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VEGETATION EFFECTS ON PEDOGENETIC FORMS OF IRON AND ALUMINIUM AND MINERALOGICAL PROPERTIES OF BASALTIC SOILS IN THE SOUTHERN GUINEA SAVANNA OF NIGERIA

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ABSTRACT

This study investigates the effects of vegetation particularly fast growing exotic species like Tectona grandis on the Newer Basalt of the Jos Plateau. In particular it determines the effects exotic tree species have on the pedogenetic forms of Fe and Al and mineralogical properties of the basaltic soils age. Soil samples were determined at the depth of 0 – 30cm and 30 – 60cm under plantation of four different ages and subjected to standard laboratory analysis. The citrate bicarbonate dithionite (CBD) extractable Fe and Al slightly decreased with aging plantation, which was ascribed to the inhibitory effects of organic matter on the crystallization of Fe and Al. Similarly the active Fe value was less than unity, which implied increased crystalline forms of Fe and Al oxides are as a result of weathering intensity. Mineralogical results indicated that the soils under the fallow and 11 year old plantation had the dominance of magnetites, while those under 21 year old plantation had mixed mineralogy, consisting of magnetites, biotites and montmorillonites. The older plantations (31 and 36 year old) were dominated by kaolinites and traces of haematites and goethites. The trend suggested an increased level of pedogenesis with aging plantations. Increase in crystalline forms of Fe and Al, kaolinites, traces of haematite and goethite concludes that Tectona grandis deteriorates soil properties over time.

Keywords: Vegetation, pedogenic Fe, Al, mineralogy, basaltic soil properties

INTRODUCTION

Vegetation plays an important role in soil formation and development as it accelerates local weathering (Phillips *et al.,* 2008), thus the effect of trees on the soil chemical properties is a function of series of factors such as nutrient uptake, leachates from tree bark, foliage, roots and organic acids from decomposing litters. Dead plant, on decomposition release water – soluble compounds which play an important role in cycling of metals, decomposition and transformation of clay minerals (Huang and Keller 1970, Schnitzer and Kodama 1976). Humic and fulvic acids produced as a result of litter decomposition are classified as naturally occurring poly electrolytes capable of attacking and degrading soil minerals. Tan (1980) noted that at pH 7.0 fulvic acids are capable of dissolving small amounts of Al from K – feldspars, biotites and muscovite. Similarly Schnitzer and Kodama (1976) reported a massive dissolution of Si, Al, Mg, Fe and K from mica mineral by fulvic acid. Direct relationship between protocatechuic acid released from plant litters and Fe and Al dissolved from the soil was reported by Andrew and John (1988). They stated that polyphenolic content was highly correlated dissolved Fe (r = 0.80) and Al (r = 0.94). Balagopalan and Rugmini (1989) studied the effects of *Tectona grandis* plantation on soil characteristics and reported high values of Fe_2O_3 and Al_2O_3 which were attributed to the effects of hydrolytic breakdown of soil minerals and their interaction with humic constituents. High Fe_d and Al_d with low Fe_o, Fe_2O_3 and Al_2O_3 were reported under tea plantation by Alekseeva *et al.*(2010). After 40 to 50 years establishment of *Laurophyllous* species. Zanellis *et al.* (2007) observed partial changes in Fe and Al content, while Fe_o/Fe_d ratio was high which was ascribed to intensive weathering. The amount and nature of amorphous and crystalline inorganic oxides of Fe and Al greatly influence soil physical and chemical properties, their distribution in soils could be used to determine soil forming processes, direction, extent of pedogenic processes and soil age (Blume and Schwertmann, 1969; Mckeaque *et al.* 1971; Alexander 1974).

The direct influence of plants on soil properties is initiated through nutrient uptake to meet their nutritional needs. This involves the ability of plant roots to exchange H_3O ions from the roots with metal ions from the soil minerals. Courchesne and Gobran (1997) corroborated the pedogenic significance of rhizosphere and the role of roots as dynamic weathering agents. Spyrikadis *et al.* (1967) reported that hydrolysis of alumino – silica minerals is as a result of the replacement of metal cations by H_3O ions with the resultant disarrangement of the crystal lattice structure and the release of Al, Fe and other components. Spyridakis *et al.* (1967) further stated that the removal of K, Mg and Fe in biotites by their substitution with H_3O ions, transformed biotites into kaolinite with a vermiculite stage. Fanning *et al.* (1989) also stated that the removal of K from interlayer biotite, transformed it into secondary 2:1 phyllosilicate which is more often vermiculite.

According to Hatton *et al.* (1987), different tree species produced different deviation linked to their ability to cycle cations and organic compunds which attack minerals.

Sohet *et al.* (1988) reported a significant decrease in the amounts of weatherable minerals (F-feldspars, albite, muscovite and 2:1 clay minerals), particularly chlorite under Norway spruce (*Picae abies*) than beech (*Fagus sylvatica*). Organic acids from decomposing litters were reported by Egli *et al.* (2001) to cause decrease in mica content and accelerated its transformation into smectite–like minerals. Similarly, Alekseeva *et al.* (2010) observed the dissolution of hydro–Al interlayer within the structure of vermiculite under tea plantation, thus transforming vermiculite to chloritized–vermiculite to kaolites and oxides.

Considering the role of vegetation in soil formation and development, it therefore becomes necessary to study the influence of exotic tree species, especially teak (*Tectona grandis*), on the pedogenetic forms of Fe and Al and mineralogical properties of basaltic soils in the southern guinea savanna of Nigeria.

