INFLUENCE OF TOPOGRAPHY AND LAND UTILIZATION TYPES ON SOIL FERTILITY TREND IN SOUTHEASTERN NIGERIA

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ABSTRACT
Influence of topographic (crest, upper slope, middle slope and lower slope) position and land utilization types (rubber and oil palm plantations; one year and five years old fallows) on fertility was studied in soils formed on coastal plain sands in southeastern Nigeria. Topography significantly ($p<0.05$) influenced soil organic carbon (SOC), base saturation, total exchangeable bases (TEB) and exchangeable sodium percentage (ESP) in the 0 – 15 cm depth, and exchangeable sodium (Na^+), exchangeable aluminum (Al^{3+}), effective cation exchange capacity (ECEC) and exchangeable sodium percentage (ESP) in the 15 – 30 cm depth. Land utilization types significantly ($p<0.05$) influenced pH, SOC, available phosphorus (P), calcium, sodium, ECEC and TEB in the 0 – 15 cm depth and sand, clay, pH, P, Mg, H^+, base saturation, TEB, aluminum saturation, Mg/K and (Ca+Mg)/K in the 15 – 30 cm depth. Use dependent properties were influenced by topography, while additional use non-variant properties were influenced by land utilization types. Out of 22 soil properties considered, 4 (18%) and 5 (23%) were significantly ($p<0.05$) influenced by topography at 0 – 15 cm and 15 – 30 cm depth respectively. Seven (32%) and fourteen (64%) of the soil properties were influenced by land utilization types at 0 – 15 cm and 15 – 30 cm depth respectively. Topographic positions and land utilization types significantly ($p<0.05$) affected soil fertility and require different management systems for sustainable crop production.
Keywords: Soil fertility, Toposequence, Land utilization types, Soil variability.

INTRODUCTION
The differences between soils of a toposequence are generally related to the differences in the topographic positions as different geochemical conditions and drainages are experienced on different positions depending on the hydrology (Lucas and Chauvel, 1992). Topography is both internal and external factor in pedogenesis as it influences soil formation or is a consequence of same (Temgoua *et al.*, 2005). Several studies in Nigerian soils have established close relationship between topography and soils (Ogunkunle and Onasanya, 1992; Ogunkunle, 1993; Olatunji *et al.*, 2007). Toposequence is defined as a succession of sites from crest to the valley bottom (Moorman, 1981), which is now used to replace catena in soil-topography relationship studies (King *et al.*, 1983; Okusami, *et al.*, 1985). Ogunkunle and Onasanya (1992) reported that different soil units exist on a toposequence and may require different management systems. Olatunji *et al.* (2007) went further to state that the influence of gradient is higher than that of parent material on the properties of soil units on a toposequence.

Soil properties and characteristics change with time but those that change within human life frame were referred to as use dependent properties (Grossman *et al.*, 2001). They defined use-dependent soil properties as those that change with land use and included soil organic carbon (SOC), bulk density, pH, salinity and aggregate stability which Tugel *et al.*

(2005) have referred to as dynamic soil properties. These soil properties either directly or indirectly influence soil fertility. Voortman *et al.* (2002) included cation exchange capacity (CEC), base saturation, total exchangeable bases, aluminum saturation, and exchangeable sodium percentage (ESP) as soil properties that could be used to characterize soil fertility. These soil properties have been found to vary with topographic position, characteristics of land use and human influence (Ritcher and Markewitz, 2001). The objective of this study therefore was to assess the influence of topographic positions and land utilization types on fertility characteristics in the coastal plain sands soils of southeastern Nigeria.

