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INFLUENCE OF SLOPE AND DEPTH ON SOIL CHEMICAL PROPERTIES IN AN OIL PALM PLANTATION

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ABSTRACT
A study was carried out in a 28-year old Oil palm (*Elaeis guineesis*) plantation established on a gently sloping terrain in NIFOR Benin, Nigeria to determine the geo-spatial distribution of soil chemical properties as influenced by slope position and depth and also the assess the relationship between soil chemical properties with slope and depth. 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 bottoms slope respectively. Each slope was further sub-divided into three (3) quadrants measuring 15 m x 15 m making a total of nine (9) plots. The slope of the study area was determined from the topographic map generated using a graphical plot of elevation against the measured distance. The slope was determined along each slope line distance 15 meters apart. A total of 72 samples covering four depths (0-15 cm, 15- 30 cm, 30-45 cm and 45-60 cm) were obtained using a soil auger. Each sampling point was geo-referenced using a GPS (global positioning system).Soil chemical properties (pH, O.C, N, P, Ca, Mg, K, Na, H) were determined in the laboratory 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 ($p<0.05$) on soil pH, N, Ca, Mg, K, H, ECEC. Soil depth significantly affected ($p<0.05$) all soil properties studied. IDW was used in generating the surface distribution maps in using Arc GIS 10.1. The findings revealed that slope and depth had a significant effect on the soil chemical properties studied.
Key words: Slope position, Depth, IDW, Soil chemical properties, Quadrant

INTRODUCTION

The physical and chemical properties of soil play a key role in its productivity. Soil properties vary spatially in nature because of variation in soil parent materials and microclimate (Zhao *et al.,* 2007). Topography influences local microclimate by changing the pattern of precipitation, temperature and relative humidity which significantly affect some soil properties (Yimer *et al.,* 2006). Ollinger *et al.* (2002) stated that the spatial variation of soil properties is significantly influenced by some environmental factors such as climate, landscape features, including landscape position, topography, slope gradient and evolution, parent material and vegetation. Several studies have documented that soil properties vary across agricultural fields causing spatial variability in crop yield (Venterea *et al.,* 2003; Bohlen *et al.,* 2001)

Soil characteristics generally show spatial dependence when samples close to each other have similar properties than those far away from each other. Sampling design has been improved greatly by the application of modern tools such as Geographic Information System (GIS) and Geo-statistics which utilizes the spatial dependence of soil properties within a sampling region and is useful in illustrating spatial dependence of soil data which reduces error, biasness and accuracy of data for interpolation.

Soil depth gives an indication of the soil volume which can be utilized by the plant and which is conducive to moisture retention. Effective soil depth is the depth where adequate moisture, nutrients and air occur. It is the vertical distance into the soil from the surface to a layer that essentially stops the downward growth of plant roots. Depth and pH in soil profiles are important factors to be considered in plant nutrient availability and quantification study because plant nutrients are located in different depths or horizons in the soils. Depth and soil pH play a major role in the nutrient availability status of most soils in the tropics

The oil palm is a monoecious crop as it bears both male and female flowers on the same tree. Each tree produces compact bunches weighing between 10 and 25 kilograms with fruitlets. Each fruitlet is almost spherical or elongated in shape. Generally, the fruitlet is dark purple, almost black and turns to orange red when ripe. Each fruitlet consist of a hard kernel (seed) enclosed in a shell (endocarp) which is surrounded by a fleshy mesocarp.

The distribution of soil chemical properties is of interest because of their direct and indirect influences on productivity, which has implications for site-specific fertility management. The pressure on land for other uses apart from agriculture is on the increase. Land as a natural resource is not renewable. The availability of flat lands for agricultural purposes has its limitations, thereby driving more people to intensify farming on highlands which are usually undulating or steep in nature.

New plantations will have to be established on hilly or steep land areas especially in places where flats are not readily available. Such lands will need to be studied to know the best way they can be put to use for oil palm cultivation.

The aim of the work was to characterize the geo-spatial distribution of soil chemical properties as influenced by slope position and depth. Secondly to better understand the relationship between soil chemical properties with 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 149.4m 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,

