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Effects of Land use on forms of phosphorus in coastal plain sands of Nigeria

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ABSTRACT

This research studied the effect of land uses changes on the forms of phosphorus within the coastal plain sands landscape of southeastern Nigeria. Satellite imageries and soil data including phosphorus fractions were used for the study. Spatial coverage of forest and agricultural (fallow and farmland) land uses, accompanying soil properties and forms of phosphorus were estimated. There was progressive increase in the agricultural land use over the years to as much as 85.7% of the study area. The agricultural land use continually undergoes circles of crop-fallow with accompanying influence on nutrient cycling and pedogenesis. Land uses studied influenced available, organic, total, bound, iron and occluded iron and aluminium forms of phosphorus whereas topography influenced iron forms. Particle size distribution influenced available, organic, total, bound iron and occluded forms of phosphorus. Soil pH influenced available and iron forms of phosphorus whereas organic matter is a major determinant in the distribution and variability of iron, occluded, occluded iron and aluminium, calcium and residual forms. Progressive increases in the spatial coverage of agricultural land use under the present production system results to preponderance of recalcitrant phosphorus in larger portion of the study area to the detriment of available forms, crop growth and yield

1.0 Introduction

The coastal plain sands of Benin formation comprised deltaic marine sediments of cretaceous to recent age and possess characteristics dominated by sandstone and siltstone lithofacies. These dominant lithofacies are quartz arenite and originate from acidic plutonic igneous rocks. The interactions between these geological materials and the environment give rise to acid sands of southeastern Nigeria. These acid sands are highly weathered and dominantly ulfisols or acrisols (Akpan-Idiok and Ukwang, 2012). The dynamics of phosphorus (P) has been found to associate with parent material, extent of weathering, drainage, pH and anion exchange capacity of soils. Highly weathered tropical Ferralsols, Acrisols, and Luvisols are generally deficient in P as a result of high degree of sorption in the presence of large quantities of exchangeable aluminium (Al) and total iron (Fe), low pH and low organic matter content.

Land use and changes have been associated with soil development (Obi, 2015; Obi and Ituen, 2017) and there is a strong relationship between P forms and stages of soil development. The implication is the significant effect of land use and changes on the dynamics of phosphorus in the soil. Selmants and Hart (2010) reported that primary forms of phosphorus dominate the soil at the initial stage of development but the progress of weathering give rise to organic, non-occluded and occluded forms. Therefore, at the late stage of soil development, phosphorus is dominated by organic and occluded forms (Yang and Post, 2011). These are indications that as soil development progresses from the young (entisols or arenosol) through maturity to

senile stage (oxisols or ferralsols), there is gradual reduction and eventual exhaustion of mineral P (apatite).

The effect of land use on the dynamics of P is associated with plant nutrition, rhizosphere interaction and extrinsic factors such as management (Walker *et al*., 2010). Changes in land use result to very highly significant differences in status of P in the soil (Lou *et al*., 2015). For instance, significant differences were reported on the levels of labile and recalcitrant forms of P contents of oxisols on natural savanna, arable, pasture and reforested lands (Neufeldt *et al*., 2000). Chimdi *et al*. (2014) reported that changing from forest and grazing to cultivated land decreased the amount of extractable Al and Fe resulting in lower total P contents of the cultivated compared to other land uses.

The highly weathered acid sand of southeastern is increasingly subject to intensive and extensive utilization in a low input and low efficiency agricultural production system. The consequence is progressive conversion of forest to arable land use. Additionally, the reduction of fallow period has almost eliminated the concept of fallow in the production system of the study area. These affect the dynamics of P within the landscape of coastal plain sands of southeastern Nigeria. Therefore, this research studied the effect of changes from forest to agricultural land use on the dynamics of P in the coastal plain sands of Akwa Ibom State, southeastern Nigeria.

2.0 Materials and Methods

2.1 Description of the study area

The study was carried out in locations underlain by coastal plain sands (CPS) in Akwa Ibom State, southeastern Nigeria (Fig. 1). The State is located between approximately latitudes 4° 30′ and 5° 30′ N and longitudes 7° 28′ and 8° 20′ E, and covers approximately 7249 km^2 out of which 70% and 5% are CPS and accompanying alluvium respectively. Akwa Ibom State was carved out of Cross River State in 1987 and Uyo the Capital City is enclosed between latitude 4° 50' and 5° 07' N and longitude 7° 45' and 8° 05' E and falls with the coastal plain sands. In 1986, the human population was 2,100,565 but has grown to 3,902,051 and 5,272,029 in 2006 and 2015 respectively.

The climate is characterized by distinct wet (March/April to October) and dry (November to March) seasons. Rainfall distribution in a year is bimodal (with peaks in July and September) and high intensity with annual range of 2000 to 4000 mm. Temperature is uniformly high ranging between 28 °C and 30 °C and relative humidity is high (approximately 75%). Previously the study area belonged to the humid tropical forest zone of southern Nigeria but currently characterized by secondary forest of predominantly wild oil palm trees of various densities, woody shrubs and various grass undergrowth.

The predominant land use is the cropping-bush fallow-cropping closed system operated with hoes and machetes. The constraints of fragmentation and primitive hand tools restrict average farm size to a maximum of 0.5 ha per site. A farmer could have several small parcels of farm scattered over a wide area. The principal food crops grown are yam, cassava, maize and cocoyam and the dominant tree crop is oil palm.