MATERIALS AND METHODS

Site description

The study examined two major land utilization types across different toposequences (slope <4%, concave and on coastal plain sands). The sites include rubber plantation at College of Agriculture Abak, oil palm plantation at Akwa Palm Estate in Uquo Ibeno, and two fallow plots (five years and one year old) both in Ikot Okoro. These sites were located in Abak, Uquo Ibeno and Oruk Anam Local Government Areas respectively of Akwa Ibom State in Nigeria. These are locations where typical conditions were encountered after reconnaissance survey. Akwa Ibom State is located approximately between longitude 4° 30' and 5° 30' E and latitudes 7° 30' and 8° 20' N within a typical humid tropical climate characterized by rainy season that lasts between February/March and November and dry season that lasts between November and February/ March. The rainy season is characterized by heavy rainfall, high relative humidity and heavy cloud cover resulting in low solar radiation. This would have resulted in high accumulation of organic matter and high fertility status of the soils. In Akwa Ibon State, about 75% of the soils are on coastal plain sands (with the remaining 25% on Beach Ridge Sands, Sandstone/Limestone mosaic and Alluvium) and highly leached, therefore fertility is seldom high. The study was conducted on soils formed from Coastal Plain Sands which have been found to be low in organic matter content and pH. Coastal Plain Sands occur on plains less than 200m above sea level with mean temperature of 27 °C and annual rainfall that ranges from 3000mm along the Atlantic coast to 2000mm in the hinterland (SLUS-AK, 1989).

Field study and sample collection

The toposequences were divided into four topographic units following the clustering procedure proposed by Ogunkunle (1993). Two composite samples were collected from each of the topographic units (i.e. crest, upper slope, middle slope and lower slope) comprising surface (0 – 15 cm) and subsurface (15 – 30 cm) samples. This gave a total of 8 samples per land utilization type (overall total of 24 samples).

Laboratory analysis

Soil samples were air-dried and partially ground and passed through a 2-mm sieve. Soil pH was determined using glass electrode in a soil / water ratio of 1:1 (Mclean, 1982). Organic carbon was determined by Walkley-Black wet oxidation method (Nelson and Sommers, 1982). Particle size was determined by hydrometer method (Gee and Bauder, 1986). Exchangeable bases (calcium, magnesium, potassium and sodium) were extracted with the ammonium acetate (pH 7.0) and determined by atomic absorption spectrophotometry (Thomas, 1982). Exchangeable aluminum and hydrogen were determined with buffered potassium chloride, while effective cation exchange capacity was by summation of total exchangeable bases and exchangeable acidity (Anderson and Ingram, 1993). Available phosphorus was extracted by the method of Bray and Kurtz (1945), and Phosphorus in extracts determined by the method of Murphy and Riley (1962). Total exchangeable bases (TEB) were calculated by summation, aluminum saturation (Al. sat.) was calculated as Na x 100/ECEC, while Ca/Mg, Mg/K, (Ca+Mg)/K and K/(Ca+Mg) were also calculated (Voortman, et al. 2002).

Statistical Analysis

Data collected were analyzed in a Latin Square Design with land utilization type as column and topographic (unit) position as the row using Analysis of Variance (ANOVA). The significantly different means were separated using Least Significant Differences (LSD) at 5% probability (SAS, 1990).

RESULTS AND DISCUSSION

The study considered both land utilization types and topographic influence as sources of soil variability. These have been found to be essential for interpreting changes in soil in as much as it does not provide all the information necessary for predicting future changes (Millar and Woolfenden, 1999; Parsons *et al.*, 1999). The time scale of change that will likely relate to both time frame of recovery (Stringham *et al.*, 2003) and impact of human management varies from decades to centuries. Consequently, Tugel *et al.*, (2005) suggested that change related soil survey products should address the human time scale. Almost all soil properties change eventually, but Tugel *et al.*, (2005) proposed the term dynamic soil properties for those soil properties that change within the human time scale. Grossman *et al.*, (2001) defined use dependent (i.e. dynamic soil properties) as properties that change with land use. They include soil organic carbon (SOC), bulk density, pH, salinity and aggregate stability.

The study sites were not contiguous, hence in as much as the soils were believed to have been formed from similar parent material (i.e. coastal plain sands), similarities in the more stable properties such as texture was assessed between the land utilization types. The relationship was further confirmed with exchangeable cation ratios (i.e. Mg/K, Ca/K, and (Ca+ Mg)/K) which

