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Soil Physico-Chemical Properties in Three Land Use Systems (Theobroma Cacao, Gmelina Arborea and Secondary Forest) in Umuahia North of Abia State, Nigeria

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ABSTRACT

A study was conducted in three land use systems (Theobroma cacao, Gmelina arborea and secondary forest) in Umuahia North of Abia State of Nigeria to determine the contribution of the land use to the soil physicochemical properties. Three profile pits per land use type were dig and used to study the soil physical and chemical properties. Results of the soil analysis were statistically analyzed using Analysis of variance (ANOVA) test at $p<0.05$ to determine how the values for the soil characteristics differed from one another across the land use types. Least significance difference (LSD) at $p<0.05$ was applied to separate difference between means values of three different land use systems. The texture of the soils was predominantly sandy loam particularly in the surface layers. The soil pH generally declined (i.e. becoming more acidic) from the topsoil to underlying layers. T. cacao had the highest organic level in all the layers investigated compared to other land use followed by G. arborea. Total N was higher in G. arborea followed by T. cacao for all the horizons. The levels of average. P, Ca2+, and Mg2+ were higher in secondary forest followed by that of G. arborea plantation for all the horizons. T. cacao plantation had significantly highest copper (Cu) distribution and the least iron (Fe) distribution. Alumininium (Al) was found in trace amount in the three land use systems. Nutrient distribution seemed to be affected by management practices in each land use types. Some soil properties were significantly different in the three land use types while most soil properties in G. arborea and secondary forest were not statistically different ($p<0.05$) exchangeable Al. In the T. cacao plantation, Cu contents were significantly and positively correlated with organic carbon and Ca2+. Al was also significantly, but negatively correlated with K+ and Na+. In G. arborea, weak correlation relationships were obtained between Fe and N, average P and a negative correlation with Al. In secondary forest, iron correlated negatively with silt and clay soils.

Keywords: Physicochemical, Properties, Land use systems, Abia State.

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1. INTRODUCTION

The soil is a medium on which plant grow. It is made up of four distinct components: organic matter, minerals, water and air, all of which are important in maintaining soil quality. Soil performs a wide range of functions amongst which are serving as home for a number of organisms, filtering out pollutants and recycling organic waste and nutrients [1,2]. Soils vary across locations; a feature that is largely dependent on the parent material [3,4,5]. Soil composition and characteristics also determine species' adaptability and long term establishment in an area or ecosystem [6]

Soils that develop under natural forest are usually well structured, of good moisture- holding capacity, low erodability and with a store of nutrient in the vegetation [7]. Such soils are capable of supporting wide range of vegetation growth and up to an appreciable height which gives an impression of high fertility. This sustainability in vegetation growth is traceable to the forest soil that has the capacity to recycle nutrients within the ecosystem [8,9,10,11,2] .

However, the last decades have witnessed unprecedented pressure on the tropical forests to meet the ever increasing man's need for food and fibre with exerted pressure causing land degradation and loss of biodiversity. Moreover, the high productivity associated with many tropical forest plantation species has contributed to their importance in meeting the world's growing demand for wood and other products. There is high concern that their high growth rate and intensive management system might lead to changes in biogeochemical properties in such site [12,13]. *Theobroma cacao* and *Gmelina arborea* plantations in Umuahia North in Abia State are land use systems that could be subjected to future changes in usage due to dwindling productivity and competing demand for land resources. Should there be any change in land use, there was the need to understudy the changes that might occur in the soils under these land use systems in order to provide information for future land management.

2. MATERIALS AND METHODS

The study was carried out in Okota/Amuzuro/Umuhute in Umuahia North of Abia State in Southeastern Nigeria. It falls within the humid rainforest belt of Nigeria and lies between latitude $5^{o}28'$ N and $5^{o.}40'$N and longitudes $7^{o}24'$E and $7^{o}30'$E.