The profiles of soils formed from coastal plain sands vary from sand on the surface to fine loamy in the subsurface and have low physical and chemical fertility due to dominance of low-activity kaolinitic clays and low organic matter content (Chikezie *et al*., 2010). They are well drained, deeply weathered and classified as Haplic Acrisol (Hyperdystric) of the World Reference Base. **Overall**

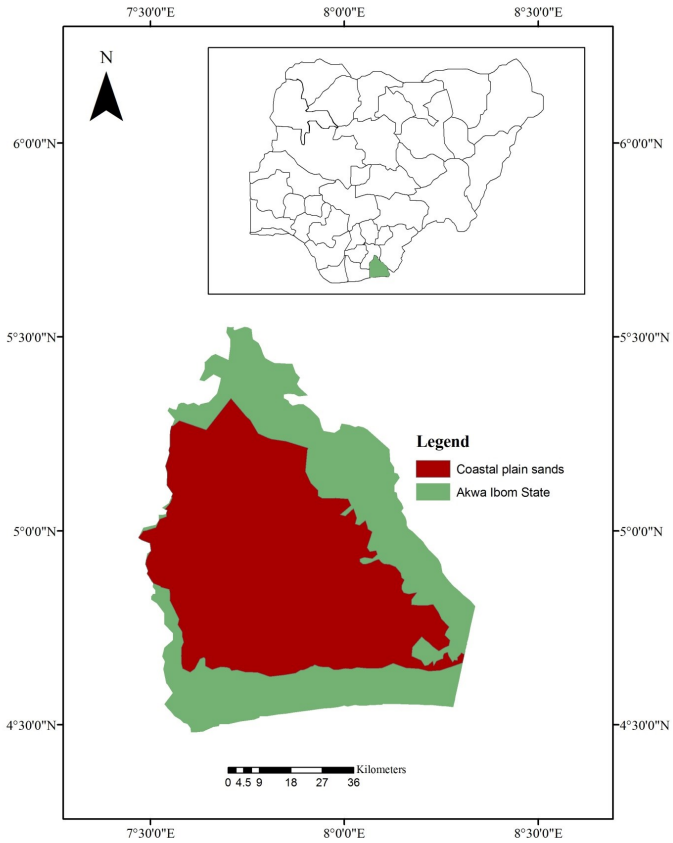


Fig. 1: Map of Akwa Ibom State showing area covered by coastal plain sands

2.2 methodology and pre-processing

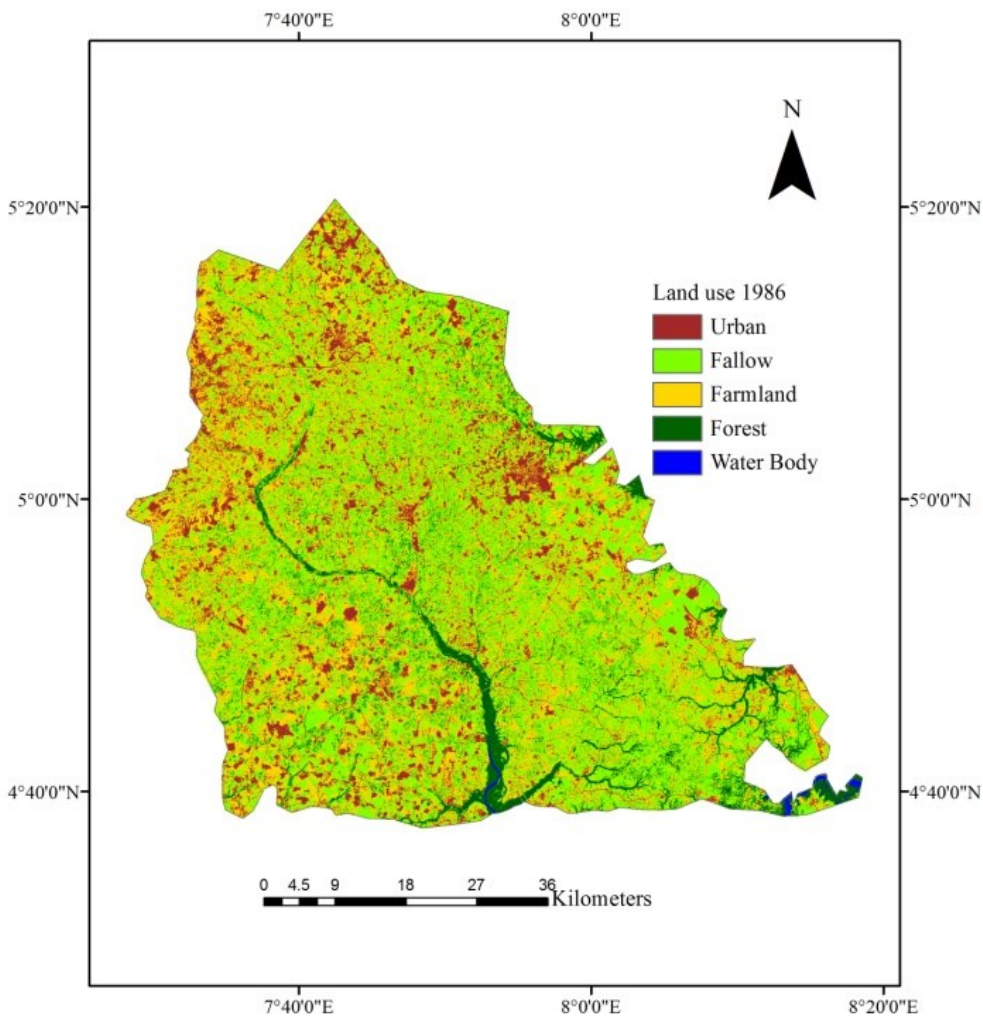
Population is a major driver of land use changes and responsible for the decrease in the arable land in Akwa Ibom State from 0.22 to 0.11 ha per person between 1986 and 2013. Therefore, the changes in the different land uses from 1986 to 2013 were estimated with the aid of remote sense techniques. The images utilized in the study based on availability were those captured in 1986, 2003, 2008 and 2013.