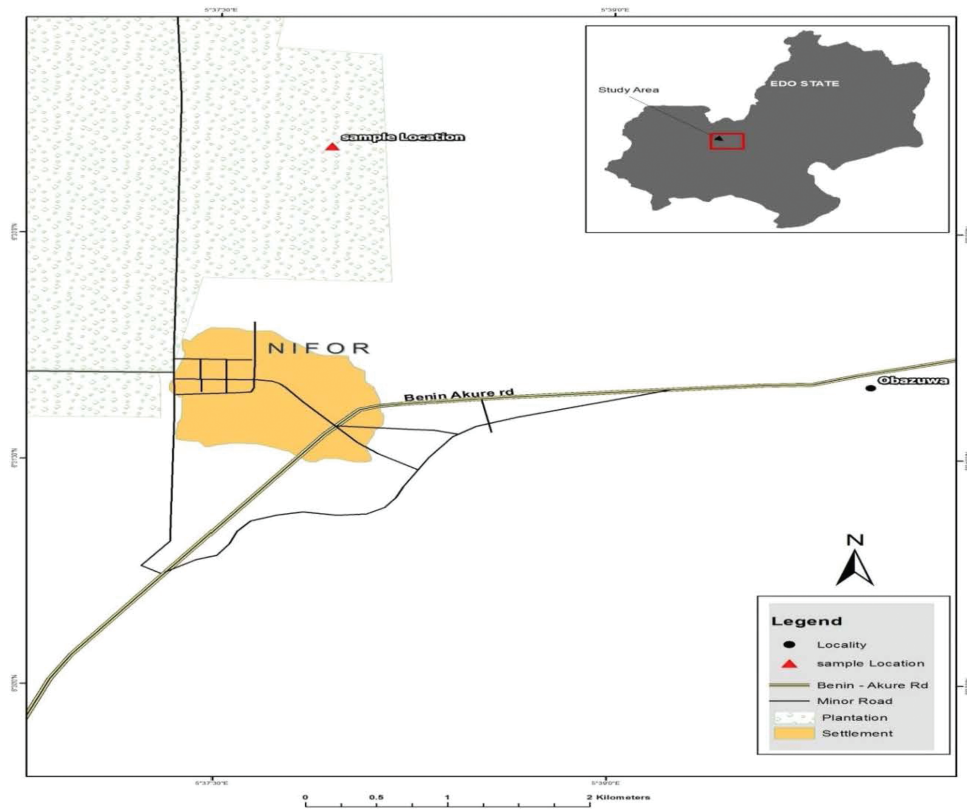

Figure 1: Map of the study location.

Ahiara and Kulfo soil series which are Rhodic Paleudult and Typic Dystropet according to U.S. Taxonomy (Ogunkunle, 1982).

Field Study

A twenty-eight (28) year old Oil palm plantation on a gently sloping land in the study area was used for the research. 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 chainage 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 chainage were used in determining the slope of the study area based on the information from the topographic map. AutoCAD software version 10.0 was used. The slope direction also known as aspect was determined with a compass in the northing and easting direction.

Soil sampling

A systematic design was employed in sampling soil for chemical properties determination. Four sampling depths of 0-15 cm, 15-30 cm, 30- 45 cm and 45-60 cm were employed. A

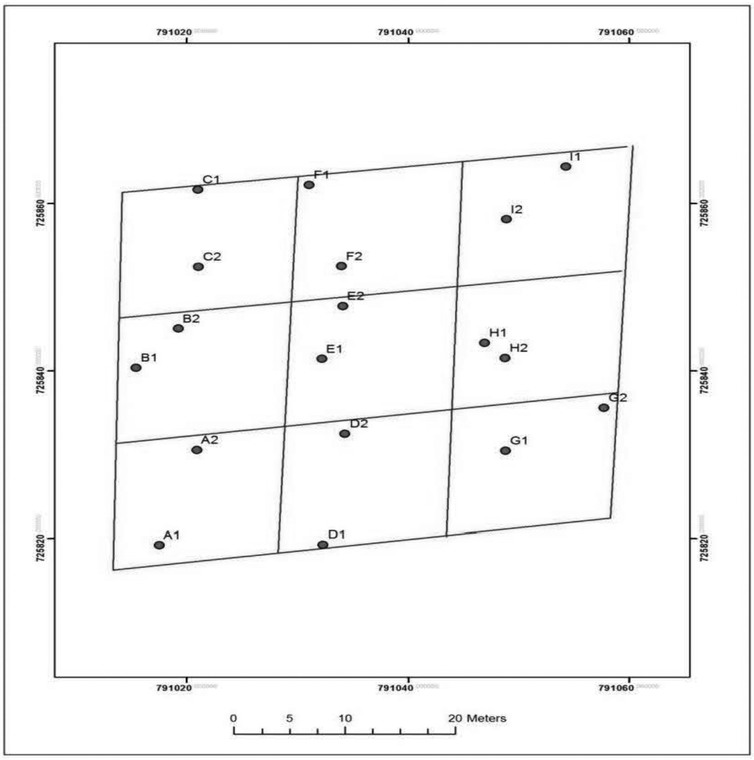

Figure 2: Map showing sampled points in the study area.

soil auger was used in the sampling. The sampling depths for the soil chemical property determination were chosen because the roots of oil palm are concentrated in the 0-60 cm depth of the soil (Ogeh and Osiomwan, 2012). Each sampling point was geo- referenced using a Garmin GPS 12.The soil samples were air-dried at room temperature, crushed, debris removed and then sieved through a 2 mm sieve.

Soil Chemical Analysis

Organic carbon was determined by the method of Walkley & Black (1934). Kjeldahl method was used in determining total nitrogen. Available phosphorus was measured colorimerically after extraction with Bray P-1 solution (Bray & Kurtz 1945). Soil extracts used for determination of exchangeable bases was obtained by leaching the soil using neutral 1Molar (1M) ammonium acetate solution. Calcium and potassium were determined by flame photometry. Magnesium was determined using atomic absorption spectrophotometer. Soil pH will be determined using a pH meter with a soil /water ratio of 1:1. Cation exchange capacity (CEC) will be determined by the summation method (Chapman 1965).

Statistical Analysis

A two way analysis of variance (ANOVA) was used to test for significant differences in soil chemical properties between 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.

Inverse distance weighting (IDW) a deterministic surface interpolation method was employed in the geospatial analysis of the soil chemical properties using Arc GIS 10.1 software.