The area is influenced by the movement of the low pressure system known as the Intertropical Discontinuity (ITD), sometimes referred to as the Intertropical Convergence Zone (ITCZ). This is a zone separating the warm humid maritime tropical (MT) air mass with its associated North easterly winds. The area has two distinct seasons as a result of the ITCZ: a dry season which extends from November to March and a prolonged wet season starting from mid March and ending about October. A brief hull in the middle of the wet season is another feature of the rainfall pattern and is referred to as the 'August break'. The average annual rainfall of the area is 2238mm.

Mean monthly temperatures are high and change only slightly during the year. The maximum temperature ranges from 33 - 35^{0}C and from 28 – 29^{0}C between August and September.

In the Southeastern zone of Nigeria where climate plays a major role in the formation process of soil, the chemical characteristics of the soils tend to reflect the nature of the parent rock. The major parent rock from which the soil is derived is shale [14] and the soil is termed coastal plain sands or acid sands [15,16,17]

2.1. Methodology

Nine representative profile pits were sited in the three land use types; three profile pits in each forest type. The points where the profile pits sited were cleared of vegetation and the pits dug to the desired dimensions using shovels. Each profile pit measured 1 x $1m^2$ in length and breadth, 1.5 m in depth and at least 1m apart from each other. The profile pits were demarcated, described and sampled according to [18]. A regular 20 cm vertical interval was used in their descriptions. The soil samples were taken from all predetermined depths and bagged in properly labeled polythene for physicochemical analysis.

2.2. Mechanical Analysis

Mechanical analysis (sand, silt and clay) were determined using Bouyoucos hydrometer method [19].

2.2.1. Chemical Analysis

- Soil pH was measured in 1:2.5 soil/ water ratio using pH meter with glass electrode [20]
- Electrical conductivity was determined in 1:2.5 soil/water ratio using conductivity bridge [21]
- Organic carbon was measured by the dichromate wet oxidation method of Walkley- Black [22]
- Total N was determined by macrokjedahl digestion and distillation method [23].
- Exchangeable bases were extracted with 1M ammonium acetate; Ca^{2+} and Mg^{2+} were measured by EDTA (ethylene diamine tetra acetic acid) titration method, while K^+ and Na^+ in the extract were determined by flame photometer [24].
- Exchange acidity was extracted with 1M KCl and determined by titration method.
- Effective cation exchange capacity (ECEC) was obtained by summation method of exchangeable bases and exchange acidity [25].
- Available P was extracted using Bray P-1 method of Bray and Kurtz as described by [26]. Phosphorus in the extract was measured by the blue colour method of Murphy and Riley [27].
- Micronutrients (Cu and Fe) were extracted using the DTPA (Diethylene tetrapenta acetic acid) method of Lindsay and Norvell [28]
- Aluminium was determined by the method of McClean, [20] The concentrations of Cu, Fe and Al were measured using atomic absorption spectrophotometer (ASS) (Unicam 939/959 model).

Results of soil analysis are presented using Figures and Tables and were statistically analyzed using Analysis of variance (ANOVA) tested at $p<0.05$ to determine how the values for the soil physic-chemical characteristics differed from one another across the three land use types. Correlation studies relating micronutrients and Al with some soil properties was also done. Least significance difference (LSD) was used to separate the means.

3. RESULTS AND DISCUSSION

3.1. Physicochemical Properties of the Soils Studied

1. Particle size distribution: Texturally, the soils were predominantly sandy loam in nature in the surface layers. High silt and clay contents were observed in the deeper layers of these soils indicating high water holding capacity. This implies that the soil are sticky when wet and are hard and cracking on drying. This also indicate clay migration by lessivage to produce the process of eluviations [29] and this supports Igwe *et al*., [30] whose study on soil physical properties of acid soil Southeastern Nigeria showed the same trend. The acid soils of eastern Nigeria are deep, porous, sandy loams or loamy sands with the clay content increasing gradually with depth [31,32].