MATERIALS AND METHODS

Setting of the study Area

Nimbia Forest Reserve is located in the southern guinea savanna of Nigeria and covers an area of about 2,282.4 hectares. It lies between longitudes 8^0 30″and 8^0 31″ E and latitudes 9^0 29″ and 9^0 30″ N (Figure 1), with an elevation of about 600 m about sea level. Nimbia Forest Reserve is located within the Jemma'a platform underlain by igneous and metamorphic rocks. The soils belong to the Nimbia series developed from weathered olivine basalts and classified as Eutropic brown by D'Hoore (1964), while Samndi (2006) classified the soil as Dystrustept and Haplustult respectively. The position of Nimbia with respect to its altitude (600m) induces orographic rain with mean annual rainfall of about 1260.11mm and mean annual temperature of about 21.7^0C.

Field Studies

The unpublished semi-detailed soil survey report by Howard (1963) and planting record map were used in preliminary site selection for the study. Areas described as Nimbia clay were investigated under the following planting years, namely 1990 (11years), 1980 (21 years), 1970 (31 years) and 1965 (36 years). A total of 12 pedons were located within the various planting periods with three pedons exposed in each planting period to a depth of at least 160 cm or to an impenetrable layer, whichever came first. Soil profile site characteristics were described according to USDA soil survey manual (Soil Survey Staff, 1981). In addition, two perpendicular 5-meter transects were laid in North – south and East - West directions in a fallow. Samples were collected from genetic horizons and transects at 0- 30 and 30-60cm depths for laboratory analysis.

Laboratory Analysis

Soil samples from the genetic horizons, 0-30 and 30-60cm depths were air-dried and passed through a 2mm sieve. Particle size distribution was determined by the hydrometer method (Gee and Bauder, 1986). Soil pH was determined in water using a soil to water ratio of 1:2.5 (IITA, 1979). The organic carbon content was determined by wet oxidation method of Walkley – Black as described by Nelson and Sommer (1982). The amorphous forms of Fe and Al were extracted by the ammonium oxalate techniques (Schwertmann, 1964). Free iron and aluminium oxides were determined according to the methods of Mehra and Jackson (1960), using citrate – bicarbonate-dithionite. The Fe in the extracts was determined with atomic absorption spectrophotometry, while Al was determined colorimetrically after the destruction of organic matter as described by Jackson (1958).

The mineralogical analysis was carried out by Differential Thermal Analysis (DTA). The samples were finely ground to < 0.75ủm and was transferred into the DTA machine (Eberbach Weston model 301-57). The sample was covered in a furnace and heated. The temperature of the samples and corresponding galvanometer readings were taken at an interval of 20^0C up to about 1000^0C. The galvanometer readings were plotted against the temperatures. The relative quantity of each clay mineral present was expressed as a function of peak intensity and area. The peaks determined were compared with reference curves and the respective clay minerals identified. Results were subjected to analysis of variance using GENSTAT V package for statistical analysis. Regression and correlation techniques were used to determine relationships between some soil variables.

RESULTS AND DISCUSSION

Oxalate extractable iron and aluminium oxides

The oxalate extractable Fe (Fe_{ox}) mean values slightly increased with plantation age, though not statistically different from those of the fallow, 31 and 36 year old plantations (Table 1). The mean values were significantly lower (P = 0.01) in the subsurface horizons and ranged between 0.19 to 0.64 percent. The increase in Fe_{ox} with plantation age, is indicated by a significant regression coefficient value (r^2 = 0.7011**, not indicated in table). This suggests that higher organic matter under the older plantations might have inhibited the crystallization of Fe (Blume and Schwertmann 1969; Nayak *et al*. 1999). The oxalate extractable aluminium (Al_{ox}) for both surface and subsurface horizons under the fallow and the various plantation ages ranged between 0.29 and 0.43 and 0.35 to 0.43 percent respectively. The mean value was slightly lower under fallow. Oxalate Fe and Al values generally decreased with increased profile depth (Table 2), particularly under the older plantations where profiles are deeper, indicating that very small quantises of amorphous Fe and Al were translocated. This diminishing contents of Fe_{ox} and Al_{ox} with depth, may largely be a function of acid complexing Fe and Al, thus reducing their mobility with depth as observed by Andriesse (1975), that oxalate extract both amorphous hydrous oxides and fulvic complexed Fe. Similar observations were also made by Juo *et al*, (1974) and Kparmwang (1993).

Citrate –bicarbonate-dithionite (CBD) extractable iron and aluminium

The CBD extractable iron (Fe_d) values are generally higher than oxalate extractable Fe oxides for both surface and subsurface horizons indicating the dominance of crystalline Fe over amorphous forms, an observation also made by Kparmwang (1993), Maniyunda (1999) and Raji *et al.* (2000). The Fe_d mean values for both horizons ranged from 3.46 to 7.12 percent. The mean values for the underlying horizons were significantly higher (P = 0.05), than the overlying horizons and slightly decreased with plantation age, a fact that might be ascribed to the inhibitory property of organic matter on the crystallization of iron. The profile distribution of Fe_d showed an increase with depth (Table 2), following the trend of clay distribution with argillic horizons recording higher values, suggesting co-migration of Fe_d with clay as indicated by a highly significant positive correlation with clay (Table 3). This is an indication of the dominance of crystalline form of Fe resulting from greater pedogenic processes, or *insitu* weathering (Asanwa, 1973; Pattil and Dosog 1997). The mean values of Al_d ranged between 1.60 and 3.82 percent, for both surface and subsurface horizons. These values increased irregularly with depth, similar to observation made by Alekseeva *et al.* (2010) though values were not significantly different from each other. The mean values of Al_{ox} and Al_d were mostly higher than those reported by Kparmwang (1993) on both the Newer and Older Basalts of Nigeria this highlights the fact the intensity of weathering is higher under plantation conditions. This was also corroborated with Zanellis *et al.* (2007) that the intensity of weathering is higher under plantation.