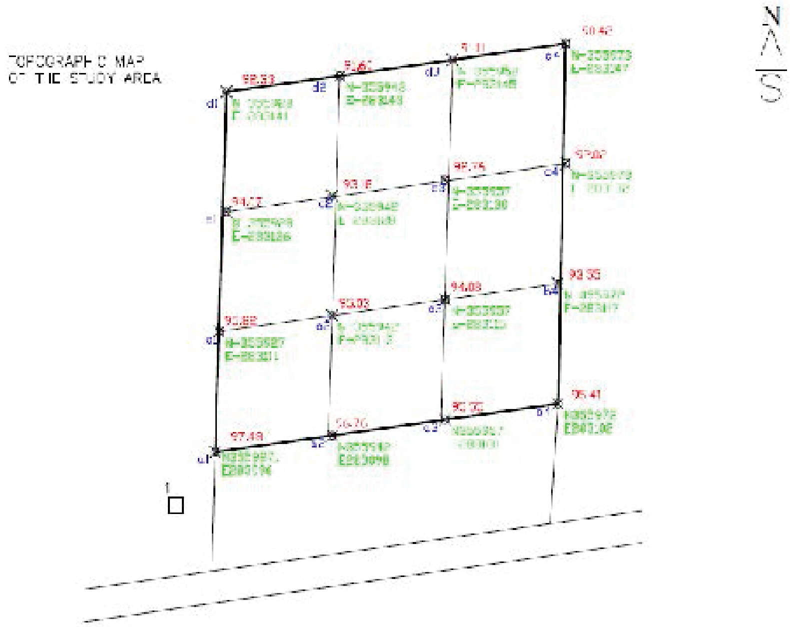

Fig 3: Topographic map of the study area

RESULTS AND DISCUSSION

Land Slope determination

The slope of the study area was determined from the topographic map using a graphical plot of elevation against the measured distance. 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.

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 had an east facing slope.

Slope Position and Depth Effects on Soil Chemical Properties

Soil pH

Soil pH is a measure of the acidity or alkalinity in soil. The soil pH of the study area was extremely acidic to strongly acidic (USDA, 1993) as shown in the pH ranges across the slopes and depths; summit slope 4.05 – 4.6, mid slope 4.1 - 4.9 and bottom slope 4.1 -5.25 respectively (Table 1).

The pH specifically affects plant nutrient availability by controlling the chemical forms of the nutrient. The distribution map of soil pH showed that the bottom slope position and depth had the highest values of soil pH when com-

Table 1: Soil chemical properties at each slope position and depth

Slope position	Depth (cm)	pH	O.C (%)	N (%)	P (mg/kg)	Ca	Mg	Na	K (Meq/100g Soil)	H^+ (Meq/100g Soil)	ECEC
Summit (a_1b_1-a_4b_4)	0-15	4.6	0.84	0.06	6.51	1.56	0.52	0.48	0.09	0.35	2.99
	15-30	4.3	0.56	0.04	4.68	1.4	0.4	0.33	0.07	0.45	2.65
	30-45	4.15	0.47	0.04	3.59	1	0.28	0.32	0.05	0.6	2.24
	45-60	4.05	0.40	0.03	2.63	0.84	0.16	0.29	0.04	0.7	2.03
	0-15	4.5	0.79	0.06	6.73	1.96	0.6	0.44	0.08	0.25	3.33
	15-30	4.4	0.64	0.04	4.34	1.35	0.44	0.36	0.07	0.35	2.56
	30-45	4.25	0.53	0.04	3.81	0.96	0.32	0.33	0.04	0.5	2.15
	45-60	4.1	0.42	0.03	2.05	0.72	0.2	0.30	0.03	0.65	1.90
	0-15	4.55	0.89	0.07	4.98	1.87	0.48	0.29	0.08	0.3	3.02
	15-30	4.4	0.66	0.04	3.72	1.5	0.4	0.27	0.06	0.4	2.63
	30-45	4.35	0.45	0.03	3.01	1.15	0.28	0.24	0.05	0.55	2.27
	45-60	4.25	0.39	0.03	2.45	0.88	0.16	0.23	0.03	0.7	2.00
Mid (b_1c_1-b_4c_4)	0-15	4.4	0.88	0.06	6.58	1.31	0.56	0.32	0.07	0.25	2.50
	15-30	4.35	0.64	0.05	3.78	1.1	0.4	0.30	0.06	0.4	2.25
	30-45	4.3	0.56	0.04	2.65	0.96	0.32	0.27	0.04	0.55	2.14
	45-60	4.15	0.44	0.03	1.73	0.84	0.2	0.26	0.03	0.65	1.98
	0-15	4.9	0.82	0.06	5.40	2.32	0.68	0.40	0.10	0.2	3.70
	15-30	4.5	0.66	0.04	4.48	1.5	0.48	0.37	0.07	0.3	2.72
	30-45	4.3	0.48	0.04	2.44	1	0.36	0.31	0.05	0.45	2.17
	45-60	4.1	0.35	0.02	2.25	0.84	0.28	0.30	0.03	0.55	2.00
	0-15	4.8	0.83	0.06	6.53	2.12	0.6	0.27	0.06	0.2	3.24
	15-30	4.4	0.60	0.04	4.31	1.29	0.4	0.25	0.05	0.35	2.33
	30-45	4.3	0.47	0.03	2.16	0.92	0.28	0.23	0.04	0.4	1.87
	45-60	4.15	0.36	0.03	1.20	0.76	0.2	0.23	0.03	0.55	1.77
Bottom (c_1d_1-c_4d_4)	0-15	4.8	0.81	0.06	8.17	2	0.72	0.31	0.07	0.25	3.34
	15-30	4.6	0.63	0.04	6.35	1.51	0.6	0.30	0.05	0.3	2.76
	30-45	4.3	0.43	0.03	5.14	1	0.4	0.28	0.04	0.45	2.17
	45-60	4.1	0.27	0.02	3.57	0.88	0.28	0.24	0.02	0.55	1.97
	0-15	5.2	0.86	0.06	4.63	2.36	0.68	0.37	0.08	0.2	3.69
	15-30	4.85	0.69	0.05	3.99	1.92	0.48	0.31	0.06	0.3	3.06
	30-45	4.5	0.51	0.04	3.15	1.3	0.36	0.28	0.04	0.45	2.42
	45-60	4.35	0.36	0.03	2.25	1.07	0.28	0.27	0.03	0.55	2.20
	0-15	5.25	0.80	0.06	5.99	2.28	0.76	0.27	0.06	0.2	3.46
	15-30	4.65	0.58	0.04	5.02	1.66	0.52	0.25	0.04	0.33	2.77
	30-45	4.45	0.40	0.03	3.12	1	0.36	0.24	0.03	0.4	2.03
	45-60	4.3	0.32	0.02	2.51	0.76	0.28	0.24	0.03	0.5	1.81