Table 1: Influence of topography on the properties of soil at 0 – 15 cm depth

		Topographic position			
		Crest	Upper slope	Middle slope	Lower slope
pH(H_2O)		5.3a	5.64a	5.96a	5.81a
pH(KCl)		4.9a	4.55a	4.80a	4.72a
Sand		702.5a	822.5a	835.0a	792.8a
Silt		74.5a	75.7a	84.3a	100.5a
Clay	g kg^{-1}	126a	97.0a	80.7a	106.8a
SOC		1.29b	1.72a	1.08b	2.62a
Base sat.		62.2b	70.1ab	64.2b	81.3a
Al. sat.	%	1.39a	0.42a	0.57a	0.55a
ESP		2.8a	7.86a	5.96a	3.12a
Avail. P	mg kg^{-1}	9.10a	10.72a	11.14a	8.747a
Exch. Calcium		2.31a	2.38a	1.64a	2.99a
Exch.Magnesium		1.70a	1.19a	1.06a	2.08a
Exch. Potassium		0.50a	0.42a	0.53a	0.69a
Exch. Sodium	cmol kg^{-1}	0.21a	0.47a	0.23a	0.35a
H^+		1.74a	1.25a	1.11a	2.47a
Al^{3+}		0.86a	0.61a	0.36a	0.46a
ECEC		7.50a	6.33a	4.81a	7.53a
TEB		6.44ab	5.70b	4.56b	8.56a
Ca/Mg		1.4a	2.03a	2.22a	1.54a
Mg/K		6.6a	5.4a	4.50a	6.93a
(Ca+Mg)/K		15.4a	16.7a	10.1a	14.9a
K/(Ca+Mg)		0.13a	0.12a	0.17a	0.16a

SOC = Soil organic carbon, Base sat. = Base saturation, Al sat. = Aluminum saturation, ESP. = Exchangeable Sodium percentage. Avail. P = Available phosphorus. Exch. = Exchangeable: ECEC = Effective cation exchange capacity, TEB = Total exchangeable bases. Values on same row followed by same letter(s) are not significantly different ($p<0.05$).

Shaw *et al.*, (2001) and Voortman *et al.*, (2002) have indicated to depend on the proportions of each of the cations in the original source (i.e. parent) material as well as the differential effect of leaching and therefore a good indicator of parent material differences.

The characteristics of the surface soil (0 – 15 cm) as influenced by the topographic positions were found not to be significantly different ($p<0.05$) with the exception of organic carbon and base saturation (Table 1). It was observed that the organic carbon content of the soil on the lower slope position (2.99 g kg^{-1}) was significantly higher than the crest, upper and middle slope positions and these were not significantly different from each other. This is because due to erosion and gravitational force, materials are generally moved and deposited at the lowest position on the landscape. Base saturation of the lower (81.3%) and upper (70.1%) slope positions were also not significantly different from each other, whereas those of the crest (62.2%), upper and middle (64.2%) slopes were equally not significantly different from each other.

Soil properties that were influenced by topography at 15 – 30 cm depth include Na^{+}, Al^{3+}, effective cation exchange capacity, and they were significantly different from each other (Table 2), while other properties were similar. The exchangeable Na contents of the soil in the lower slope was 0.93 cmol kg^{-1} which was significantly different from 0.48 cmol kg^{-1}, 0.25 cmol kg^{-1} and 0.17 cmol kg^{-1} for upper slope, crest and middle slope positions respectively. The effective cation exchange capacity of the soils on lower slopes, crest and upper slope positions (7.91 cmol kg^{-1}, 6.24 cmol kg^{-1} and 5.81 cmol kg^{-1} respectively) were not significantly different from each other, whereas those of the crest, upper slopes and middle slopes (4.09 cmol kg^{-1}) were equally not significantly different ($p<0.05$) from each other. These are to say that effective cation exchange capacity of the lower slope soils are significantly ($p<0.05$) different from those of middle slope.

The properties of soil as influenced by land utilization types were as shown in Tables 3 and 4. The effect of land utilization types on the surface soil were not significantly ($p<0.05$) different in the entire soil properties with the exception of organic carbon, available phosphorus, exchangeable calcium, potassium and effective cation exchange capacity (ECEC) in the 0 -15 cm depths and sand, clay, pH, available phosphorus, exchangeable magnesium, potassium and base saturation in the 15 – 30 cm soil depths. The variations observed in the sand and clay content of the soils (15 – 30 cm) as influenced by land utilization types could be attributed to localized differences in the pedoturbating activities as these soil properties (particle size) are not largely influenced by land use within the human life frame. It was further observed that land utilization types (rubber and one year old fallow) had the