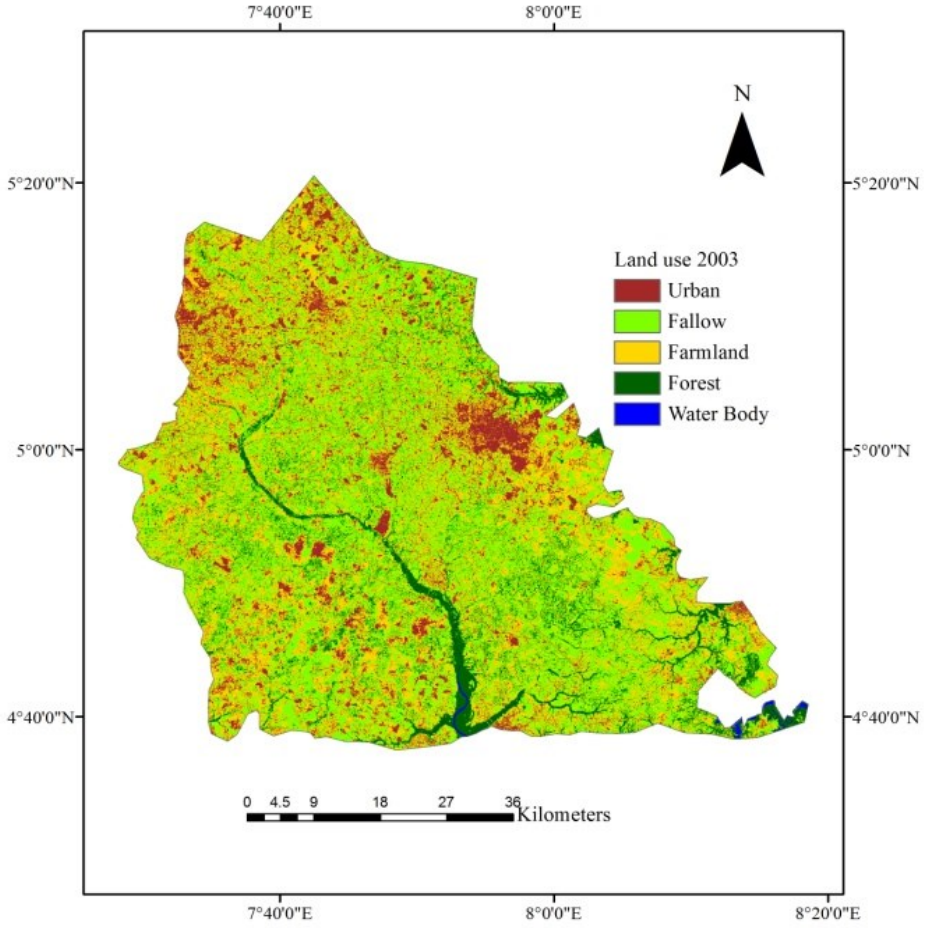
Landsat TM and ETM+ images with spatial resolution of 30 m^2 captured in 1986 and 2003 and Nigeriasat 1 images captured in 2008 and 2013 with spatial resolution of 32 m^2 were acquired and used for the study. Large-scale aerial photographs of 2002 were also acquired from Akwa Ibom State Ministry of Lands and Housing for selection of training areas and accuracy assessment of the classified images. The steps involved in image processing were as described in Tokula and Ejaro, (2012). Anderson *et al*. (1976) classes was modified for use in the study area and five land use and land cover classes were defined and adopted for use. The modified land use and cover classes include water body, forest, fallow, farmland and urban. Supervised signature extraction was adopted in conjunction with the maximum likelihood algorithm to derive meaningful classes from the images.

2.3 Field studies and laboratory analysis

Typical toposequences of gently undulating coastal plain sands geomorphic unit is characterised by slopes of less that 5%. Three representative and contiguous toposequences per land use (i.e. forest, fallow and arable) were selected in three villages to give a total of nine sampling locations within the coastal plain sands geomorphic unit. The villages include Use Offot (longitude 7° 58' 396" and latitude 5° 01' 849"), Ntak Inyang (longitude 7° 55' 818" and latitude 5° 04' 964") and Idu (longitude 8° 00' 212" and latitude 5° 01' 895"). Oil palm plantation that is more than 40 years of age was used to represent forest land use. Fallow land use is land formerly used for crop production but abandoned as a result of very poor yield and has stood for a minimum of four years. Arable land use is a cassava farm from which maize crop have been harvested.

A total of 54 auger soil samples comprising 27 each from the surface (0-15 cm) and subsurface (15-30 cm) were collected from the upper, middle and lower slope positions of the selected toposequences and preserved for laboratory analysis. The samples were pulverized, sieved through 2.0 mm mesh sieve and used for laboratory analysis. Particle size analysis was carried out using the method of Dane and Topp (2002). Soil organic carbon (OC) content was determined as described in Sparks (1996) and organic matter content is OC multiplied by 1.729 (Odu *et al*., 1986). Soil pH was determined in 1:2.5 (soil:water) solution using pH meter (McLean, 1982).