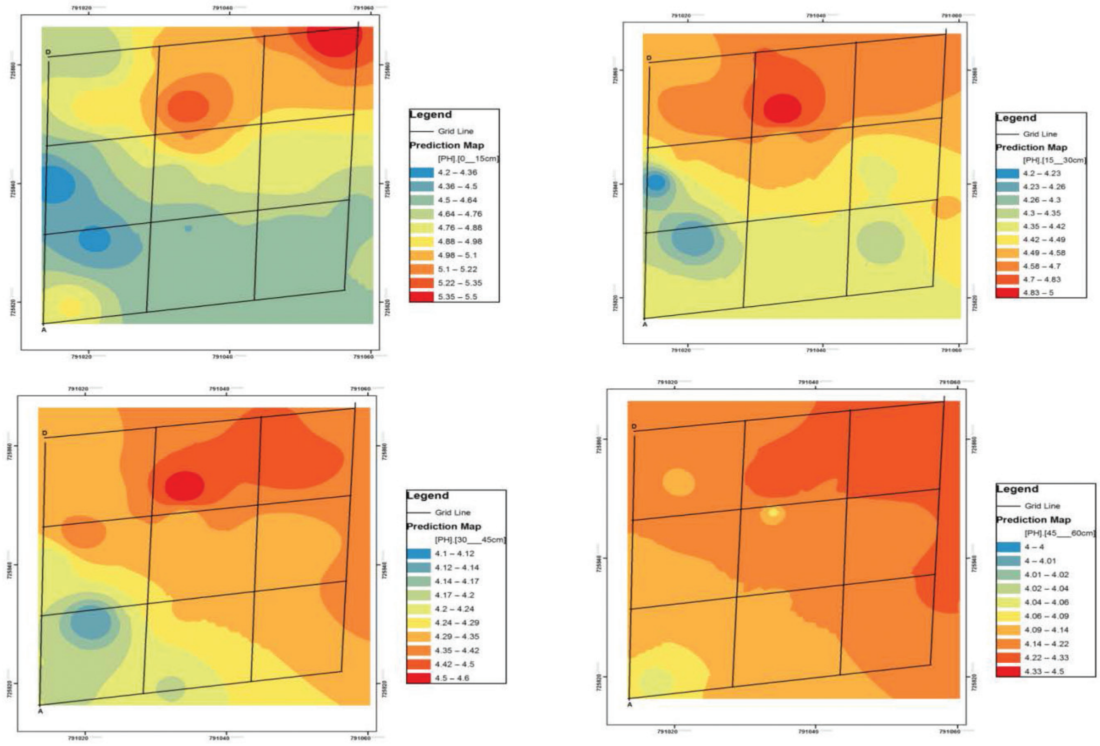

Figure 4: Distribution of soil pH in the study area.

pared with the summit and bottom slopes and depths Figure 4.

Soil pH was significantly ($p<0.05$) affected by the slope position. The bottom slope position had the highest value of pH while the summit position had the lowest value of pH. This is in line with Farmanullah *et al.* (2013) and Ofori *et al.* (2013). The increase in the pH value down the slope could be due to an increase in the exchangeable cations especially magnesium and