Table 1: Extractable Iron, Aluminium and Active iron in surface and subsurface horizon in Nimbia Forest Reserve.

Ages (years)	Fe_{ox}	Fe_d	Al_{ox}	Al_d	Active - Fe
	------------------------------------	---------%	----------------------------------		
Surface horizons (0 – 30cm)					
Fallow	0.62a	3.85cb	0.29c	1.68ba	0.16a
11	0.39b	5.97a	0.43a	3.82a	0.07b
21	0.48ba	5.68a	0.43a	2.64ba	0.09ba
31	0.58a	4.23b	0.33bc	3.19a	0.14a
36	0.66a	3.46c	0.41ba	3.05a	0.19a
LSD	0.19	1.63	0.10	2.20	0.11
Subsurface horizons (30 – 60cm)					
Fallow	0.19b	4.43b	0.35ba	1.60	0.04
11	0.31ba	6.54a	0.43a	3.60	0.05
21	0.40ba	7.12a	0.35ba	1.95	0.06
31	0.64ba	4.43b	0.35ba	1.95	0.15
36	0.56ba	4.63b	0.38ba	1.68	0.12
LSD	0.46	1.49	0.11	2.9	0.30

Means within a column followed by the same letters are not significantly different at p = 0.05 by Duncans multiple range test.

Active iron and clay dithionite iron ratios

According to Blume and Schwertmann (1969) and Juo *et al.* (1974), the ratio of oxalate to dithionite extractable iron (Fe_{ox}/Fe_d) is referred to as active Fe ratio. The ratio is used to determine the degree of aging or crystalline form of free iron oxides which is a major pedogenic process. The mean values of active Fe in the surface horizons were lower (0.01 to 0.02) than those reported by Otilio *el at.* (2002) on basaltic andesite. This suggests the dominance of crystalline Fe oxides, views expressed by Blume and Schwertmann (1969) and Aniku and Singer (1990). The transformation of amorphous Fe to crystalline form indicates an advanced stage of weathering. For the underlying horizons, active Fe values were significantly lower (P = 0.01) than those of the overlying horizons, though the range was similar (0.01 to 0.02). This suggests a higher proportion of Fe oxides were more in the crystalline form (Juo *et al.* 1974; Lekwa and Whiteside 1986). Generally active Fe ratio decreased irregularly with profile depth (Table 2) irrespective of plantation age, implying higher degree of weathering the subsoil horizons. The active Fe ratios in both surface and subsurface horizons slightly decreased with plantation age, thus suggesting the transformation of iron into less active forms under the older plantations (Nayak *et al*, 1999).

Mineralogical properties

According to Mackenzie (1957) and Plante *et al.*(2009), Differential Thermal Analysis (DTA) permits a number of valid mineralogical assessments to be made. The differential thermograms of the soils studies are presented in Figures 2 to 6, the minerals identified in both surface and subsurface horizons are shown in Table 4. Thermograms of the soils under the fallow, showed moderate and strong exothermic and endothermic peaks at 580 and 700^{0}C, followed by other weaker peaks at 350 and 380^{0}C. These peaks indicated the presences of biotite, amphibole, kaolinite and magnetite. Weaker exothermic peaks between 500 and 900^{0}C indicated the presences of amphibole, biotite, montmorillonite and magnetite in the subsurface horizons under the fallow.

The dominance of these weatherable minerals in both horizons implies the soils under the fallow are moderately weathered. Surface horizons under 11 year old plantation, showed strong exothermic peaks at 500, 700 and 800^{0}C, with weak peaks at 600 and 800^{0}C. These peaks identified the dominance of biotite and magnetite with amphibole being the least mineral identified. These are indices of early stages of basaltic weathering. It would be remembered that nutrient uptake have been reported by Nettleton *et al.* (1973) to be an important mechanism in the transformation of biotite. Peaks were generally weak in the subsurface horizons, with a strong endothermic peak at 800^{0}C indicating the dominance of magnetite and montmorillonite over chlorite and kaolinite. The presences of these secondary minerals implied an increased weathering compared with the fallow. This observation is also corroborated by Ojanuga (1973), who reported that the first stage of biotite weathering is the dissolution of octahedral Fe and Mg, followed by the loss of K, thus giving rise to montmorillonite. Magnetite (580^{0}C), montmorillonite (850^{0}C exo) and kaolinite (700 and 800^{0}C endo) dominated the mineralogy of the surface horizons under 21 year old plantation, traces of amphiboles and biotites were also observed in both horizons. The dominance of montmorillonite, kaolinite and magnetite are indications of increased level of weathering with aging plantation.

Table 2: Extractable iron and aluminum and their ratios of pedons under Teak plantation in Nimbia Forest Reserve.

