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OXISOL (FERRALSOL) DEVELOPMENT IN TWO AGRO-ECOLOGICAL ZONES OF GHANA: A PRELIMINARY EVALUATION OF SOME PROFILES

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ABSTRACT

Oxisoils (or Ferralsols) have been recognized in the High Rain Forest (HRF) agro-ecological zone of Ghana. There is no documented information about these soils in the Moist Semi-Deciduous Forest (MSDF) agro-ecological zone of Ghana where climatic conditions conducive for Oxisol formation have been identified in parts of the zone. The paper seeks to establish the development of Oxisols or Ferralsols in parts of the MSDF so that appropriate management practices can be adopted for their sustainable use in the zone. Nine soil profiles were dug, described and sampled along a transect running from the HRF to MSDF zones of Ghana. Four of the profiles were located in the HRF and five in the MSDF. The HRF soils are Ninisu, Ankasa, Boi and Bremang series, while Wacri, Kukurantumi, Bekwai, Nzima and Kokofu series are the MSDF soils. Using rainfall and evapotranspiration data, morphological and easily measurable physico-chemical properties in the laboratory, the soils were evaluated for the development of Oxisols in the two agro-ecological zones in Ghana. These properties were also used to classify the soils into the Soil Taxonomy, world Reference Base for Soil Resources (WRB) and the Ghana Soil Classification Systems. Rainfall is higher in the HRF than MSDF. However, evapotranspiration distribution is similar in the two zones. Munsell hue is less variable in the HRF than the MSDF. This indicates greater moisture variability in the MSDF compared to the HRF. All the soils in the HRF and two in the MSDF (Wacri and Kukurantumi series) show pseudosand structure in the subsoil, which is characteristic with Oxisols (or Ferralsols). Though the soils are highly weathered with ECEC values being <12 cmol(+)/kg soil, the intensity is greater with the HRF soils. Silt:clay ratios are <0.7 in the subsoils of the HRF soils compared to those of the MSDF. CEC:clay are mostly <0.3 in all the soils, indicating kaolinitic clay mineralogy. Under the Soil Taxonomy system, all the HRF soils and two in the MSDF (Wacri and Kukurantumi series) are Oxisols. The remaining three MSDF soils are Ultisols. The Oxisols classify as Ferralsols and the Ultisols, Acrisols in the WRB. This preliminary assessment shows that Oxisosl (or Ferralsols) also occur in the MSDF under udic moisture regimes. This is important for soil management in the MSDF.

Keywords: *Oxisols, Ferralsols; agro-ecological zone; weathering intensity; pseudosand.*

INTRODUCTION

Globally, oxisols (or ferralsols) occupy about 9.8 million hectares which is equivalent to 7.5% of the global and 25% of the tropical land area. More than 95% of oxisols can be found in the tropics. The key factors considered to be responsible for the formation of oxisols are the age of the soils which has resulted from their occurrence on very old geomorphic surfaces and high degree of weathering (Beinroth *et aI.*, 1974; Sanchez and Buol, 1974, Sanchez, 1976; Lepsh *et al.*, 1977, van Wambeke *et al*., 1983). They can also develop in recently deposited pre-weathered sediments that originate from old regoliths (Eswaran and Tavernier, 1980; Batjes, 1996). In fact, geomorphic evolution of the landscape is considered an important factor in the formation of oxisols more than the kinds of soil. Daniels *et al*. (1971) have observed that oxisol development is controlled by the interaction of geomorphic, formative factors, rates and degrees of expression of pedogenic processes. Oxisols are also in the group of acid soils, and occur under udic, perudic and ustic moisture regimes (von Uexkull and Mutert, 1995; soil Survey Staff, 1998). According to Beinroth *et al*. (2000), the bulk of oxisols can be found in south America with most occurring in Brazil while the "Democratic Republic of Congo has the largest in Africa.