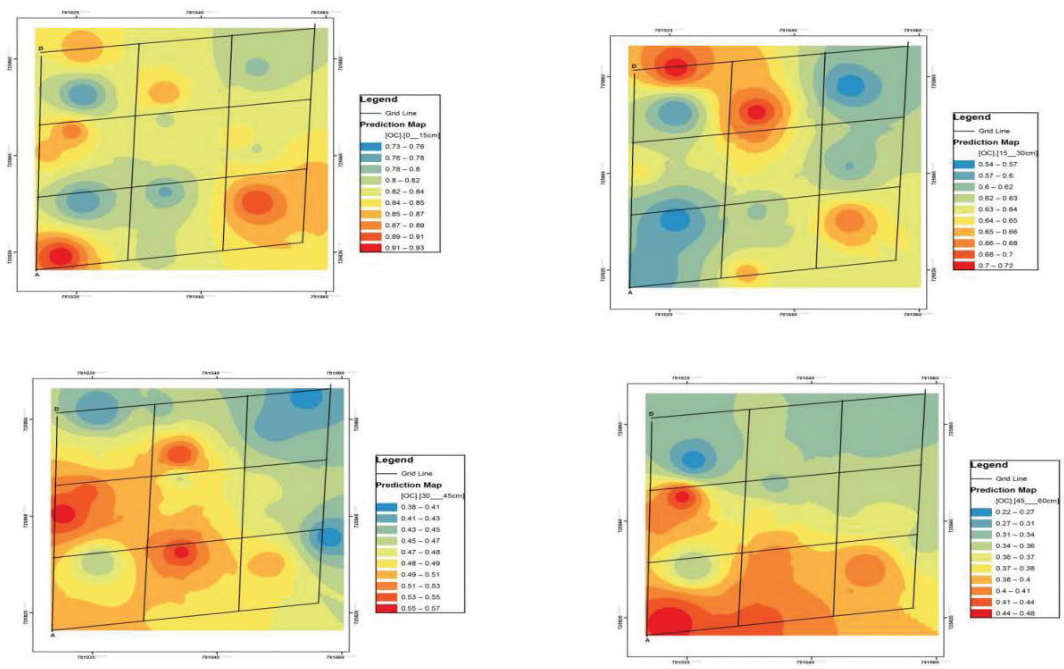

Figure 5: Distribution map of soil organic carbon in the study area.

calcium in the bottom slope position due to more clay content. The lower pH experienced at the summit is an indication of leaching of plant nutrient and runoff. Depth had a significant (P<0.05) effect on the soil pH. The pH trend was decreasing down the depth. The highest value was experienced at 0-15 cm depth while the lowest was at 45-60 cm depth. .

Soil organic carbon (O.C)

The soil organic carbon in the study area ranged from; 0.39 – 0.89 % in the summit, 0.35 – 0.88 % in the mid and 0.27 – 0.86 % in the bottom slopes and depths respectively (Table 1). The distribution map reveals that the soil organic carbon was higher in the summit and mid slopes and depth when compared with the bottom slope (Figure 5).

This agrees with Rasool *et al.* (2014). This could be attributed to higher elevation and vegetation cover. Soil organic carbon was not significantly affected (p> 0.05) by slope position though the mid position had the highest organic carbon when compared with the summit and bottom slope. There was a significant effect (p<0.05) on the soil organic carbon content across the depth. The highest value of organic carbon was found at 0-15 cm depth while the lowest value was found at the 45-60 cm depth.

Total Nitrogen (N)

The Nitrogen content of the soil in the study area ranged from; summit 0.03 – 0.07 %, mid 0.02 – 0.06 % and 0.02 – 0.06 % bottom slope and depth respectively (Table 1). The distribution map of nitrogen in the study area shows that the concentration of nitrogen was in the summit and mid slopes and depths (Figure 6). There was a significant effect (p<0.05) on the total nitrogen across the slope positions. The summit and mid slope had the highest values while the bottom

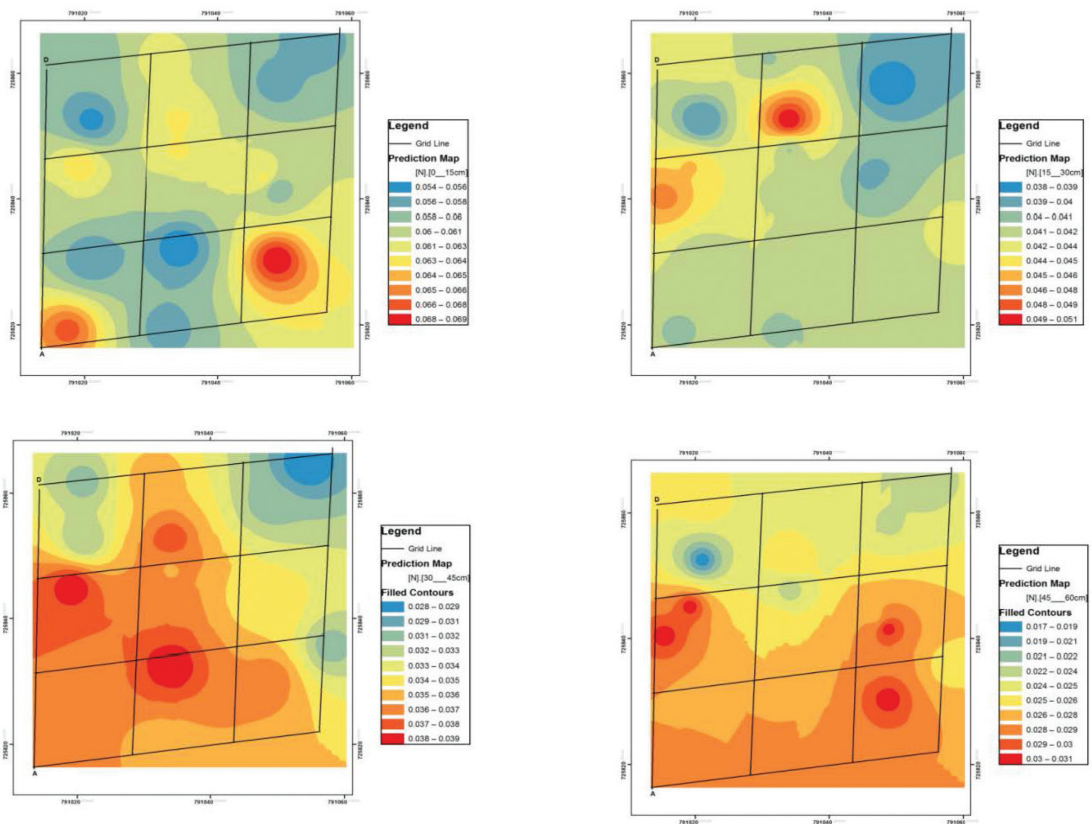

Figure 6: Distribution map of Nitrogen in the study area.

had the lowest value. This agrees with Zak *et al.* (1991) and Fisk *et al.* (1998) studies on the effects of topography on nutrient cycling in a hardwood forest and alpine tundra systems, respectively. Depth had a significant effect ($p<0.05$) on the total nitrogen content of the soil. 0-15 cm depth had the highest values of total nitrogen while 45-60 cm depth had the lowest value.