Table 2: Influence of topography on the properties of soil at 15 – 30 cm depth

		Topographic position			
		Crest	Upper slope	Middle slope	Lower slope
pH(H_2O)		5.48a	5.69a	5.90a	5.57a
pH(KCl)		4.61a	4.91a	4.54a	4.49a
Sand		702.5a	822.5a	835.0a	792.8a
Silt		84.5a	51.0a	47.5a	58.8a
Clay	g kg^{-1}	125.3a	101.0a	106.0a	126.8a
SOC		1.89a	1.21a	1.01a	1.74a
Base sat.		57.6a	60.8a	71.0a	68.7a
Al. sat.	%	1.9a	0.6bc	0.4c	1.4ab
ESP		4.3a	9.5ab	3.4b	14.4a
Avail. P	mg kg^{-1}	8.63a	9.69a	10.38a	9.46a
Exch. Calcium		1.73a	1.15a	1.50a	2.20a
Exch.Magnesium		1.19a	1.19a	1.53a	1.78a
Exch. Potassium		0.46a	0.67a	0.57a	0.63a
Exch. Sodium	cmol kg^{-1}	0.35a	0.48a	0.17a	0.94a
H^+		1.70a	1.56a	1.26a	1.44a
Al^{3+}		0.71a	0.35b	0.24b	0.93a
ECEC		6.24ab	5.81ab	4.09b	7.91a
TEB		5.53b	5.05b	5.02b	6.99a
Ca/Mg		2.97a	1.00a	1.05a	1.25a
Mg/K		3.89a	3.75a	5.29a	8.21a
(Ca+Mg)/K		13.49a	9.54a	9.96a	18.76
K/(Ca+Mg)		0.17a	0.30a	0.21a	0.23a

SOC = Soil organic carbon. Base sat. = Base saturation. Al sat. = Aluminum saturation. ESP. = Exchangeable Sodium percentage. Avail. P = Available phosphorus. Exch. = Exchangeable: ECEC = Effective cation exchange capacity. TEB = Total exchangeable bases. Values on same row followed by same letter(s) are not significantly different ($p<0.05$).

highest amount of sand and lowest clay content but still had comparable base saturation and effective cation exchange capacity which was not significantly different from those of other land utilization types. This is important because Voortman *et al.* (2002) referred to the base saturation and cation exchange capacity as compound soil characteristics that could be used to characterize soil fertility. Additionally, these variations could only be found to influence such crops as those whose rooting zone exceed 0 – 15 cm depths. The observed variations could also be an indication that these land utilization types (rubber and one year old fallow) have better slope stabilizing properties that need to be further investigated on. The species composition of the fallows and other components of the plantation were not considered in the study and these may have contributed in the slope stabilization by the land utilization types.

The results in Tables 1 and 2 revealed that the coastal plain sands soils did not display much variation in their characteristics due to the influence of topography in contrast with the effect of pediments on the soil on basement complex where topography had significant influence on gravel content, coarse sand, clay, pH(H_2O), available phosphorus, exchangeable acidity and copper (Olatunji *et al.*, 2007). In the surface soil (0 – 15 cm depth). TEB of crest (6.44 cmol kg^{-1}) and lower slope (8.58 cmol kg^{-1}) were significantly different from each other, while upper slope (5.70 cmol kg^{-1}), middle slope (4.56 cmol kg^{-1}) and crest (6.44 cmol kg^{-1}) were not significantly different from each other.

There was no significant difference in the Al saturation while ESP that was influenced in the upper slope (7.9%) and was significantly ($p<0.05$) different from middle slope (6.0%), lower slope (3.1%) and crest (2.8%) which in turn was not significantly different from each other. Within 15 - 30 cm depths. TEB (7.0 cmol kg^{-1}) was significantly ($p \leq 0.05$) different from crest, upper and middle slopes (5.3 cmol kg^{-1}, 5.1 cmol kg^{-1} and 5.0 cmol kg^{-1} respectively). Aluminum saturation in the crest and lower slope positions were 1.9% and 1.4% respectively, and were not significantly different, equally upper and middle slopes (0.6% and 0.4% respectively) were not significantly different from each other. ESP was 14.3% in lower slope, 9.5% in upper slope (not significantly different), while crest, upper slope and middle slopes were not significantly different from each other. TEB, Na^{+} saturation and Al^{3+} saturation of 15 – 30 cm depth were influenced by topography. Interaction was not tested in the study but results indicated that there was existence of interactions between topography and land utilization types.