Beinroth *et al.* (2000) stated that oxisols are the most extensive soil group in the humid tropical forest ecosystem. They also consist of very large pool of sequestered carbon and special ecological niches of significant biological diversity. Von Uexkull and Mutert (1995) observed that the natural vegetation on these soils is an important factor for a stable global climate and the ultimate well-being of the human race particularly in terms of being a resource for food, timber, medicine and other products for humankind. These soils form a major land resource base for mankind and one of the few remaining frontiers for agricultural development, especially in Africa and South America.

The development, characteristics and classification of Ghanaian soils are significantly influenced by local climate and vegetation (Obeng, 1987) and this is observed in the tremendous differences among the soils in the country. The soils in the forest zone of the country differ from those in other parts by having a much thicker surface horizon due to high organic matter accumulation resulting from abundant leaf fall under the forest vegetation. The forest zone, which occupies an area of approximately 73,000 square kilometers, consists of the High Rainfall Forest (HRF) and the Moist Semi-Deciduous Forest (MSDF) which are two important agro-ecological zones in the country, particularly, in terms of agricultural production. The dominant soils in the HRF are Oxisols (Ferralsols), Ultisols (Acrisols), Aquents and Aquepts (Gleysols), while in the MSDF they are Alfisols (Lixisols and Luvisols), Ultisols, Plinthaqualfs and Plinthaquults (Plinthosols), Inceptisols (Cambisols), and Aquents and Aquepts (Obeng 1987; Asiamah, 1987).

In Ghana, the climatic conditions especially udic moisture regimes in the HRF, in particular, and other areas in the MSDF favour the development of oxisols. Oxisols have been identified in the HRF where they develop over a variety of parent materials such as unconsolidated Tertiary deposits, peneplain drifts on high level erosion surfaces, Tarkwaian quartzites and pyritiferous phyllites in the Lower Birimian formations (Brammer, 1962). Charter (1958) used a synonymous term oxysols to classify them in the Interim Ghana Soil Classification System. However, their development in the MSDF has not been reported. As a result, they are considered as either Ultisols (Acrisols) or Alfisols (Luvisols and Lixisols) and managed as such.

The objective of this paper is to establish the occurrence of Oxisols or Ferralsols in the Moist Semi-Deciduous Forest (MSDF). The objective is achieved by examining some climatic conditions, especially rainfall, analyzing some key easily measurable soil properties with respect to Oxisol or Ferralsol development and then comparing these with those in the HRF where these have already been established. This will assist in the adoption of appropriate management practices for the sustainable use of these soils in the MSDF.

Materials and Methods

The study sites were located along a transect measuring 400 kilometers, and running northwards from south-west in a north-easterly direction from the High Rain Forest (HRF) to the Moist Semi-Deciduous Forest (MSDF) agro-ecological ones of Ghana (Figure 1) the HRF is at the extreme south-western section and the MSDF, the south-central section of the country. The latter zone occupies about 80% of the entire forest zone of Ghana. A synoptic station in each zone (Axim in the HRF and Tafo in the MSDF) was examined to determine the mean monthly rainfall distribution and mean annual ranges together with evapotranspiration for a 35 -year period (from 1961-1995).

The soils examined in the two zones are developed from granites and Lower Birimian phyllites. However, the granites are different – they are biotite granites in the HRF and hornblende granites in the MSDF but both are of pre-Cambrian age (Junner, 1940; Bates, 1962). The Lower Birimian phyllites are metamorphosed clay sediment of pre-Cambian age. Nine soil profiles (four in HRF and five in MSDF) were dug to depths ranging from 1.50 – 2.00 m. In each zone and geology, the soils were examined in a catenary sequence. In the HRF, the catenas examined were *Ninisu-Ankasa* (developed over granite) and *Boi-Bremang* (developed over lower Birimian phyllites). *Ninisu*, *Ankasa* and *Boi series* are upland soil occurring on summits, upper and middle slopes, while *Bremang series* occurs on lower slopes. These catenas can be found in the Lower Tano drainage basin within the HRF (Ahn, 1961). In the MSDF, the catenas were *Wacri-Kukurantumi* (both developed over hornblende granite) and *Bekwai-Nzima-Kokofu* (all developed over lower Birimian phyllites). Apart from *Kokofu series*, which is a lower slope soil, the rest are upland soils. In the study area of the MSDF we used, the two catenas can be found in the Ayensu/Densu drainage basin (Adu and Asiamah, 1992). The latter also occurred in the Kumasi Region and Birim drainage basin.

