slope being 11.41% i.e. 11.11 + 11.50 + 11.63 = 34.24/3 = 11.41%

The same procedure was repeated for slope line a2-b2-c2-d2 which gave an average slope value of 11.46%, slope line a3-b3-c3-d3 gave an average slope value of 9.87% and slope line a4-b4-c4-d4 gave an average slope value of 11.10 %.

The slope in the eastern aspect was obtained by finding the average of the various slope line values. i.e. 11.41 + 11.46 + 9.87 + 11.10 = 43.84/4 =10.96 % approximately 11%

The land slope in the eastern aspect is 11%.

The same procedure was carried out for the northern aspect. The first slope line a1-a2-a3-a4 gave an average value of 4.6%, slope line b1-b2-b3-b4 gave an average value of 5.03%, slope line c1-c2-c3-c4 gave an average slope value of 4.57% and slope line d1-d2-d3-d4 gave an average slope value of 4.46%. The slope in the northern aspect was found to be 4.65% approximately 5%. Comparing the slope values obtained from both slope aspects the eastern slope had a higher value (11%) when compared with the northern slope (5%). Thus, the study area has an east facing slope.

Slope Position and Depth Effects on Soil Physical Properties

Soil Moisture

There was no significant effect ($p>0.05$) of slope position on the soil moisture. However, the bottom slope had the highest soil moisture content as compared with the summit and mid slope positions but this was not statistically significant p = 105. This agrees with Aweto and Enaruvbe (2010), Ofori *et al.* (2013). Soil moisture was significantly ($p<0.05$) affected by depth. The soil moisture had an increasing trend as the depth increased. 45 - 60 cm depth had the highest value of soil moisture with 0-15 cm having the lowest. This could be due to the accumulation of clay materials in the bottom slope.

Bulk Density

Bulk density is a vital soil property which describes the relative properties of soil and void in a soil. It is a ratio of its mass to its volume. The bulk density varied across the slope positions and depths in the study area. The summit slope ranged from 1.33 – 1.77 g/cm^3, mid slope ranged from 1.43 – 1.79 g/cm^3 and bottom slope ranged from 1.36 – 1.84 g/cm^3 (Table 1. Statistical analysis indicated a significant effect ($p<0.05$) of slope position on the soil bulk density p=.018. The bottom slope position had the highest bulk density values when compared to the mid and the summit slopes. Rasool *et al.* (2014) had a similar result in their work. The high bulk density can be attributed to the higher clay content present in the bottom slope position due to transportation and deposition of materials rich in clay minerals. Depth had a significant effect on the soil bulk density, p=.005 with the highest bulk density experienced in the 45-60 cm depth and the lowest experienced in the 0-15 cm depth.

Saturated Hydraulic Conductivity (Ksat)

Saturated hydraulic conductivity varied across slopes and depth with the summit slope having a range between 0.65 – 7.52 cm/hr, 0.35 – 10.5 cm/hr for mid slope and 0.25 -8.75 cm/hr) for bottom slope (Table 1). Saturated hydraulic conductivity was not significantly affected ($p>0.05$), p = 859 by slope position. Depth significantly ($p<0.05$) affected the saturated hydraulic conductivity of the soil. The highest variation was experienced in the 0 -15 cm depth with the lowest value at 45- 60 cm depth.

Porosity

The porosity of the soil in the study area ranged from; summit slope 33– 50 %, mid slope 32 – 46% and bottom slope was 31 – 49 % respectively (Table 1). The porosity of soil is influenced by the soil type which can ultimately affect soil productivity. Slope position had a significant effect ($p>0.05$) on the porosity of the soil with the highest value obtained at the summit position and the lowest in the bottom slope position. This is in agreement with Rasool *et al.*