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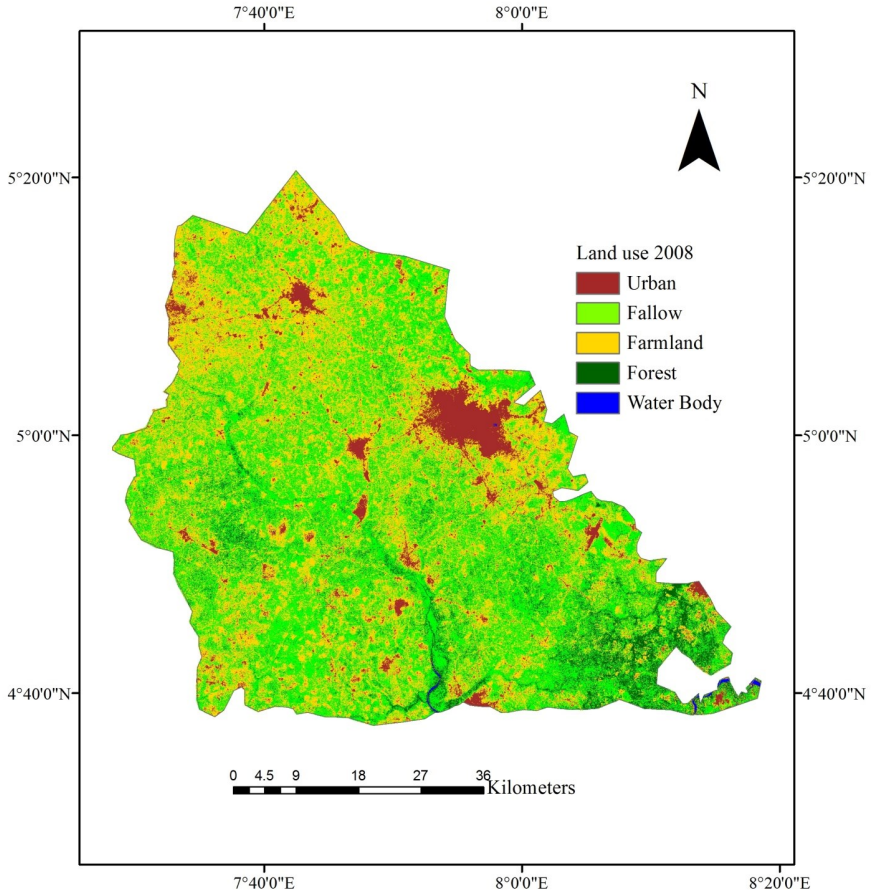
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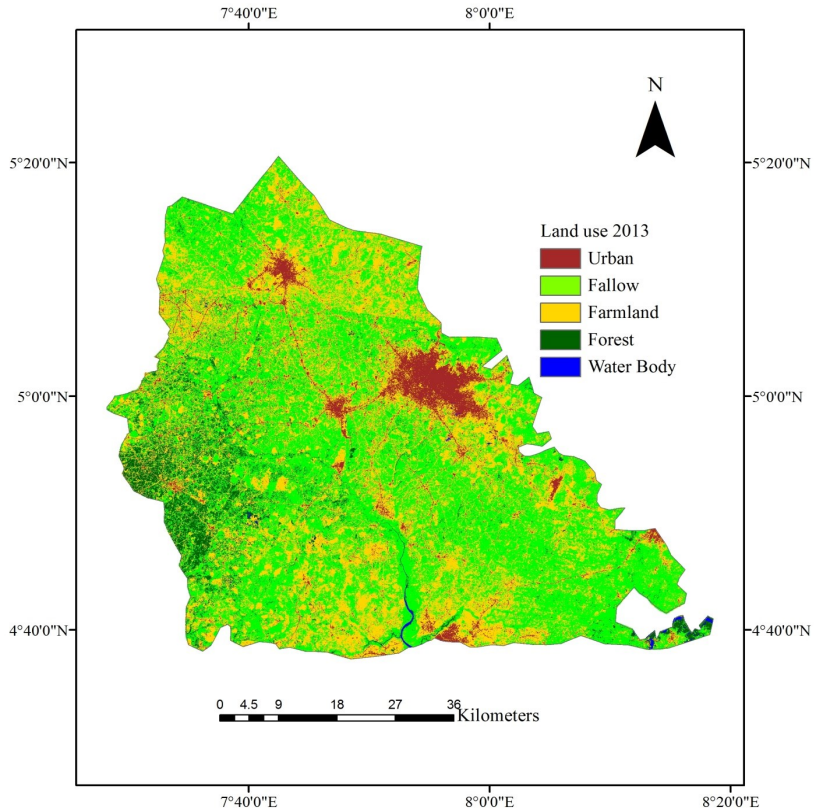

Fig. 2: Land use/cover map of area covered by coastal plain sands in Akwa Ibom State

Exchangeable bases were extracted with Mehlich No. 3 extraction (Mehlich, 1984). Potassium (K) and sodium (Na) contents were determined with flame emission spectrophotometer, calcium (Ca) and magnesium (Mg) with atomic absorption spectrophotometer (AAS). Available P (AvP) was extracted according to the Bray and Kurtz (1954). Exchangeable acidity (EA) was extracted with unbuffered potassium chloride solution and titration with 0.01 M solution of sodium hydroxide to the first permanent pink endpoint, while effective cation exchange capacity (ECEC) and base saturation (BS) determinations were as described by Anderson and Ingram (1993).

Organic phosphorus (Por) content was measured by the ignition method (Kuo, 1996), for which phosphorus in the ignited (550 °C) and unignited soil samples were extracted by 0.5 M H_2SO_4. Selective sequential fractionation of inorganic phosphorus (Pinor) in the soil was performed, using the stepwise extraction scheme. Soluble and loosely bound phosphorus (S/LP), aluminium bound phosphorus (AlP), iron bound phosphorus (FeP) and Ca bound phosphorus (CaP) were selectively extracted by NH_4Cl, NH_4F, NaOH, $Na_2S_2O_4$, and H_2SO_4, respectively (Kuo, 1996). Phosphorus in the extracted supernatants was determined colorimetrically using the blue colour method of Murphy and Riley (1962). The secondary mineral or occluded form of phosphorus was determined using 0.1 M NaOH, 0.3 M $NaC_3H_6O_7$ + 1M $NaHCO_3$ + $Na_2S_2O_4$. Residual phosphorus (RES-P) was given by the difference between the total phosphorus (TP) content and the sum of inorganic and organic fractions.

2.4 Statistical analysis

Soil samples were collected in a 3 x 3 factorial experiment in randomized complete block design (RCBD) with three replications. The two factors were land use and slope position while locations served as the blocks. Data collected were analysed using analysis of covariance with subsurface and surface soil as the dependent and independent variables respectively. The subsurface soil is not as variable as the surface soil. Pair wise comparisons were conducted with least squares means. Pearson's correlation was carried out to establish the relationship between the different forms of P and other soil properties. All statistical analyses were carried out using Statistical Analysis System.

3.0 Results

3.1 Changes in land uses within coastal plain sands

The land use maps of coastal plain sands geomorphological unit in Akwa Ibom State between 1986 and 2013 were shown in Figure 2. The distribution of urban land use indicated a drift towards few central locations. Farmlands were equally found to concentrate within the fringes of urban land use while fallow and forest land uses followed in that order. These confirmed indiscriminate establishments of small farms by large number of individuals in a low input low efficiency crop production system within the fringes of urban land use.

The result revealed that there was gradual and progressive increase in the coverage of agricultural (farmland and fallow) to the detriment of forest land use (Table 1). Cumulatively, agricultural land use occupied between 76.7% and 85.7% which implied that this amount of land is constantly going through the circles of cropping and fallowing with accompanying influence on nutrient recycling and pedogenesis

Table 1: Spatial coverage different of land uses within the study area between 1986 and 2013

		Farmland	Fallow	Forest	Urban	Water body	Total
1986	Area (ha)	182360.3	234410.9	58043.2	67144.9	1715.7	543675
	(%)	33.5	43.1	10.7	12.4	0.3	100
	Cumulative (%)	33.5	76.7	87.3	99.7	100	
2003	Area (ha)	203807.6	262332.3	69874.5	5516.6	2144.0	543675
	(%)	37.5	48.3	12.9	1.0	0.4	100
	Cumulative (%)	37.5	85.7	98.6	99.6	100	
2008	Area (ha)	233009.2	223468.4	52764.8	32267.7	2164.8	543675
	(%)	42.9	41.1	9.7	5.9	0.4	100
	Cumulative (%)	42.9	84.0	93.7	99.6	100	
2013	Area (ha)	214905.0	246690.7	56835.6	23174.1	2069.6	543675
	(%)	39.5	45.4	10.5	4.3	0.4	100
	Cumulative (%)	39.5	84.9	95.4	99.6	100	