Horizon	Depth (cm)	Fe_{ox}	Fe_d	Al_p	Al_{ox}	Al_d	Ratio Fe_{ox} / Fe_d
				%			
Pedon NF 90 P1				***11 year old plantation***			
Ah	0 – 14	0.09	5.00	0.47	0.04	0.34	0.01
AB	14 – 24	0.05	6.16	0.23	0.05	0.33	0.01
BC	24 – 70	0.09	6.16	0.02	0.05	0.42	0.01
C	70 – 120	0.05	5.58	0.05	0.04	0.17	0.01
Pedon NF 80 P1				***21 year old plantation***			
Ah	0 – 10	0.08	6.15	0.28	0.04	0.34	0.02
AB	10 – 20	0.05	6.74	0.28	0.04	0.58	0.01
BC	20 – 62	0.04	7.32	0.23	0.02	0.25	0.01
C	62 – 140	0.04	6.16	0.02	0.04	0.09	0.01
Pedon NF 70 P1				***31 year old plantation***			
Ah	0 – 23	0.05	5.00	0.45	0.03	0.17	tr
BA	23 – 44	0.06	3.85	0.36	0.04	0.48	0.02
Bt1	44 – 51	0.13	3.85	0.18	0.04	0.25	0.04
Bt2	51 – 81	tr	6.16	0.15	0.04	0.33	tr
Bt3	81 –165	0.02	6.16	0.10	0.03	Tr	tr
Pedon NF 65 P1				***36 year old plantation***			
Ah	0 – 20	0.07	2.69	0.08	0.04	0.25	0.03
BA	20 – 40	0.07	4.43	0.31	0.04	0.01	0.02
Bt1	40 – 70	0.07	5.00	0.07	0.04	Tr	0.01
Bt2	10 – 120	0.05	2.69	0.18	0.04	0.25	0.19
Bt3	120 – 150	0.06	2.69	0.22	0.03	0.17	0.02

Table 3: Correlation coefficient matrix of pedogenic oxides of iron and aluminium and related soil properties of profiles under Teak plantation in Nimbia Forest Reserve

	Sand	Clay	pH	Org. C	Fe_{ox}	Fe_d	Al_{ox}	Al_d
Sand	1.000							
Clay	-0.530**	1.000						
pH	0.526**	0.222	1.000					
Org. C	0.575**	-0.404**	0.394**	1.000				
Fe_{ox}	0.114	-0.143	0.023	0.133	1.000			
Fe_d	-0.257	-0.445**	0.157	0.132	-0.124	1.000		
Al_{ox}	0.298*	-0.035	0.336*	0.266*	0.010	0.017	1.000	
Al_d	0.047	-0.093	0.146	0.318*	0.059	0.083	0.202	1.000