Phosphorus (P)

The phosphorus content in the study area ranged between; 2.05 – 6.73 mg/kg summit, 1.20 – 6.58 mg/kg mid and 2.25 – 8.17 mg/kg bottom slope and depth (Table 1). The distribution map of the available phosphorus in the study area shows that the bottom slope had the highest concentration when compared with the summit and mid slopes (Figure 7). Results showed that there was no significant difference ($p>0.05$) between the three slope positions in respect to the available phosphorus in the soil. The bottom slope had the highest phosphorus when compared with the mid and bottom slope. These differences were statistically not significant. This agrees with Farmanullah *et al.* (2013) and Rasool *et al.* (2014) who reported that the highest value of phosphorus occurred at the bottom slope. Depth had a significant effect ($p>0.05$) on the soil phosphorus. The highest value was observed in the 0-15 cm depth, while the lowest value was observed in the 45-60 cm depth.

Calcium (Ca) and Magnesium (Mg)

The calcium and magnesium content of the soil in the study area ranged between; summit 0.72 – 1.96, 0.16 – 0.6 meq/100g soil, mid 0.76 – 2.32, 0.2 – 0.68 meq/100g soil and foot 0.76 – 2.36, 0.28 – 0.76 meq/100g soil respectively (Table 1). The distribution maps of calcium and magnesium show that the bottom slope and depth had the highest concentration of calcium and magnesium when compared with the