3.2 Effect of land use and slope positions on soil properties

The results shown in Tables 2 and 3 indicated that land use and topography did not significantly affect the distribution of sand and clay, but silt content. The silt content of the forest was lower than that of fallow and arable and this could be attributed to similarity in the two land uses. Fallow and farmland are continually interchanged in a circle of at least one in four years. The effect of topography on the particle size distribution of the soils revealed that the silt content of the upper slope position was not significantly different from that of the middle, but from that of the lower slope, while that of the middle slope was also not significantly different from that of lower. This indicated the overlapping

Table 2: Effect of land use and slope position on the soil properties in the study area

		Land use			Slope position		
Soil properties		Arable	Fallow	Forest	Upper	Middle	Lower
Sand	--(g kg^{-1})--	825.2	829.8	834.2	827.6	843.1	818.7
Silt		56.2a	47.6a	25.1b	47.3ab	27.3b	56.2a
Clay		118.4	120.7	138.4	125.1	127.3	125.1
Organic matter		4.0	3.8	4.4	4.0	4.00	4.3
pH		5.72a	5.54b	5.57ab	5.68	5.63	5.52
Calcium	----(cmol kg^{-1})---	3.91a	3.44ab	3.29b	4.18a	2.93b	3.53b
Magnesium		1.29	1.33	1.07	1.37	0.98	1.33
Potassium		0.09ab	0.10a	0.08b	0.09	0.09	0.08
Sodium		0.06	0.06	0.06	0.06	0.06	0.06
Acidity		1.92	2.36	2.52	2.29	2.10	2.29
ECEC		7.27	7.30	7.02	8.00a	6.16b	7.44a
Base saturation	(%)	72.9a	68.3ab	63.8b	70.4	68.0	66.6

ECEC=Effective cation exchange capacity

Row values with similar alphabets are not significantly ($p<0.05$) different

Table 3: Interaction of land use and slope position on the variation of soil properties in the study area

			Arable			Fallow			Forest		
Soil properties			Lower	Middle	Upper	Lower	Middle	Upper	Lower	Middle	Upper
Sand		--(g kg^{-1})--	838.0	867.6	838.0	807.4	826.2	832.8	846.1	791.5	820.8
Silt			53.8ab	31.8ab	45.6ab	71.8a	37.5ab	46.4ab	24.2b	37.0ab	44.7ab
Clay			105.03	103.39	119.24	123.39	132.45	120.00	131.69	164.15	133.33
Organic matter			4.34	4.21	3.82	4.13	3.66	3.83	4.15	4.45	4.03
pH			5.52	5.78	5.52	5.56	5.56	5.76	5.58	5.62	5.59
Exchangeable	Calcium	---(cmol kg^{-1})---	3.79b	2.79bc	4.88a	3.24b	3.33bc	3.80ab	3.65bc	2.64c	3.82ab
	Magnesium		1.21	0.91	1.72	1.72	1.09	1.20	1.07	0.94	1.22
	Potassium		0.08b	0.08b	0.09ab	0.11a	0.09ab	0.10ab	0.07b	0.08b	0.09ab
	Sodium		0.06	0.07	0.06	0.07	0.06	0.05	0.06	0.06	0.06
	Acidity		2.04	1.92	2.32	2.58	2.56	2.05	2.73	1.96	2.27
ECEC			7.06	5.68	8.96	7.83	6.78	7.34	7.48	6.01	7.64
Base saturation		(%)	71.87	68.00	73.10	67.33	66.52	70.38	63.53	64.40	70.00

ECEC=Effective cation exchange capacity

Row values with similar alphabets are not significantly ($p<0.05$) different

effect of gravity and erosion on the distribution of the particle size fractions. Particle size distribution is a compositional soil variable and the accumulation of sand fractions at the lower slope position will invariably lead to a reduction in the either silt or clay content and in this case silt. It was further confirmed that the locations that manifested significant differences in the silt content were the lower slope positions of forest and fallow land uses (Table 3). This is a further confirmation of the similarity in the particle size distribution of the agricultural land use.

Land use influenced the variability of pH, Ca, K content and base saturation, whereas topography influenced Ca content and ECEC. The effect of land use resulted in the similar trends observed in the variability of calcium, potassium content and base saturation (Table 3). Topographic factors are responsible for variation in the Ca content and ECEC of the soils. The combined effect of land use and topography result to decreases in Ca content from the upper slope downwards (Table 3).

3.2 Forms and distribution of phosphorus on coastal plain sand

The relative abundance of the different forms of P within coastal plain sands of Benin formation was as shown in Fig. 3 while the influence of land use and topography were as shown in Tables 4 and 5. The relative abundance of P was found to be more similar in the agricultural compared to the forest land use. The available, organic, total, bound, iron and occluded Fe and AlP P were influenced by land use. Topography was the major determinant of distribution of FeP and there were interactions between land use and topography in AvP and CaP. The AvP and TP content of the agricultural land use were similar while arable and forest land use were significantly different from each other. The total P was significantly different from each other in the fallow and forest land uses. The highest iron oxide (37.42 mg kg^{-1}) and occluded Fe and AlP (33.07 mg kg^{-1}) content was found in fallow land use and these were significantly different from 32.22 mg kg^{-1} and 27.47 mg kg^{-1} respectively found in forest land use. The lowest amount of iron oxide (30.56 mg kg^{-1}) and occluded Fe and AlP (27.24 mg kg^{-1}) content was found in farmland use. Relative similarity was observed in the forms and distribution of P as a result of the influence of topography because significant differences were found only in the iron occluded P. The iron occluded P content of the upper (34.73 mg kg^{-1}), middle (33.24 mg kg^{-1}) and lower (32.24 mg kg^{-1}) slope positions were significantly different from each other (Table