2. Soil pH, exchange acidity and electrical conductivity: As observed from Table 1, the soil reaction ranged from strongly to moderately acidic. The soils of Southeastern Nigeria are known to be generally strongly acidic with a pH range of 3.5-6.1 and most below 5.2 on the surface [15,33,34]. The soil of *Gmelina arborea* plantation was moderately acidic at the surface but strongly acidic at the deeper horizons while soils under *Theobroma cacao* were moderately acidic throughout the profile as obtained in the secondary forest (Table 1). This may be due to the ability *Gmelina arborea* has to moderate acidity by introducing significantly high concentration of Ca^{2+} and other bases from the leaves into the soil through litter fall. Research has shown the huge moisture, mineral/nutritive composition of Gmelina leaves as can be seen in its choice as livestock feed [35]. This attribute can be utilized as a strategy to reduce acidity which soils of Southeastern Nigeria are known for. *Gmelina arborea* can grow on soils with pH of 4.6- 6.7 [36,37].

Exchange acidity was moderate in the three land use systems but slightly higher in the secondary forest than in *Gmelina arborea* and *Theobroma cacao* plantations (Table 1). Electrical conductivity in all the land use systems was low and decreased down the profile (Table 1). The EC_{25} values in the soils were less than $1dSm^{-1}$, indicating that the soils are non saline in nature. Therefore the soil will not pose any salinity problems to crops should it be converted to a farmland since according to [38], salinity problems are only encountered when EC_{25} is above $2dSm^{-1}$.

3. Organic carbon, total nitrogen and available phosphorus: Soil organic carbon contents were observed to be relatively high in the surface layers of the soils of the three land use systems. However, organic carbon in *Theobroma cacao* plantation (30.7g kg^{1}) at the surface layers was higher than that of *Gmelina arborea* plantation (28.3g kg^{-1}) and secondary forest (26.80g kg^{-1}) (Table 1). This can be attributed to the decomposition of litter fall, slashed undergrowth and decayed cacao pods especially at the soil surface. It is at the soil surface that most biological activity (other than termite) is concentrated [7, 39]. Moreover, long years of accumulation of litter on the plantation floor would have contributed to increase in organic matter. The organic carbon content of these soils have been described as being generally low with values ranging from 0.42% to 1.63% (4.2 to 16.3g kg^{-1}) but values as high as 2.3% to 4.63% (23.0 to 46.3g kg^{-1}) have been reported for surface soils with content decreasing with depth [32]

Total nitrogen was observed to be high in the three study sites but Gmelina plantation was highest particularly at the surface layers (Table 1). The levels of N were within plant sufficiency range in soils. The high level of total N in the soil may have resulted from microbial mineralization of organic residues, especially litter falls and partially because *Gmelina arborea* to some extent can fix N in the soil. This can be seen in its choice as one of the species planted in home gardens to increase soil fertility [40]. Also, forest and plantation systems if left undisturbed tend to recharge their nutrients from the litter.

Table 1 show that available phosphorus in these soils was very high. The high amount of P in these soils may have been due to the relatively high organic matter contents particularly in the surface layers. Phosphorus fixation and unavailability is a major constraint in acid soils containing large amount of free iron and Al oxides

[38]. Although Fe content was high in these soils, Al concentration was found in traces amount, hence less phosphate was immobilized by aluminium and this results in accumulation of P in large quantity in the soil.