Significant level = *P<0.05, **P<0.01

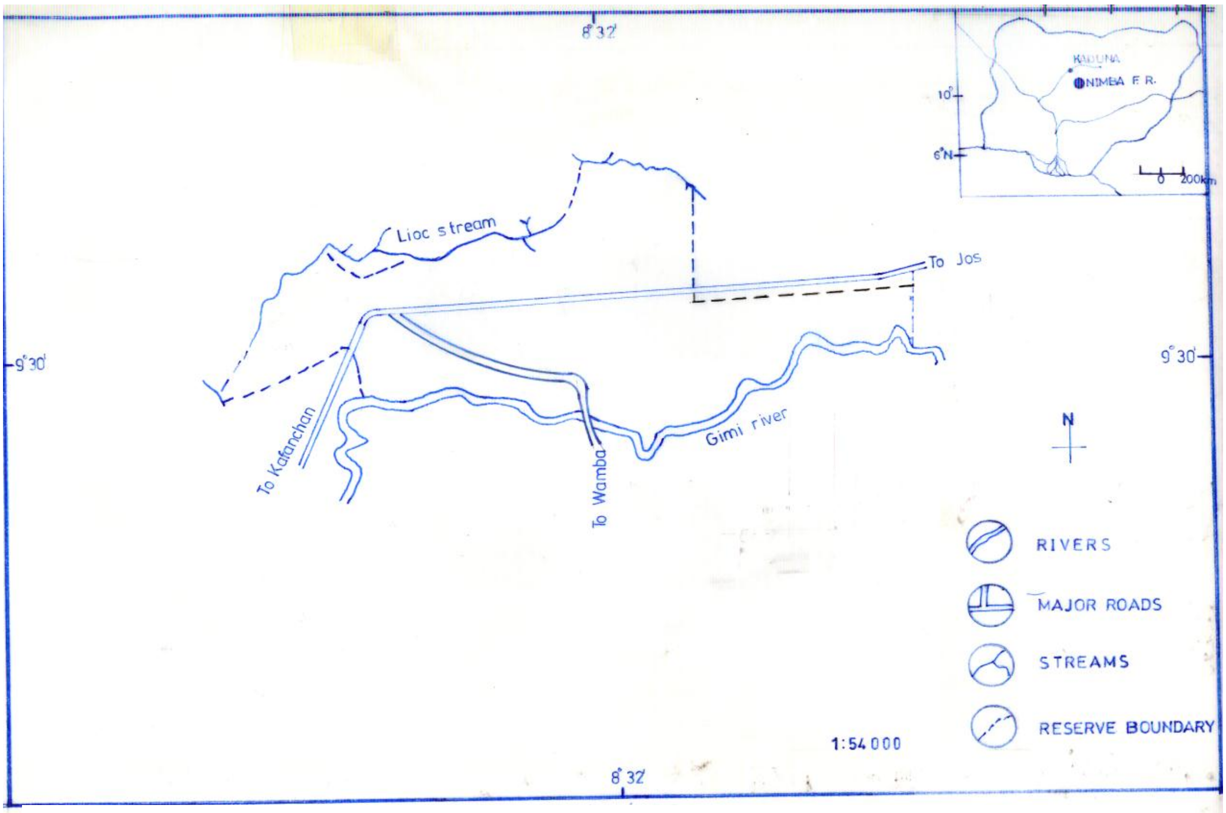

Figure 1: Map of Nimbia Forest Reserve Showing Drainage and Boundary (Insert Map

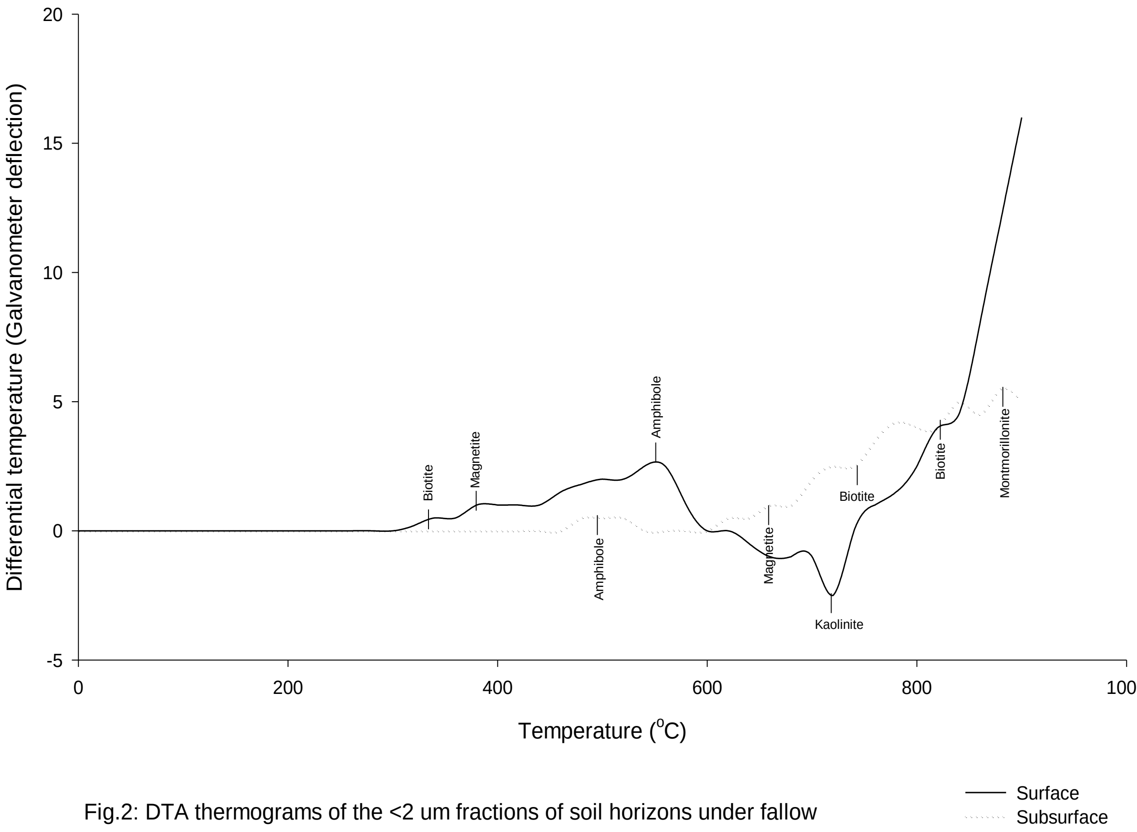

Fig.2: DTA thermograms of the <2 um fractions of soil horizons under fallow