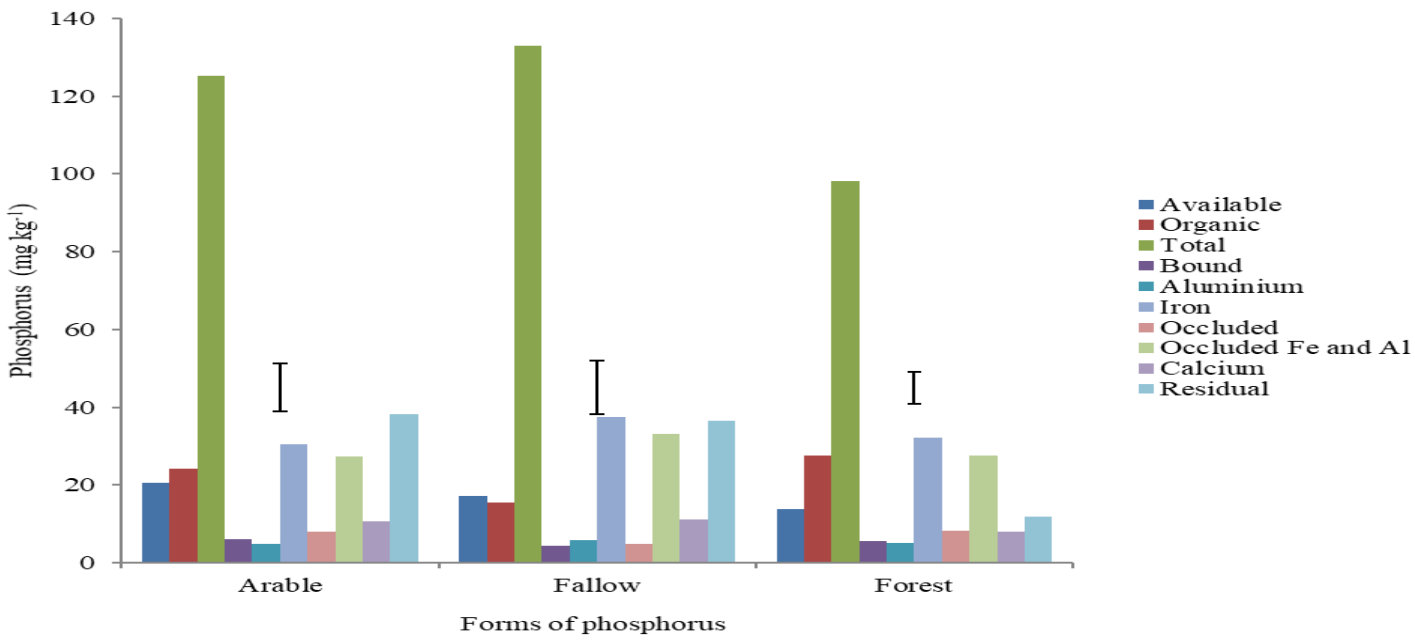

Fig. 3:

Table 4: Effect of land use and slope position on the forms of phosphorus

Forms of phosphorus (mg kg^{-1})	Land use			Slope position		
	Arable	Fallow	Forest	Upper	Middle	Lower
Available	20.44a	17.17ab	13.87b	17.78	15.50	18.20
Organic	24.30	15.51	27.55	17.89	22.77	26.71
Total	125.22a	132.99a	98.19b	124.12	106.06	126.22
Bound	6.00	4.27	5.51	5.20	5.38	5.20
Aluminium	4.93	5.87	5.07	4.93	5.60	5.33
Iron	30.56c	37.42a	32.22b	34.73a	33.24b	32.22c
Occluded	7.87	4.80	8.27	7.20	5.47	8.27
Occluded Fe and Al	27.24b	33.07a	27.47b	29.42	29.42	28.93
Calcium	10.53	11.09	8.00	11.02	10.40	8.20
Residual	38.09	36.48	11.91	31.88	16.55	38.07

Fe and Al = iron and aluminium

Row values with similar alphabets are not significantly ($p<0.05$) different

Table 5: Interactive effect of land use and slope position on the forms of phosphorus

Forms of phosphorus ($mg\ kg^{-1}$)	Arable			Fallow			Forest		
	Lower	middle	Upper	Lower	middle	Upper	Lower	middle	Upper
Available	20.23a	19.80a	20.30a	14.47ab	18.81ab	15.75ab	14.60ab	11.91b	18.57ab
Organic	20.51	39.97	18.65	19.82	17.77	13.59	39.78	20.59	11.41
Total	127.87	119.78	140.13	125.03	109.13	113.37	117.79	117.95	98.17
Bound	3.94	6.21	7.16	4.13	4.76	3.52	5.81	6.24	5.56
Aluminium	5.27	4.87	4.46	5.86	5.46	5.46	5.27	6.47	4.47
Iron	33.40	33.40	33.40	33.40	33.40	33.4	3.34	33.40	33.40
Occluded	11.07	5.58	7.41	6.90	4.96	5.76	5.25	8.05	6.82
Occluded Fe and Al	26.51	27.54	33.79	29.77	31.68	28.20	27.18	31.64	27.01
Calcium	6.31b	15.20a	10.71ab	8.38ab	7.66ab	12.74ab	7.98ab	11.42ab	8.45ab
Residual	50.80	21.15	40.37	38.24	23.00	24.28	29.45	21.76	10.48

Fe and Al = iron and aluminium

Row values with similar alphabets are not significantly ($p<0.05$) different

4).The combined influence of land use and topography resulted to significant interaction in the available and calcium P. The entire topographic positions on the arable land use were neither significantly different from each other nor from other locations but middle slope position of the forest land use. Also, middle slope position of the forest land use was not significantly different from all but the entire landscape on arable land use which was a confirmation that arable land use is an active modifier of AvP.

The distribution of different forms of P on the coastal plain sands is dependent on the factors of soil formation and such extrinsic factors as land use and management. Particle size fraction of coastal plain sands influenced available, organic, total, bound iron and occluded forms of P (Table 6). The sand ($r = -0.55$) and clay content ($r = 0.60$) of the soils highly significantly ($p<0.01$) correlated with AvP. Similar trends of significant ($p<0.01$) correlation characteristics of particle size fractions was observed between sand, clay and bound ($r = -0.47$ and 0.56 respectively), iron ($r = -0.61$ and 0.64 respectively) and occluded ($r = -0.40$ and 0.37 respectively) forms of P. Additionally organic and total P significantly correlated with silt ($r = -0.39$, $p<0.01$) and clay ($r = 0.34$, $p<0.05$) respectively.