4. Exchangeable bases, cation exchange capacity and percent base saturation: These land use types were moderately supplied with exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+}). Calcium was the most abundant in the adsorption complex. The abundance of the exchangeable basic cation was in the decreasing order of Ca^{2+}, Mg^{2+}, K^{+} and N^{+} while Ca^{2+}, K^{2+}, and Na^{+} decreased, Mg^{2+} increased with depth. The secondary forest had the highest amount of Ca^{2+} and Mg^{2+} at 0-20cm (7.42 cmol $kg^{-1}$and 2.74 cmol kg^{-1}) and 20-40cm (5.64 cmol kg^{-1} and 1.44 cmol kg^{-1} respectively). In the tropics, recycling is efficient especially in the biomass and organic matter which is the store of nutrients and it is the surface layer with its fine roots that is important in concentrating energy flow from decomposing organic matter back into the plants [41]. Secondary forest had the highest family of plant species in the study area and this probably gave rise to large amount of Ca^{2+} and Mg^{2+} on decomposition. Also the clay content in the secondary forest was higher than that of *Gmelina arborea* and *Theobroma cacao* plantations and it has been reported that a positive correlation exist between clay content and level of nutrient bases [42]. Furthermore, the family *Verbanaceae* which Gmelina belongs to, tend to immobilize calcium in their biomass.

Effective Cation Exchange Capacity (ECEC) was relatively high in the surface layers of these soils than in the subsurface (Table 1). It was highest in the secondary forest than in *Gmelina arborea* and *Theobroma cacao* plantations. This appeared not surprising since there was higher content of Ca^{2+}, Mg^{2+}, and Na^{+} in the soil of secondary forest averagely across the horizons than in any of the other two study sites. Also, the higher clay content would have contributed to this superiority. Interestingly also, the secondary forest had the highest diversity of plant species which had different quality as well as decay rates of litter. Unlike the dominantly monoculture type of vegetation in the *Gmelina arborea* and *Theobroma cacao* plantations, the diversity of species in the secondary forest would have contributed to higher value of ECEC. Therefore the frequent supply of basic cations by microbial decomposition of organic residues of this litter may have caused the high ECEC.

The base saturation in these soils was high and reflected the dominance of the basic cations on the adsorption complex. The values were higher than the critical level of 50% [43] This shows that the soils are fertile because of the presence of plants and the ability of these plants to recycle nutrients in the soil.

The *Theobroma cacao* plantation recorded the highest concentration of Cu (Fig. 2) and lowest concentration of Fe while the secondary forest had the highest concentration of Fe (Fig. 3) and lowest concentration of Cu. The high amount of Cu in the *Theobroma cacao* plantation could be attributed to the application of pesticides (Gammalin 20) to control *Phytophthora palmivora* which causes blackpod of cocoa. This supports [44] whose study in a *Theobroma cacao* plantation in Bende district in Southeastern Nigeria showed the same trend. Exchangeable Al in these soils was found in trace amount but highest value was obtained in *Theobroma cacao* plantation (Fig. 4). The low level of Al indicates that hydrogen ions rather than Al were responsible for the acidity of these soils [21]

The correlation studies relating micronutrients and Al with some soil properties in the three soils studied indicated that in *Theobroma cacao* plantation soils, Cu positively and significantly correlated with EC (r = 0.672**), organic carbon (r = 0.685**), ECEC (r = 0.703**), Ca (r = 0.701**) implying that these parameters regulate availability of Cu in this soil (Table 2). Fe positively significantly and weakly related with Mg (r = 0.6178), clay (r = 0.609*) implying that Mg and clay may regulate the availability of Fe in this soil. Al also significantly but negatively correlated with K (r = - 0.685**) and Na (r= - 0.623**) indicating that when exchange acidity increases K and Na decrease in the soil.

In *Gmelina arborea* plantation, weak correlation relationships were obtained between Fe and N (r = 0.544*), available P (r = 0.614*) and a negative correlation with Al (r = - 0.614*). Cu only correlated negatively with clay (r = - 0.527*). In secondary forest, Fe correlated with silt (r = - 0.582*) and clay (r = - 0.540*), implying that silicate minerals in the particle sizes could regulate the availability of Fe in the soil.