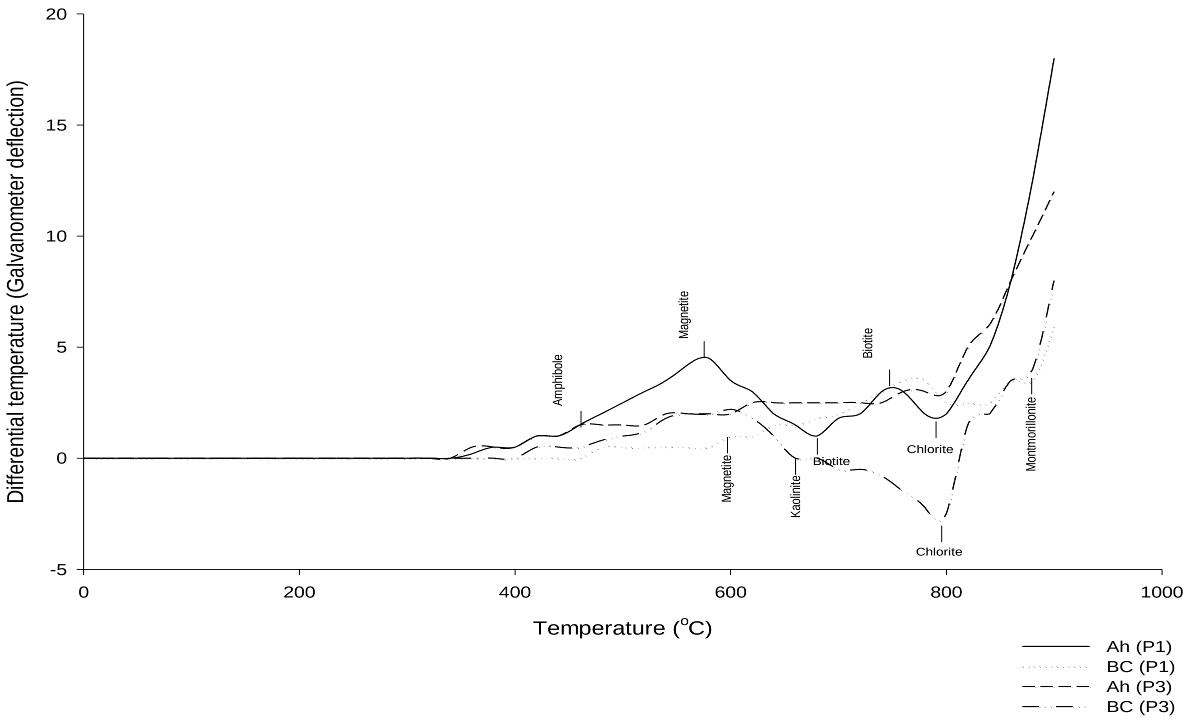

Fig. 3: DTA thermograms of the <2um fractions of soil horizons under 11 year old plantation

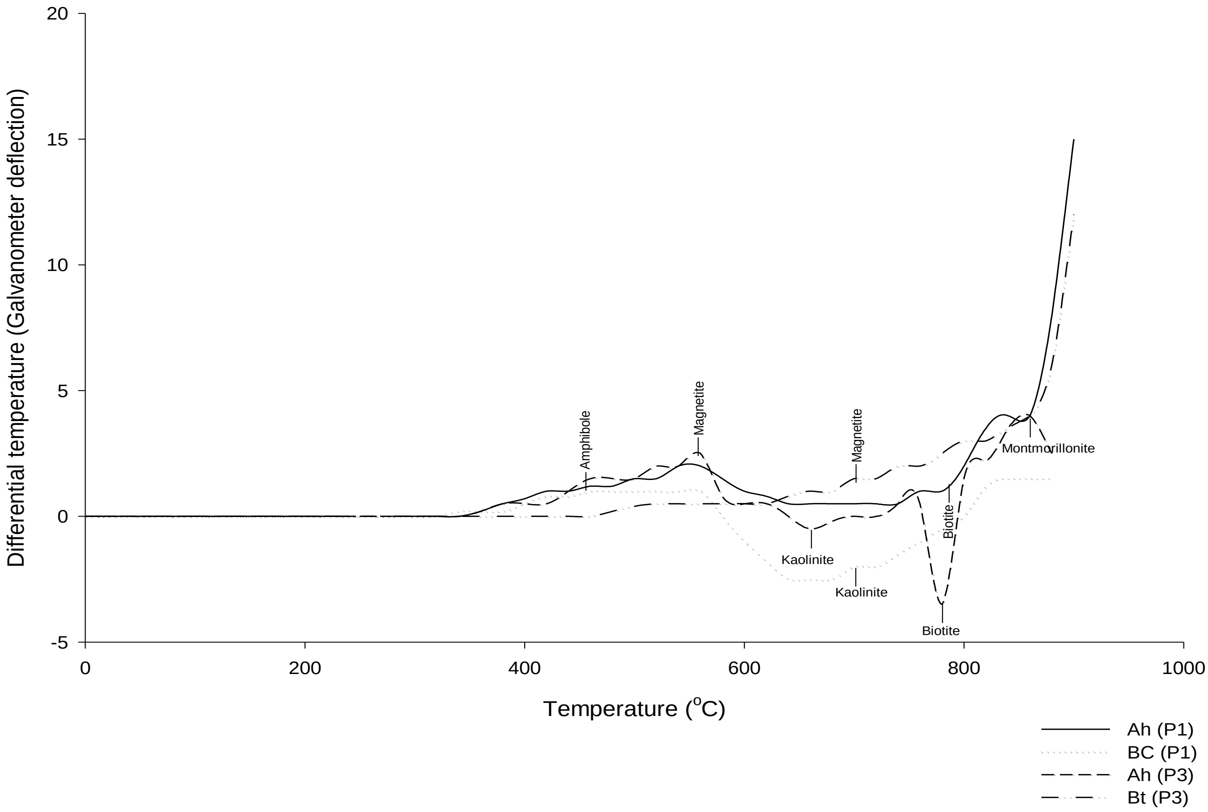

Fig. 4: DTA thermograms of the <2 um fractions of the soil horizons under 21 year old plantation