Table 3: Influence of land utilization types on the properties of soil at 0 – 15 cm depth

		land utilization types			
		Rubber	Oil palm	5years fallow	1year fallow
pH(H_2O)		6.18a	6.06a	5.91a	4.60a
pH(KCl)		5.37a	4.88ab	4.64bc	4.03c
Sand		844.0a	784.8a	759.8a	759.3a
Silt		74.5a	93.5a	105.8a	65.3a
Clay	g kg^{-1}	74.5a	121.8a	155.8a	80.5a
SOC		1.57ab	2.51a	1.67ab	1.32b
Base sat.		69.2a	71.5a	68.8a	68.4a
Al. sat.	%	0.5a	1.1a	1.2a	0.6a
ESP		8.1a	6.3a	3.3a	2.7a
Avail. P	mg kg^{-1}	11.26a	6.18a	4.53c	17.69a
Exch. Calcium		2.00b	2.25ab	3.34a	1.83b
Exch.Magnesium		1.13a	1.54a	2.14a	1.20a
Exch. Potassium		0.49a	0.65a	0.66a	0.32a
Exch. Sodium	cmol kg^{-1}	0.50a	0.38ab	0.26ab	0.12b
H		2.74a	1.33a	1.27a	1.23a
Al^{3+}		0.35a	0.67a	0.85a	0.42a
ECEC		5.87ab	6.83ab	8.13a	5.42b
TEB		6.85ab	6.16ab	7.67a	4.71b
Ca/Mg		2.22a	1.49a	1.91a	1.58a
Mg/K		5.71a	2.78a	8.68a	6.30a
(Ca+Mg)/K		14.56	6.55a	20.53a	15.50a
K/(Ca+Mg)		0.16a	0.17a	0.14a	0.11a

SOC = Soil organic carbon. Base sat. = Base saturation, Al sat. = Aluminum saturation. ESP. = Exchangeable Sodium percentage. Avail. P = Available phosphorus. Exch. = Exchangeable: ECEC = Effective cation exchange capacity. TEB = Total exchangeable bases. Values on same row followed by same letter(s) are not significantly different ($p<0.05$).

The influence of land utilization types was significant in the TEB and not in Al^{3+} and Na^{+} saturation of the surface soil, while TEB and Al^{3+} saturation were significantly influenced in the 15 - 30 cm depth. In the 0 – 15 cm depth, five year old fallow had the highest TEB of 7.67 cmol kg^{-1} and this was not significantly different from 6.85 cmol kg^{-1} (rubber) and 6.16 cmol kg^{-1} (oil palm). In 15 -30 cm depth, five year old fallow had 7.21 cmol kg^{-1} in TEB, and this was not significantly different from rubber plantation (5.82 cmol kg^{-1}) but significantly ($p<0.05$) different from one year old fallow that had 4.31 cmol kg^{-1} indicating that actually nutrients are built as fallow lasts longer. Considering the ratios of exchangeable cations in the soils as influenced by

Table 4: Influence of land utilization types on the properties of soil at 15 – 30 cm depth

		land utilization types			
		Rubber	Oil palm	5years old fallow	1year old fallow
pH(H_2O)		6.18a	6.13a	5.56ab	4.77b
pH(KCl)		5.41a	4.86ab	4.36bc	3.91c
Sand		871.0a	758.5b	785.0b	864.5a
Silt		44.3a	62.0a	76.3a	59.3a
Clay	g kg^{-1}	84.8bc	156.0a	138.8ab	79.5c
SOC		1.48a	1.54a	1.36a	1.45b
Base sat.		61.7ab	54.0b	71.5a	71.1a
Al. sat.	%	1.7a	1.4a	0.9ab	0.2b
ESP		7.1a	8.7a	8.1a	7.4a
Avail. P	mg kg^{-1}	10.72b	5.54c	2.56d	19.34a
Exch. Calcium		1.28a	1.34a	2.40a	1.55a
Exch. Magnesium		1.36b	0.97ab	2.36a	1.00a
Exch. Potassium		1.07a	0.56ab	0.49b	0.20b
Exch. Sodium	cmol kg^{-1}	0.44a	0.43a	0.62a	0.36a
H^+		1.66ab	1.76a	1.35ab	1.20b
Al^{3+}		0.95a	0.64a	0.68a	0.16b
ECEC		6.77a	6.11a	6.54a	4.64a
TEB		5.82ab	5.06bc	7.21a	4.31c
Ca/Mg		0.96a	2.07a	0.97a	1.61a
Mg/K		1.55b	2.05ab	9.90a	7.84a
(Ca+Mg)/K		2.58a	7.13a	20.47a	21.79a
K/(Ca+Mg)		0.42a	0.25ab	0.14b	0.09b