Soil selection for the study was based on geology and soil moisture regimes, which are phyllites, granites and udic moisture regimes. Van Wambeke (1992) established udic moisture regimes in the south-western part of Ghana (where the HRF is located) and some parts (e.g. Bunso, Kade and Tafo) in the Eastern Region of Ghana (which is part of the MSDF). Moisture regime, in particular, is an important factor in Oxisol development. Besides, the two groups of soils are very important in the zones in terms of land use. They are used for cocoa, Ghana’s number one foreign exchange earner, rubber and oil palm (an important crop in the manufacturing industry, particularly soap and pharmaceuticals).

Each profile was described fully according to the Guidelines for soil Description (FAO< 1990). The profiles were sampled according to genetic horizons for the following physico-chemical analyses: particle size distribution determined on particles < 2 mm in diameter by the hydrometer method (Bouyoucous, 1962); soil reaction (1:1 soil-water ratio) (Mclean, 1982); organic carbon determined by wet combustion method of Walkley and Black (Nelson and Sommers, 1982); total nitrogen by Kjeldahl digestion and distillation (Bremner, 1965); exchangeable bases determined in neutral ammonium acetate leachate (Thomas, 1982); exchangeable acidity by titration in 1.0M potassium chloride extract and effective cation exchange capacity (ECEC) by the summation of exchangeable acidity and exchangeable bases. Available phosphorus and available potassium were determined colorimetrically and by flame photometry respectively after extraction with Bray’s P1 solution (Bray and Kurtz, 1945; Carson, 1975). The physico-chemical data were used in classifying the soils into the World Reference Base for Soil Resources (1998) and Soil Taxonomy (Soil Survey Staff, 1999). From the analytical data, two parameters – silt:clay ratio and ECEC – were used to determine the weathering intensity of the soils in the two zone. In the case of the latter parameter, the relation ECEC x 100/% clay [Van Wambeke (1967) and Westin (1969)].

The ECEC values were corrected for organic matter (OM) on the assumption that 1% OM contributes 2 cmol to the overall (Brady and Weil, 1996). The physico-chemical data and the weathering intensity values obtained for the soil in the MSDF were compared with those of the HRF, where Oxisols have already been identified by Ahn (1964). The relation CEC clay content was used to determine the clay mineralogy of the soils based on the criteria of Soil survey Staff (1995).