4. CONCLUSIONS

Generally, the soil in the three land use types are fertile as reflected in the high base saturation level. The study also noted the ability of *Gmelina arborea* to moderate acidity for which the soil of Southeastern Nigeria is known. Nutrient concentration was higher in the soil surface (0-20cm) and most nutrient levels decreased with soil depth. Longer years of accumulation of litter, decaying cleared undergrowth and cacao pods contributed to higher organic carbon in the *Theobroma cacao* plantation. Although organic carbon was higher in *Theobroma cacao*, higher total nitrogen in *Gmelina arborea* plantation soil was due to the ability of Gmelina to some extent fix nitrogen. Higher plant diversity, and clay content may have contributed to higher phosphorus, calcium and magnesium in the secondary forest soil. Furthermore, application of agrochemicals resulted in higher concentration of copper in *Theobroma cacao* plantation.

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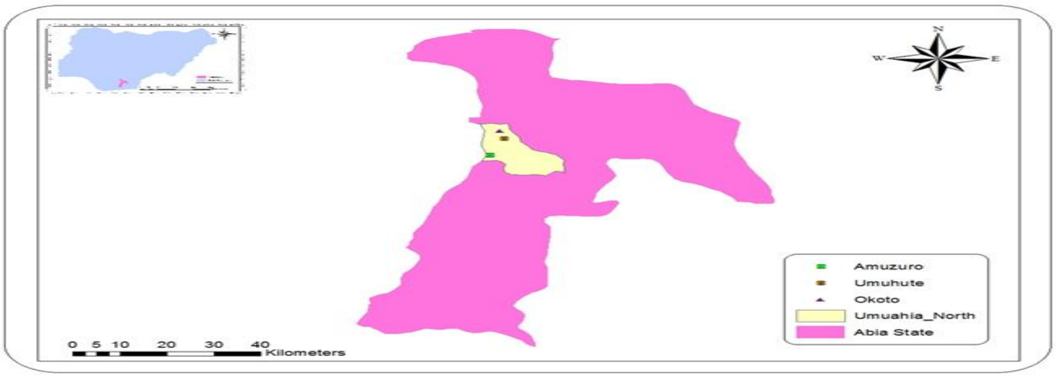

Fig-1. Map of Abia State, Nigeria showing the study area.

Table-1. Means and SD of soils' Physico-chemical properties under different land use types.

	Land use types		
Soil properties	**Cocoa plantation**	**Gmelina plantation**	**Secondary forest**
Sand (g/kg)	773.57 ± 79.781a	654.71 ± 83.167b	629.08 ± 78.66b
Silt(g/kg)	79.43 ± 161.90b	161.90 ± 35.525a	151.20 ± 60.91a
Clay(g/kg)	149.40 ± 43.20c	185.67 ± 48.623b	219.05 ± 31.65a
pH	5.3 ± 0.618b	4.96 ± 0.5969c	5.57 ± 0.853a
EC (dS/m)	0.12 ± 0.099b	0.12 ± 0.091b	0.15 ± 0.085a
OC (g/kg)	13.75 ± 10.42a	8.93 ± 10.624c	10.66 ± 9091b
TN (g/kg)	1.08 ± 0.708b	1.14 ± 0.682a	0.97 ± 0.658c
Av.P (mg/kg)	209.97 ± 98.78a	201.28 ± 72.119b	210.63 ± 91.92a
EA	0.97 ± 0.282b	0.85 ± 0.322c	1.27 ± 0.594a
Ca^{2+} (cmol/kg)	3.05 ± 0.928b	3.25 ± 0.776b	4.71 ± 1.851a
Mg^{2+} (cmol/kg)	0.97 ± 0.308 b	1.16 ± 0.646b	1.76 ± 1.076a
K^{+} (cmol/kg)	0.33 ± 0.1 19b	0.36 ± 0.110a	0.32 ± 0.112c
Na^{+} (cmol/kg)	0.11 ± 0.043b	0.19 ± 0.076a	0.19 ± 0.078a
ECEC (cmol/kg)	5.52 ± 1.157b	5.77 ± 1.409b	8.26 ± 2.994a
BS (%)	81.47 ± 6.542b	84.76 ± 6.332a	84.01 ± 6.902a
Cu (mg/kg)	10.36 ± 5.764a	8.06 ± 3.271b	1.348 ± 2.49c
Fe (mg/kg)	1040.27 ± 94.240b	1126.60 ± 10.218a	1133.67 ± 13.34a
Al (mg/kg)	0.02 ± 0.018a	0.01 ± 0.005a	0.01 ± 0.005a

Figures followed with the same letter within the row are not significantly different ($P \leq 0.05$).