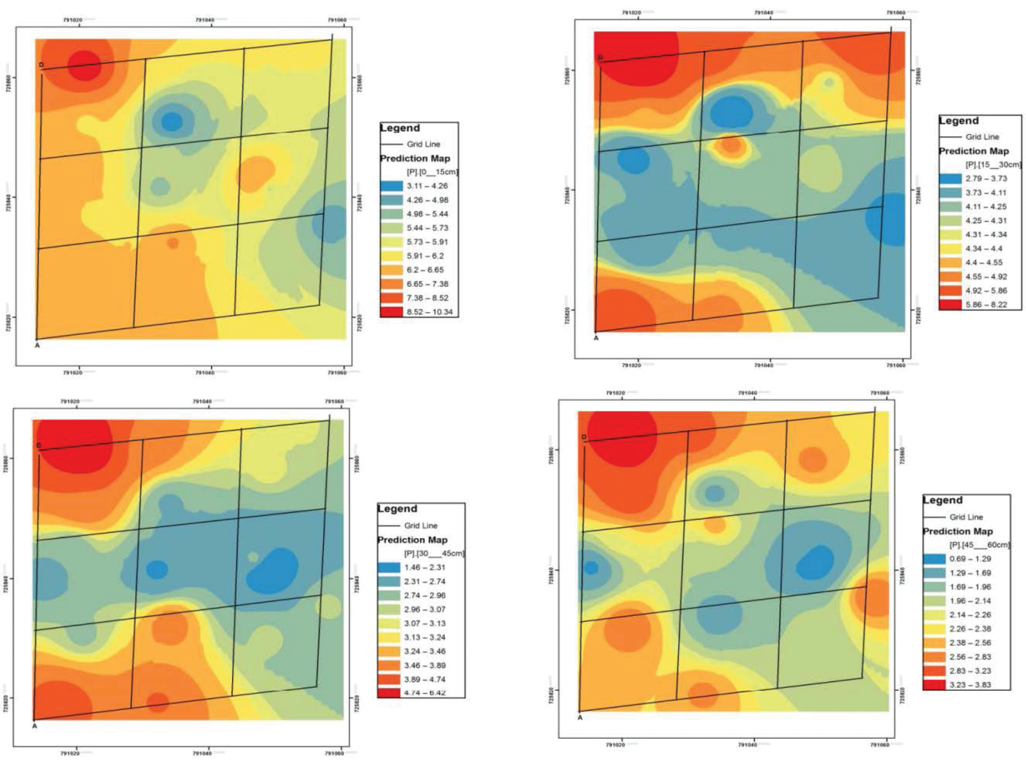

Figure7: Distribution map of phosphorus in the study area

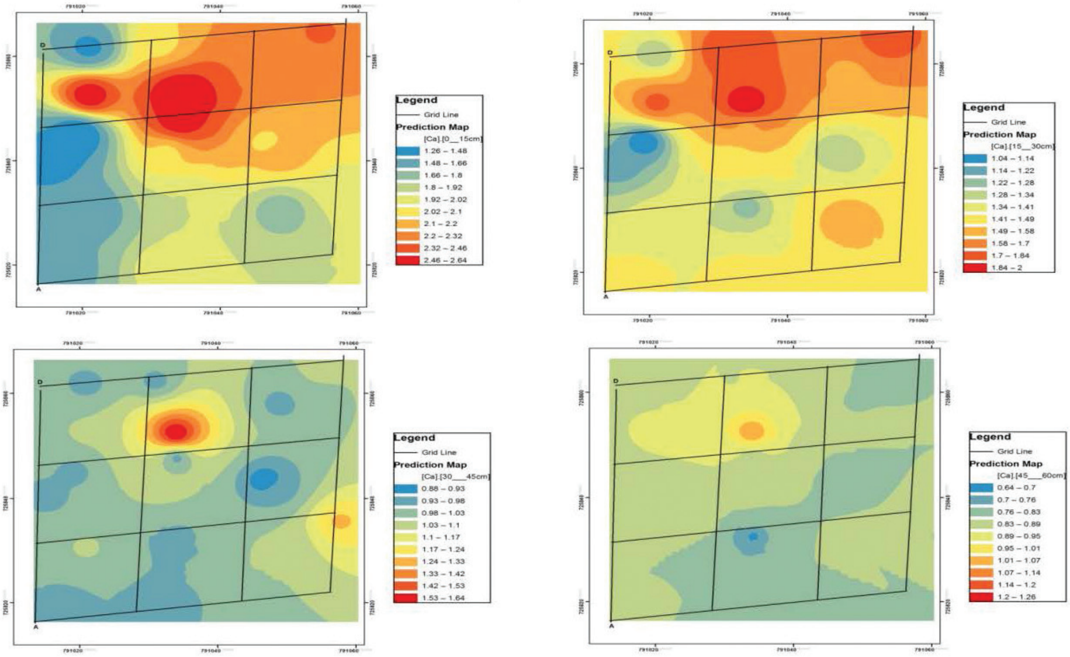

Figure 8: distribution map of calcium in the study area.

summit and mid slope and depth (Figure 8 and Figure 9). Calcium and magnesium were significantly ($p<0.05$) affected by different slope positions. The bottom slope position had the highest values for calcium and magnesium, while the summit slope position had the lowest value for calcium and magnesium table. This is due to an increase in the clay content at the bottom slope, hence an increase in the CEC of the soil. Depth had a significant effect ($p>0.05$) on calcium and magnesium content. The highest value was recorded at the 0-15 cm depth while the lowest value was recorded at the 45-60 cm depth.

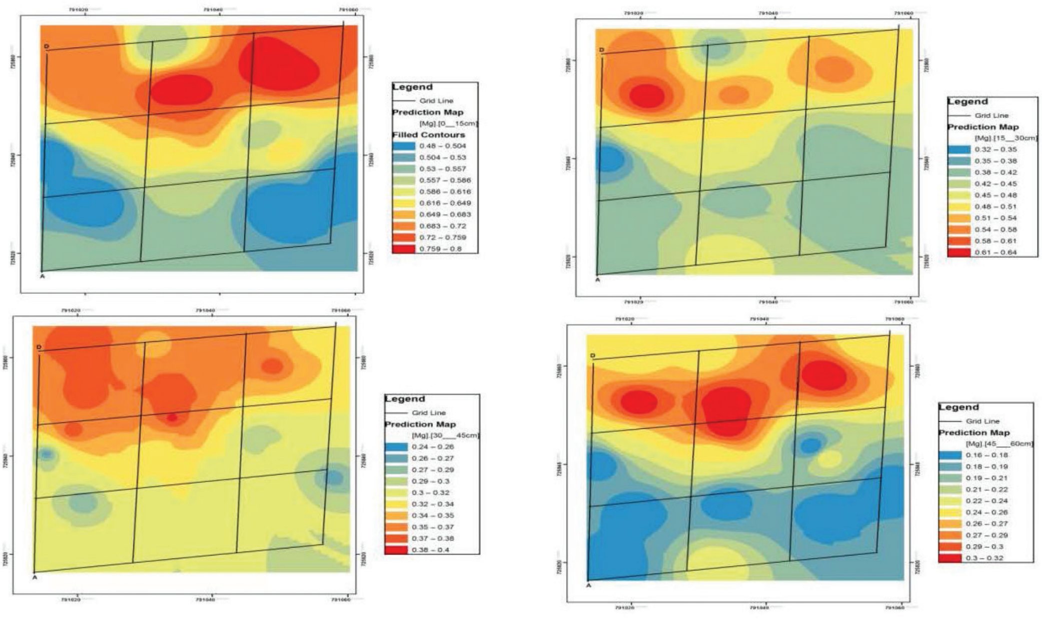

Figure 9: Distribution map of magnesium in the study area.

Potassium (k)

The potassium range in the study area was; summit 0.03 – 0.09 meq/100g soil, mid 0.03 – 0.10 meq/100g soil and 0.03 – 0.08 meq/100g soil for bottom slope and depth (Table 1). From the distribution map it can be seen that the summit and mid slope and depth had a higher concentration when compared with the bottom slope and depth (Figure 10).

The potassium was significantly ($p<0.05$) different at the three slope positions. The summit slope position had the highest value of potassium while the bottom slope position had the lowest value of potassium. This is in line with Rasool *et al.* (2014). Potassium was significantly affected ($p>0.05$) by across the depths. 0-15cm depth had the highest occurrence while 45-60 cm had the lowest occurrence.

Effective Cation exchange capacity (ECEC)

The ECEC of the soil in the study area ranged from summit 1.90 – 3.33 meq/100g soil, mid 1.77 – 3.70 meq/100g soil and 1.81 – 3.69 meq/100g soil bottom slope and depth. The ECEC were significantly affected ($p>0.05$) by slope positions. ECEC was highest in the bottom slope position and lowest in the summit slope position. This could be as a result of an increase in the exchangeable calcium and magnesium found in the bottom slope position. Depth had a significant effect on the exchangeable hydrogen and ECEC. The ECEC had the highest value in the 0-15 cm depth and lowest value in the 45-60 cm depth.