SOC = Soil organic carbon, Base sat. = Base saturation, Al sat. = Aluminum saturation, ESP. = Exchangeable Sodium percentage, Avail. P = Available phosphorus, Exch. = Exchangeable: ECEC = Effective cation exchange capacity, TEB = Total exchangeable bases. Values on same row followed by same letter(s) are not significantly different ($p<0.05$).

either land utilization types or topography. it was observed that and Ca/Mg. Mg/K. (Ca+Mg)/K and K/(Ca+Mg) were not significantly influenced by topography in both the surface and subsurface soil as significant difference was not established between the topographic positions. This was an indication that the parent materials of these soils were largely similar as it was further confirmed by the similarity in particles size distribution of the soils. Similarly, significant differences were not observed between the land utilization types on the surface soil.

The fact that the particle size distribution (sand, silt and clay) did not display any significant differences was indication that the soils were from similar parent material, and there wasn't lithological discontinuity (Langohr, *et. al.*, 1976). This was further confirmed in the similarity of the ratios of such exchangeable cations as Ca/Mg" Mg/K' Al x Ca + Mg)/)K' and K/(Ca + Mg).

These were used by Shaw *et al.* (2001). Voortman *et al.* (2002) and Olatunji *et al.*, (2007) to assess similarity of parent material of soils on toposequences. This showed that variations in soil fertility parameters were actually the effect of different land utilization types. The land utilization types have been found to enhance soil fertility but with differing intensities. The fact that the fallow had higher variation in plant species with differing types of root system suggests that it had higher capacity to improve soil fertility than the plantations (Ewel.

1986). It had previously been reported by Juo and Wilding. (1996) that upland soils in the humid forest zone are strongly weathered and dominantly kaolinitic ultisols and oxisols (normally highly leached) acidic and contain very low mineral nutrient such as calcium, magnesium, potassium and phosphorus.

CONCLUSION

Generally soil properties influenced by either topography or land utilization types were use-dependent, while the use-independents were more stable. Approximately 18% and 23% of the 22 soil properties considered in 0 – 15 cm and 15 – 30 cm depths respectively were influenced by topography, while 32% and 64% in 0 – 15 cm and 15 – 30 cm depths respectively were influenced by land utilization types. This showed that influence of land utilization types on fertility parameters was double the effect of topography at the soil surface and tripled at the subsurface soil. Therefore in coastal plain sands, topographic positions affect fertility minimally in comparison to land utilization types. Yet, these factors (topography and land utilization types) significantly affect soil fertility and will attract different soil management systems for sustainable crop production. Interactions were not tested in this study but it was observed that there could be interaction between the effect of topography and land utilization types on soil fertility trend and subsequently crop production and which could be further investigated.

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Generally soil properties influenced by either topography or land utilization types were use-dependent, while the use-independents were more stable. Approximately 18% and 23% of the 22 soil properties considered in 0 – 15 cm and 15 – 30 cm depths respectively were influenced by topography, while 32% and 64% in 0 – 15 cm and 15 – 30 cm depths respectively were influenced by land utilization types. This showed that influence of land utilization types on fertility parameters was double the effect of topography at the soil surface and tripled at the subsurface soil. Therefore in coastal plain sands, topographic positions affect fertility minimally in comparison to land utilization types. Yet, these factors (topography and land utilization types) significantly affect soil fertility and will attract different soil management systems for sustainable crop production. Interactions were not tested in this study but it was observed that there could be interaction between the effect of topography and land utilization types on soil fertility trend and subsequently crop production and which could be further investigated.

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