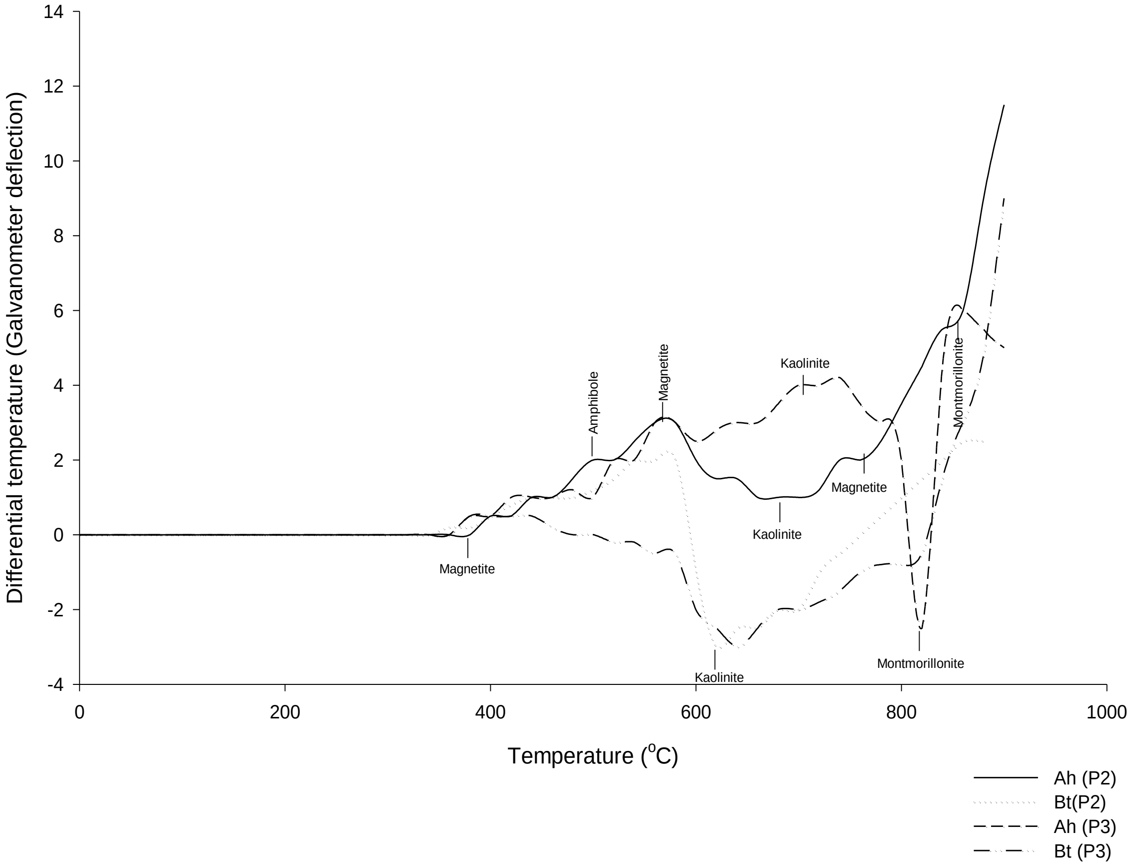

Fig. 5: DTA thermograms of the <2um fractions of soil horizons under 31 year old plantation

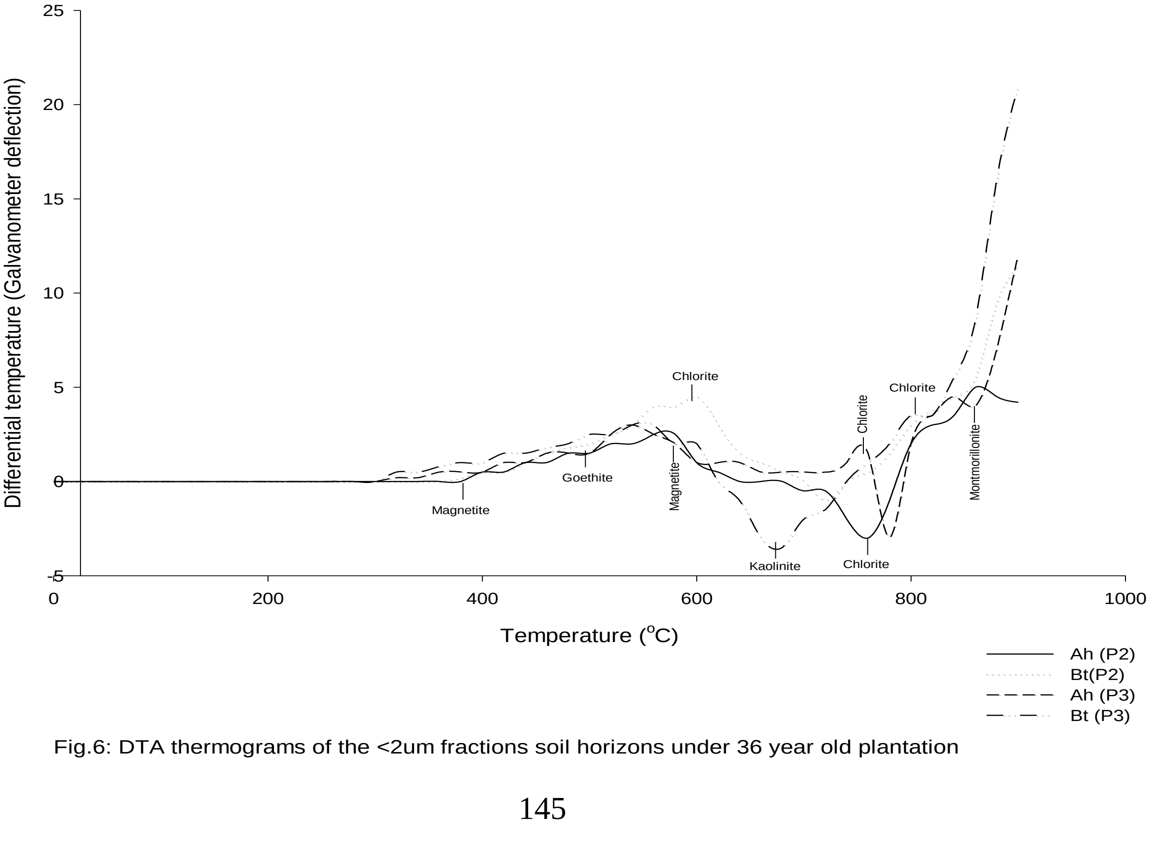

Fig.6: DTA thermograms of the <2um fractions soil horizons under 36 year old plantation

Table 4: Differential thermal analysis of surface and subsurface horizons under the fallow and the various plantation ages.