Correlation Studies between Slope Position, Depth and Soil Chemical Properties

Correlation studies (Table 2) showed a significant positive correlation between slope position and pH (r=0.409*). Slope position had relationships with other soil chemical properties but they were not statistically significant. Depth had a significant correlation with all the

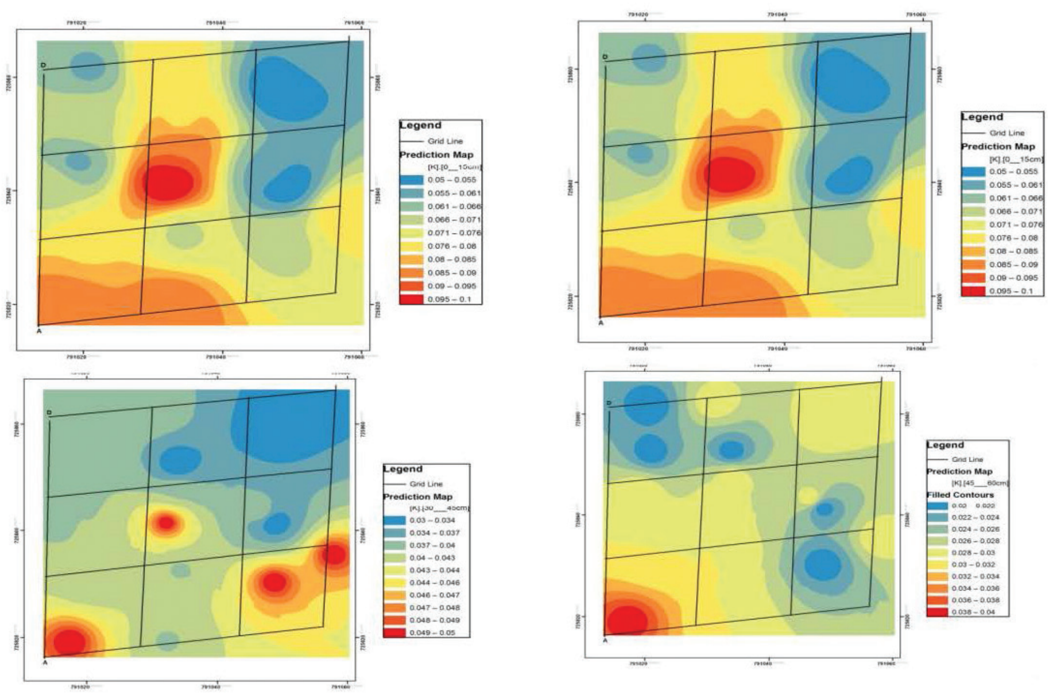

Figure 10: Distribution map of potassium in the study area.

Table 2: Pearson correlation coefficient between slope, depth and soil chemical properties.

Parameter	Slope	Depth	pH	O.C	N	P	Ca	Mg	Na	K	H	ECEC
Slope	1											
Depth	0.000	1										
pH	.409*	-.775**	1									
O.C	-.073	-.963**	.751**	1								
N	-.080	-.949**	.746**	**.984****	1							
P	.110	-.866**	.638**	.802**	.780**	1						
Ca	.179	-.883**	.920**	.863**	.856**	.757**	1					
Mg	.312	-.913**	.884**	.858**	.841**	.877**	.916**	1				
Na	-.307	-.563**	.312	.589**	.582**	.523**	.469**	.492**	1			
K	-.242	-.889**	.622**	.890**	.894**	.709**	.788**	.754**	.769**	1		
H	-.306	.912**	-.833**	-.845**	-.822**	-.789**	-.866**	-.939**	-.427**	-.742**	1	
ECEC	.119	-.886**	.889**	.875**	.869**	.788**	.987**	.918**	.581**	.834**	-.836**	1

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

soil chemical properties. The highest positive correlation was with the hydrogen ion with r=0.912**, while the highest negative correlation was with organic carbon with r=-0.963**. pH was positively correlated with Ca and Mg (r=0.92**, 0.884**) and negatively correlated with hydrogen ion (r=-0.833**). The relationship between O.C and N were found to be positive and statistically significant (r=0.984**). P and K were positively correlated (r=0.709**), while the relationship between Ca and Mg was positive and significant (r=0.916**). Na and K were also positively correlated (r=0.769**).

CONCLUSION

Slope position had a significant effect on soil pH, N, Ca, Mg, K, H, ECEC, bulk density and porosity. Soil depth significantly affected all soil properties studied. The bottom slope the highest Effective Cation Exchange capacity and exchangeable calcium and magnesium. Soil pH gradually increased down slope thus implying an increased availability of plant nutrients in the bottom slope position.

The soil pH was extremely acidic to strongly acidic across the slope positions and depths. This is expected due to the fact that the study area falls within the rain forest ecology characterized with heavy rainfall result in leaching of plant nutrients due to the dominance of sandy soils in the study area. Thus, the soils are referred to as acid sands. Soils in the three slope position and depth contain low level of nutrients as observed from the values obtained from analysis of field data. Available phosphorus level was below 10 mg/kg while K was below the critical limit of 0.15 meq/100g (Uponi and Adeoye, 2000).

The correlation studies revealed that depth had a more significant correlation (positive and negative) than slope position with all soil properties under the study as depicted by the correlation coefficients. An integrated approach of organic and inorganic fertilizer application can be adopted to boost up the nutrient levels which are low in the soil.

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