SD = Standard deviation; EC = Electrical conductivity, OC = organic carbon, TN = total nitrogen, Av P available phosphorus, EA = Exchangeable acidity, ECEC = effective cation exchange capacity, and BS = Percent Base saturation.

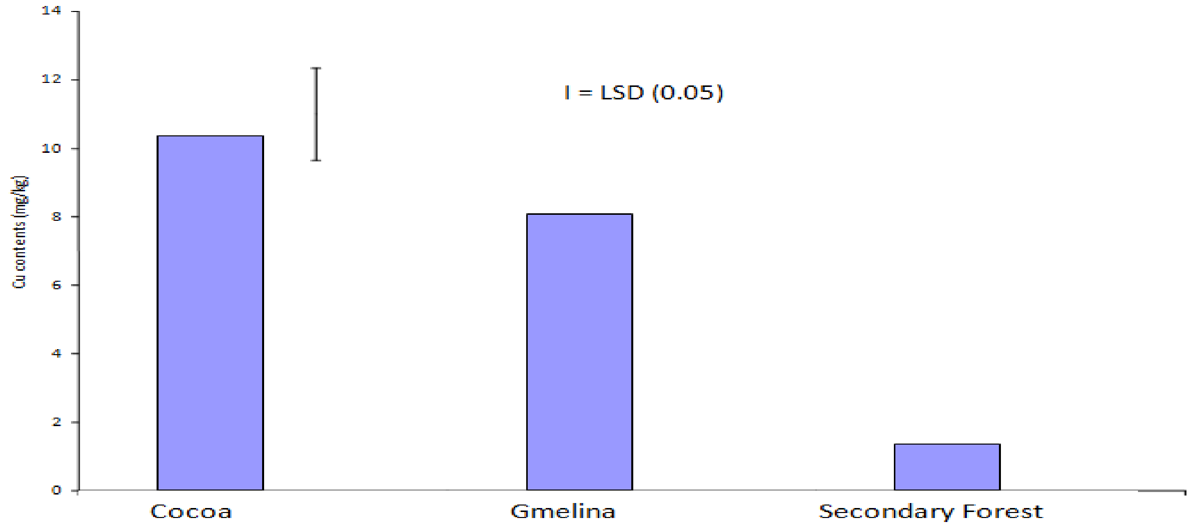

Fig-2. Distribution of Cu content in the three land use systems.