Table 1 Soil physical properties at each slope position and depth

Slope position	Depth (cm)	Soil moisture (%)	Bulk density (g/cm^3)	Ksat (cm/hr)	Porosity (%)	Clay (%)	Silt (%)	Sand (%)
Summit	0-15	7.3	1.61	5.12	40	4.15	3.3	92.55
(a_1b_1-a_4b_4)	15-30	7.3	1.45	5.25	45	8	2.1	89.9
	30-45	8.8	1.73	8.5	35	15	1.7	83.3
	45-60	8.6	1.77	0.85	33	20.75	1.05	78.2
	0-15	4.4	1.47	2.76	45	4.15	2.95	92.9
	15-30	6.6	1.33	3.25	50	8.2	2.05	89.75
	30-45	7.6	1.33	2.37	50	13	1.6	85.4
	45-60	7.6	1.34	0.65	49	17.7	1.05	81.25
	0-15	4.2	1.35	7.52	49	3.7	3.8	92.5
	15-30	6.4	1.5	4.87	43	8.7	2.65	88.65
	30-45	7.4	1.65	2	38	14.65	1.65	83.7
	45-60	9.6	1.66	0.85	37	19.9	1.25	78.85
Mid	0-15	3.6	1.57	10.5	41	4.15	3	92.85
(b_1c_1-b_4c_4)	15-30	4.8	1.6	3.87	40	8.5	2.35	89.15
	30-45	5.9	1.64	1.25	38	13.25	1.8	84.95
	45-60	9.9	1.73	0.35	35	19.05	1.2	79.75
	0-15	4.3	1.43	1	46	4	3	93
	15-30	6.2	1.56	4.25	41	8.5	2.2	89.3
	30-45	7.1	1.65	3.87	38	13.3	1.8	84.9
	45-60	7.3	1.58	0.5	40	19.2	0.8	80
	0-15	5.7	1.43	8.5	46	4	3.15	92.85
	15-30	6.7	1.67	8.25	37	8.8	2.35	88.85
	30-45	8.2	1.7	3	36	15.25	1.65	83.1
	45-60	9.1	1.79	1	32	20.1	1.2	78.7
Bottom	0-15	5.9	1.54	5.5	42	4.1	3.15	92.75
(c_1d_1-c_4d_4)	15-30	6.2	1.68	7	37	8.85	2.65	88.5
	30-45	6.9	1.82	1	31	14.75	1.6	83.65
	45-60	8.9	1.84	0.25	31	21.5	0.9	77.6
	0-15	4.9	1.36	7.25	49	3.8	3.3	92.9
	15-30	7	1.61	3.25	39	9	2.55	88.45
	30-45	7.9	1.73	3.25	35	14.7	2	83.3
	45-60	9	1.69	0.25	36	20.8	1.4	77.8
	0-15	6.8	1.53	9.5	42	3.9	3	93.1
	15-30	8.2	1.76	3.75	34	8.3	2.2	89.5
	30-45	8.7	1.63	8.75	38	13.8	1.55	84.65
	45-60	9.6	1.79	1	32	19.3	1.05	79.65

(2014). The lower bulk density in the summit position could explain the higher value experienced for soil porosity. Depth had a significant effect ($p>0.05$) on the porosity of the soil. Porosity had a decreasing trend across the depth. The highest value was in the 0- 15 cm depth while the lowest was in the 45- 60 cm depth.

Particle Size Distribution

The textural class of the soil in the study area based on the particle size distribution (sand, silt and clay fractions) is mainly sandy but becomes loamy sand as the soil depth increases using a soil textural triangle (Table1). The highest concentration of sand was found in the summit slope (table 1). There was no significant difference ($p> 0.05$) across the three slope positions (summit, mid and bottom) in respect to soil particle size distribution. The clay and silt fractions were highest in the bottom slope position with the summit position having the lowest value. Sand was the dominant inorganic fragment in the three slope positions with the highest value occurring at the summit and the lowest value at the bottom slope. However, these differences were statistically non-significant. This is in line with the work of (Aweto and Enaruvbe 2010; Ezeaku and Eze 2014; Farmanullah *et al.* 2013). It was observed that there was an increasing trend of silt and clay going down the slope but a decreasing trend for sand down the slope. Depth had a significant difference ($p<0.05$) on clay, silt and sand fractions across the various depths. The clay content increased down the depth with the highest value obtained in 45- 60 cm and lowest value at a depth of 0-15 cm. the silt and sand fractions were highest at the 0-15 cm and decreased downwards with its lowest value at 45-60 cm depth.

CONCLUSION

The findings from this research reveal that in a sloping terrain soil properties vary along the slope and depth. Major factors accounting for the variations in the soil properties studied were the slope position and soil depth. Slope position had a significant effect on bulk density and porosity. Soil depth significantly affected all soil physical properties studied.

The bottom slope had the highest clay content across the slope positions and depths. More clayey soils as observed in the bottom slope position implies a higher nutrient content since more nutrients will be attracted to the exchange site. Consequently, variations in particle size distribution especially the clay fraction in a predominantly sandy soil such as occured in the study area influence soil fertility status and hence plantation productivity. Further studies can consider other soil physical properties that were not included in this current work.

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