Soil pH as shown in Table 6 highly significantly ($p<0.01$) correlated with AvP ($r = -0.35$) and FeP ($r = -0.54$). Organic matter correlated with Fe ($r = 0.41$, $p<0.01$), occluded ($r = 0.55$, $p<0.01$), occluded Fe and Al ($r = -0.41$, $p<0.01$), Ca ($r = -0.37$, $p<0.01$) and residual ($r = -0.31$, $p<0.05$). Magnesium and potassium significantly correlated with FeP, each with $r = -0.28$ ($p<0.05$). Exchangeable acidity significantly correlated with available (0.31, $p<0.05$), total, bound (0.33, $p<0.05$) and iron (0.42, $p<0.01$) form of P confirming their dependence on soil acidity. The importance of iron oxide in pedogenesis could be the explanation for the strongest correlation between iron P and particle size fractions which are major determinants of pedogenesis. This is contrary to the AlP which did not correlate significantly with any of the soil properties in as much as aluminium oxide is contributory to the acidity of the coastal plain sands. This could be a further indication that distribution and variability of forms of P in coastal plain sands is associated with pedogenesis. Aluminium participate more in the pedogenesis of poorly or imperfectly drained (alluvial) soils.

Table 6: Relationship between the forms of phosphorus and other soil properties in the study area

	Forms of phosphorus									
	Available	Organic	Total	Bound	Aluminium	Iron	Occluded	OclFeAl	Calcium	Residual
Sand	-0.55^{**}	0.05	-0.26	-0.47^{**}	-0.15	-0.61^{**}	-0.40^{**}	0.23	0.01	-0.07
Silt	0.06	-0.39^{**}	-0.08	-0.06	-0.09	0.10	0.15	-0.13	-0.08	-0.11
Clay	0.60^{**}	0.15	0.34^{*}	0.56^{**}	0.22	0.64^{**}	0.37^{**}	-0.19	0.03	0.14
pH	-0.35^{**}	-0.12	-0.23	-0.25	-0.04	-0.54^{**}	-0.17	-0.03	0.24	-0.08
OrgM	0.24	-0.13	-0.16	0.12	0.13	0.41^{**}	0.55^{**}	-0.41^{**}	-0.37^{**}	-0.31^{*}
Ca	0.11	-0.04	0.11	0.13	0.02	-0.17	-0.17	0.20	0.15	0.15
Mg	-0.05	-0.12	0.01	0.06	0.03	-0.28^{*}	-0.11	0.18	0.06	0.07
Na	0.33^{*}	-0.01	-0.17	0.30^{*}	0.10	0.41^{**}	0.52^{**}	-0.37^{**}	-0.34^{*}	-0.34^{*}
K	-0.23	-0.17	0.07	-0.20	0.14	-0.28^{*}	-0.22	0.13	0.17	0.19
EA	0.31^{*}	0.19	0.33^{*}	0.29^{*}	0.24	0.42^{**}	0.16	0.16	-0.13	0.21
ECEC	0.21	0.02	0.23	0.24	0.13	-0.03	-0.09	0.28^{*}	0.07	0.23
Bsat	-0.20	-0.19	-0.17	-0.18	-0.14	-0.44^{**}	-0.23	0.07	0.20	-0.06

OclFeAl = Occluded iron and aluminium, OrgM = organic matter, Ca = exchangeable calcium, Mg = exchangeable magnesium, Na = exchangeable sodium, K = exchangeable potassium, EA = exchangeable acidity, ECEC = effective cation exchange capacity, Bsat = base saturation.

4.0 Discussion

4.1 Pattern of land use, changes and forms of phosphorus

Point to point change detection revealed that there was continual interchange between fallow and farmland (agricultural), and losses in forest land use are gains to the agricultural. The fact that cumulatively less than 7% of the study area was under urban and water land use indicated that up to 93% was either under agricultural or to a lesser extent forest. These interchanges between different land uses are significant in nutrient management, recycling and P dynamics.

Changes in land use results to very highly significant differences in status of soil P. Phosphates in soils originate largely from primary minerals, secondary minerals and/or organic sources and availability for plant utilization is dependent on redox potential, pH, temperature, equilibrium criteria and chelating agents. Factors that affect sorption are mineralogy, clay content, pH and temperature, and coastal plain sands of southeastern Nigeria met all the conditions for high P sorption (Agbenin *et al*., 2015).

Under the forest land use, accumulation of organic matter and reduced leaching enhances buffering capacity and moderates soil temperature to the extent that could decrease the sorption capacity of the soils and the contrast is true for fallow and farmland (Negassa and Leinweber, 2009). Therefore the prevailing condition in the study area is the decreasing trend in the sorption capacities from forest through fallow to arable land use. This implied that cumulatively between 76.7% and 85.7% of the study area occupied by agricultural land use are continually and cyclically exposed to the processes of sorption and desorption. Point by point change detection indirectly confirmed the sorption desorption cycle from the evidence of continual interchanged between fallow and farmland uses in a four year circle (Ituen, 2015).

The crop production system involving very minimal application of fertilizer indicated that the P sorption will continue unabated as the cycles of fallow - farmland use does not replenish P enough to encourage desorption (Agbenin *et al*., 2015). Combination of low yield and population surge created the need for production of more food through intensification and extensification with resultant increase in the sorption.

4.2 Terrain characteristics and variability of coastal plain sands

The particle size fraction of coastal plain sands is characterized by dominance of sandy textured fragments and these have been found to influence the distribution and variability of their physical and chemical properties. Obi (2015) reported that the particle size fractions are the major determinants of pedogenesis in coastal plain sands. The soil properties that could contribute significantly in the distribution of P are clay content, pH, organic matter and calcium content. This indicated that the characteristics imposed on coastal plain sands landscape through geogenic and pedogenic processes were found not to significantly vary in such properties that influence the forms of P as clay and organic matter but pH and Ca. The minimal variability of the pH reported by Obi and Udoh (2011) which resulted from land use is a confirmation that organic matter contributes to the buffering capacity of coastal plain soils. Similarly, Obi and Udoh (2011) reported that Ca content of coastal plain sands are highly variable and strongly spatially dependent indicating that such variability was extrinsic and associated with management. This confirmed the significant effect of land use and topography on the distribution and variability of exchangeable calcium observed in this study.