RESULTS AND DISCUSSION

Rainfall and evapotranspiration distribution in the two zones

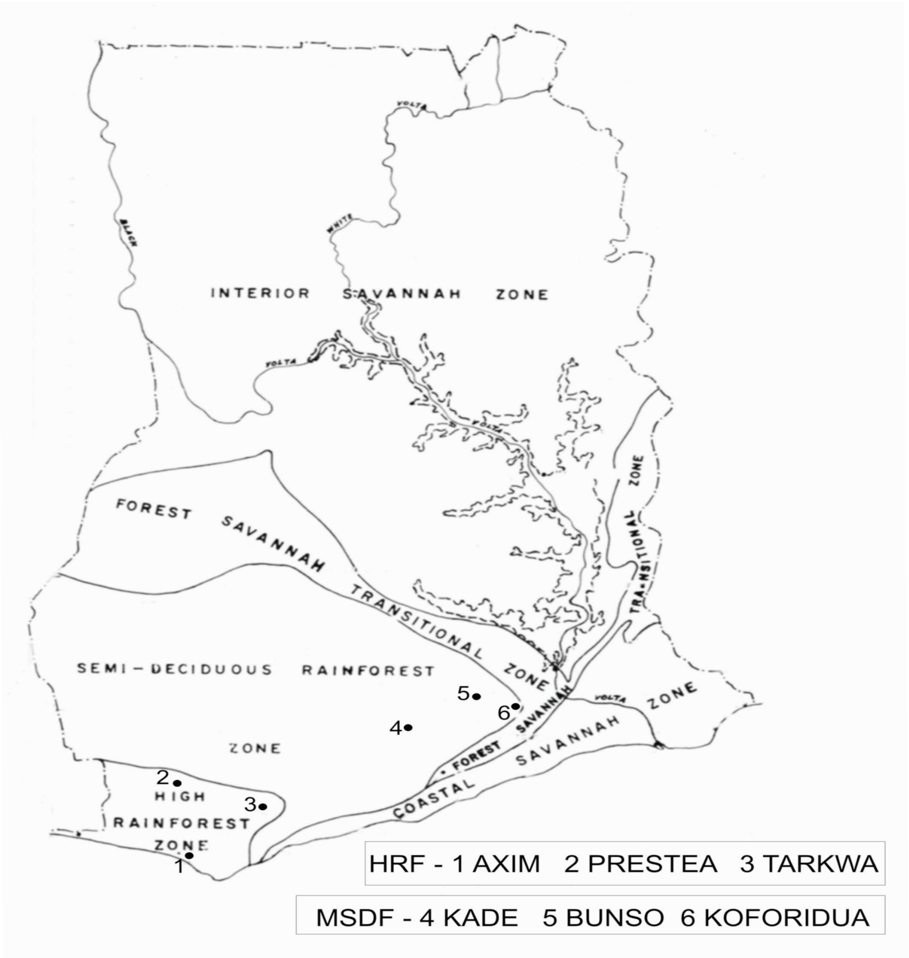

Figure 1: Location of sampling sites in the HRF and MSDF

Rainfall is bimodal in the two zones (figure 2). The mean rainfall in the HRF is > 2000 mm while in the MSDF it is around 1700 mm. In the two zones, the highest mean monthly amounts are recorded in June. The lowest rainfall amounts occur in January and February in the HRF but in December and January within the MSDF. Monthly evapotranspiration distribution is more or less the same in the two zones (Figure 2). Evapotranspiration exceeds rainfall in the dry months of November to March in the MSDF. These observed differences in evapotranspiration and rainfall throughout the year are necessary for the development of Oxisols (or Ferralsols) (van Wambeke, 1992). Where rainfall exceeds evapotranspiration in the year, as observed between the months of April and August (HRF) and May to August (MSDF), excess water percolates through the solum (Miller, 1983) and encourages leaching of soluble products resulting from weathering (van Wambeke *et al.*, 1983).

Landscape, morphological and physical characteristics of the soils

Topography in the two zones is generally gently rolling (10-15%). However, steeply dissected (>30%) areas can also be found in the HRF. Above the general level of gently rolling topography, flat summits occur giving an indication of ancient peneplain residuals (Brash, 1962). In the two zones, particularly areas occupied by Birimian rocks, low-lying and flat areas can be found. These are the result of weathering which penetrates deeply into the rock mass, especially in the HRF. Throughout the HRF and MSDF, river terraces can be found at variable heights which range from 7-36 m above local base level (Brash, 1962).