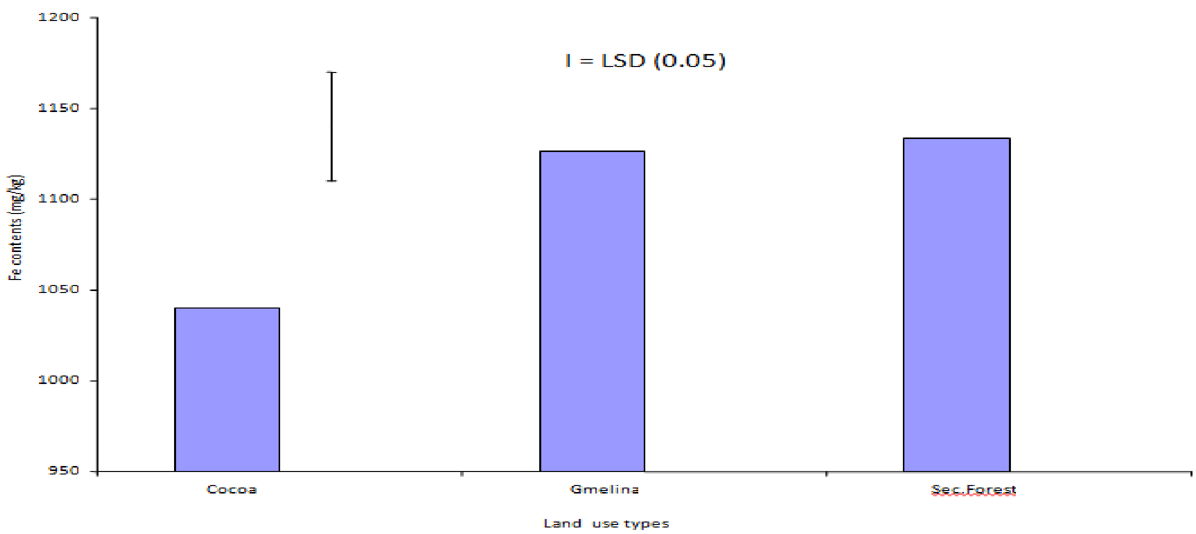

Fig-3. Distribution of Fe content in different land use types.

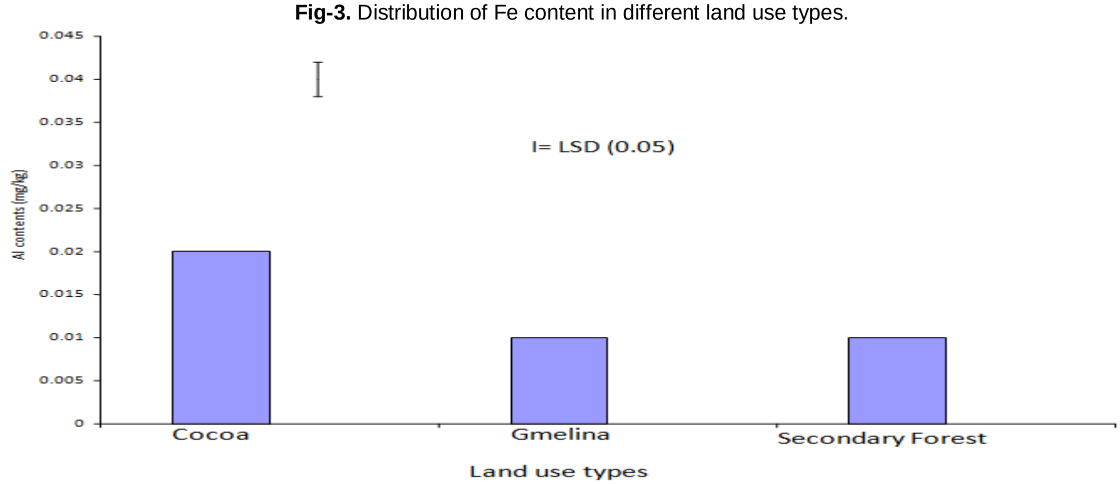

Fig-4. Distribution of Al content in different land use types.

Table-2. Correlation of soil properties with micro nutrients.

Soil properties	Cu	Fe	Al
Theobroma cacao			
EC	0.672**		
Organic Carbon	0.685**		
Total nitrogen	0.544*		
Av. P	0.622*		
ECEC	0.703**		
Ca	0.701**		
Mg		0.617*	
K			-0.685**
Na			-0.623*
Sand		-0.711**	
Clay		0.609*	
Gmelina arborea			
Total nitrogen		0.544*	
Av. P		0.614*	
Clay	-0.527*		
Al		-0.548*	
SEC.FOREST			
Sand		0.593*	
Silt		-0.582*	
Clay		-0.540*	

* = Significant ($p \leq 0.05$) and ** = Significant ($p \leq 0.01$). EC = Electrical conductivity, Av. P = Available phosphorus, ECEC = Effective cation exchange capacity, Ca = Calcium, Mg = Magnesium, K = Potassium, Na = Sodium, Cu= Copper, Fe = Iron, and Al = Aluminium