4.3 Characteristics of phosphorus on coastal plain sands landscape

The characteristics of P on any landscape depend on the sources, environment and soil. The major source of the P on the terrestrial environment is geological, could be supplemented with fertilizer application in agricultural land uses, but the circumstances of very low and inadequate applications indicated that major source is geological. Coastal plain soils have been classified as ultisols or acrisols indicating that they are highly weathered and dominated by Fe and Al oxides. They are also characteristically acidic in reaction, low in organic matter and fertility status. These characteristics predisposed coastal plain sands to high rate of sorption to the extent that as much as 62% of total P exists in inorganic or reverted form (Yang *et al*., 2012). The dominance of crystalline forms of iron oxide in these well drained soils equally explained the dominance of Fe and occluded Fe and AlP over other forms including available (Yang and Post, 2011). The moisture conditions within the toposequence decreasing from upper to lower slope position, influences solute transport, pedogenesis and characterise chronosequence of soils (Griffiths *et al*. 2009; Obi *et al*., 2014). This same trend was observed in the decrease of FeP down the slope.

Other forms of P found to exist in relatively large quantities included residual, organic and available. Phosphorus released from primary minerals could either enter the organic P reservoir through biota or become sorbed onto the surface of secondary minerals in the soil to become non occluded P which subsequently gradually become occluded. Residual P (RES-P) is the difference between the total P and the sum of reactive (inorganic) fractions which are mainly organic P (Por). Inorganic P (Pinor) is the difference between the TP and Por. The consequence of intensification is large accumulation of RES-P as observed in agricultural compared to the forest land use. This corresponded to the findings that total P content of the cultivated soil was 29% lower than that of the adjacent permanent pasture and the major loss (74% of total P lost) was Por and RES-P (Negassa and Leinweber, 2009). Negassa and Leinweber (2009) revealed that medium and long term cultivation without P application depleted P fractions, whereas most P fractions increased with continuous P application regardless of the amount and source.

4.4 Effect of soil properties on the forms and distribution of phosphorus

The soil properties that influence P dynamics are clay, organic matter and soil reaction. But it was observed in this study that both sand and clay content significantly influenced the distribution of available, bound, iron and occluded P. Silt content also associated with organic P in an inverse relationship. The Por was found to depend on silt content and not any of the other soil properties considered in this study. Phosphorus in soils had been reported to depend almost entirely on soil particles due to their sorption - desorption characteristics (Obi, 2015). The contributions of clay could easily be understood because the major source of P in the soil is apatite. The contributions of the sand content may be explained from the previous assertions from Obi (2015) that the sand content of coastal plain soils significantly influence pedogenesis and acidification of the profiles and these are major contributors to the complex processes of sorption and desorption of P.

The association between Por and silt content may be explain from the context that the Por is yet to be reverted. It has been established that the characteristics of the soil that influence acidification and subsequent sorption is dependent on the sand fractions and previous study have shown that silt content of coastal plain sands had minimal relationship with sesquioxides (Obi, 2015). Silt is unreactive and their presence could inhibit organocomplex formation (Schlichting, *et al*., 2002) hence the inverse relationship between Por and silt content of coastal plain sands. The increasing presence of iron oxides in the coastal plain sands acts parallel to the formation of Por with which silt does not associate as it does not directly influence the extent of weathering and soil genesis. Then it could be averred that sand content of the coastal plain sands indirectly modify the distribution and variability of the forms of P. The association between clay content and forms of P is direct while that of sand is indirect. These implied that increase in the sand content could lead to higher acidification, higher sorption capacity and increase in Pinor. The significant correlation between total P and clay content is a confirmation of the major source of P in coastal plain sands.

The pH of the coastal plain sands associated with Avp and FeP both in an inverse relationship as a result of its effect on sorption – desorption processes and the influence of sesquioxides on the soil reaction. The exchangeable acidity was found to associate with available, total, bound and FeP which is almost similar to the relationship they shared with clay content but for the occluded form. Proper understanding of the relationship between exchangeable acidity and the forms of P will be more appropriate when these relationships were studied on the basis of the individual components of the exchangeable acidity (i.e. hydrogen and aluminium ions). The coastal plain sands are characteristically low in soil organic matter which has been found to be reservoir for available and non-occluded P as they are released from the primary mineral before occlusion progresses. These may explain the relationship between the soil organic matter and the residual P. Other forms such as Fe, occluded, occluded Fe and Al and Ca could be associated with the capacity of the organic matter to form organometacomplexes.

There is an indication that the process of deforestation tend to deplete the TP content of the soils converting them to available. The TP content of the soil decreased as the land is opened for agricultural use (fallow and arable interchange) and the consequence is the increase in AvP at the detriment of TP in the forest land use. Available P does not exist in same form for a long time in the soil but are quickly converted to occluded and consequently reverted to inorganic forms under the favourable conditions of coastal plain sands and the prevailing humid tropical environmental conditions of southeastern Nigeria. The extensive, intensive and low efficiency cropping which utilizes low input system made it difficult for sustained high yield in as much as up to 85% of the land is under agricultural use. This is a confirmation that as more land is converted to agricultural use recalcitrant P will continue to dominate to the detriment of the available.

The importance of iron oxide in pedogenesis could be the possible explanation for existence of strongest correlation found between FeP and particle size fractions which are major determinants of pedogenesis and with most of other soil properties (i.e. 75% of soil properties studied) compared to other forms. This is contrary to the AlP which did not correlate with any of the soil properties in as much as Al_2O_3 is contributory to the acidity of the coastal plain sands. This could be a further indication that distribution and variability of forms of P in coastal plain sands is associated with pedogenesis. Additionally, aluminium manifests itself more in the pedogenesis of poorly or imperfectly drained (alluvial) soils.

5.0 Conclusion

This research studied the effect of changes in land use on the forms of P in coastal plain sands. The trend observed in the spatial coverage of the land uses was fallow > arable > forest. The agricultural land use occupied approximately 86% of the study area. The dominance of crystalline iron oxide explained the dominance of Fe and occluded Fe and AlP over other forms. The gradual but continuous increase in the spatial coverage of agricultural land use results to dominance of recalcitrant P to the detriment of available forms, crop growth and yield.

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