Horizon	**Surface horizon**				**Subsurface horizon**			
	Depth (cm)	**DTA Peak**	**Exo/Endo**	**Mineral**	**Depth (cm)**	**DTA Peak**	**Exo/Endo**	**Mineral**
Fallow	0-30	350	Exo	Biotite	30-60	500	Exo	Amphibole
		380	Exo	Magnetite		640	Exo	Magnetite
		580	Exo	Amphibole		700	Exo	Biotite
		640	Endo	Magnetite		900	Exo	Montmorillonite
		700	Endo	Kaolinite				
11 Year old plantation								
NF 90 P1 Ah	0-30	580	Exo	Magnetite	BC 24-70	600	Exo	Magnetite
		700	Exo	Biotite		780	Exo	Biotite
		750	Exo	Biotite		850	Exo	Montmorillonite
		800	Exo	Biotite				
NF 90 P3 Ah	0-10	450	Exo	Amphibole	BC 10-50	600	Exo	Magnetite
		600	Exo	Magnetite		650	Endo	Kaolinite
		800	Exo	Biotite		800	Endo	Chlorite
						850	Exo	Montmorillonite
21 Year old plantation								
NF 80 P1 Ah	0-10	450	Exo	Amphibole	BC 20.62	580	Exo	Magnetite
		580	Exo	Magnetite		700	Endo	Kaolinite
		800	Exo	Biotite		850	Exo	Montmorillonite
		840	Exo	Montmorillonite				
NF 80 P3 Ah	0-15	580	Exo	Magnetite	Bt 37-75	700	Exo	Magnetite
		700	Endo	Magnetite		800	Exo	Biotite
		800	Endo	Biotite		850	Exo	Montmorillonite
		850	Exo	Montmorillonite				

Table 4 (Contd): Differential thermal analysis of surface and subsurface horizons under the fallow and the various plantation ages.

Horizon	*Surface horizon*				*Subsurface horizon*			
	Depth (cm)	**DTA Peak**	**Exo/Endo**	**Mineral**	**Depth (cm)**	**DTA Peak**	**Exo/Endo**	**Mineral**
31 Year old plantation								
NF 70 P2 Ah	0-17	500	Exo	Amphibole	Bt 36-65	600	Exo	Magnetite
		580	Exo	Magnetite		610	Endo	Kaolinite
		680	Endo	Haematite		680	Endo	Haematite
		700	Exo	Magnetite		700	Exo	Kaolinite
		780	Exo	Magnetite		850		Montmorillonite
		850	Exo	Montmorillonite				
NF 70 P3 Ah	0-19	500	Exo	Amphibole	Bt 45-77	580	Endo	Chlorite
		580	Exo	Magnetite		620	Endo	Kaolinite
		680	Endo	Haematite		700	Endo	Kaolinite
		700	Exo	Magnetite		800	Endo	Chlorite
		820	Endo	Montmorillonite				
		850	Exo	Montmorillonite				
36 Year old plantation								
NF 65 P2 Ah	0-12	580	Exo	Magnetite	Bt 36-77	380	Endo	Goethite
		680	Endo	Haematite		600	Exo	Magnetite
		700	Endo	Chlorite		680	Endo	Haematite
		780	Endo	Chlorite		700	Endo	Kaolinite
		850	Exo	Montmorillonite		800	Exo	Biotite
NF 65 P3 Ah	0-18	500	Exo	Amphibole	Bt 30-62	507	Exo	Goethite
		780	Exo	Chlorite		600	Exo	Chlorite
		800	Endo	Chlorite		620	Endo	Kaolinite
		900	Exo	Montmorillonite		700	Endo	Kaolinite
						850	Exo	Montmorillonite

CONCLUSION

The effects of *Tectona grandis* on soil properties showed high values of Fe_{ox} and $Al_{d,}$ which implied an increased vigour in weathering. Active Fe values were lower than 1 for the respective plantation ages and profile depths. This suggests that as plantation becomes older, crystalline forms of Fe and Al increased, indicating an evidence of increased weathering intensity. The general trend of surface mineralogy under the fallow and the various plantation ages indicated that under the fallow, magnetite was the dominant mineral, biotite montmorillonite and chlorite were the dominant minerals under 11, 21, 31 and 36 year old plantations. For the subsurface horizons, biotite was the dominant mineral under the fallow and 11 year old plantation, with montmorillonite being the dominant clay mineral under 21 and 31 year old plantations. Kaolinite was the dominant clay mineral obtained under oldest plantation, thereby implying that kaolinization increases as plantation becomes older as a result of increased level of weathering. The presence of high contents of crystalline forms of Fe, Al, kaolinites and traces of haematite and goethite deducts that *Tectona grandis* deteriorates soil properties with time.

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