Landscape evolution in the two zones is mainly the result of erosion. A balance is achieved

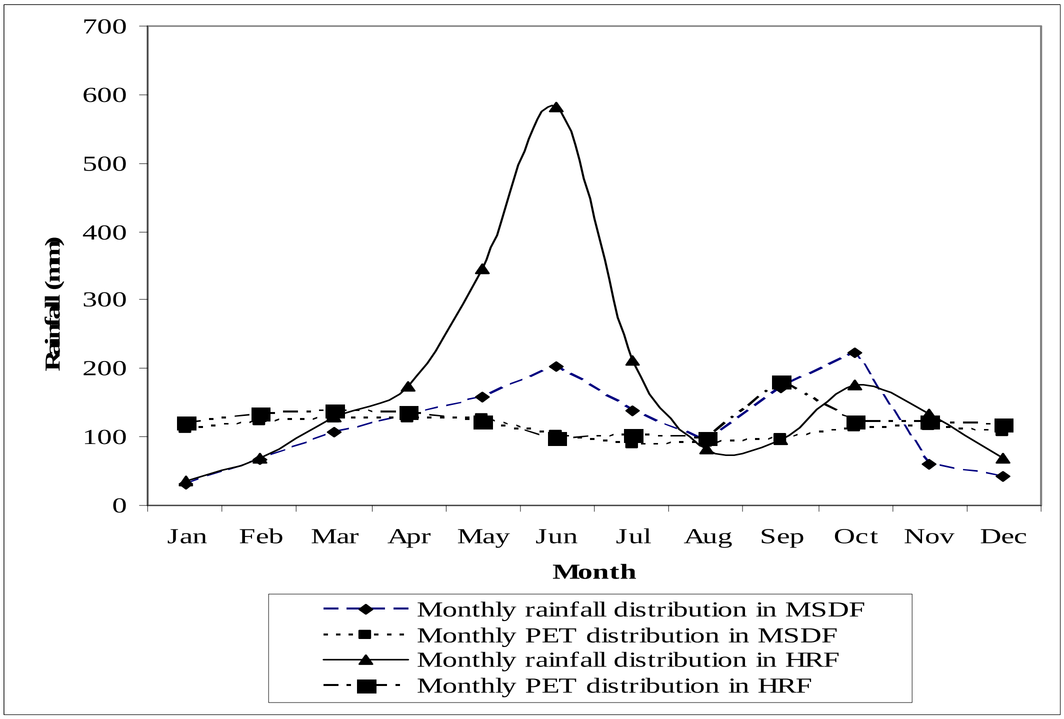

Figure 2: Monthly rainfall evapotranspiration distribution in the MSDF & HRF

between weathering, erosion and deposition.
The process of erosion is slowed down by the vegetative cover in the two, but more in the HRF. Removal of the vegetation, as seen now, accelerates the erosion process. These processes of weathering and erosion result in the degradation of the uplands with a corresponding accumulation of materials in the lowlands, thus resulting in leveling of the topography.

Munsell hue is less variable in the HRF soils than those in the MSDF (Tables 1a and 1b). The dominant topsoil hues in the uplands of the HRF are 5YR and 7.5YR, while the subsoils have 2.5YR and 5YR with soil colours ranging from strong brown to yellowish red and red. The lower slope soils (*Bremang series*) have 10YR as the dominant hue with the colour being yellowish brown (Table 1a). The hues are similar for *Wacri* and *Kukurantumi series* studied in the MSDF. With the rest of the soils (*Bekwai* and *Nsima series*), hues are 10YR, 7.5YR, 5YR and 2.5YR (Table 1b). Schaefer *et al*., (2002) observed similar hues for some Brazilian upland Oxisols developed on the Diamantina Plateau found on the uplands of Minas Gerais State. The colours for the upland soils indicate well-drained conditions, while the lower slope soils show imperfectly drained conditions. All the soils in the HRF and two in the MSDF (*Wacri* and *Kukurantumi series*) show pseudosand structure in parts of the subsoil. This is a structure developed in an oxic (or ferralic) horizon and characterized by strong microaggregation and friable consistence (WRB, 1998). However, the dominant structure in the HRF and MSDF soils is weak to moderate, fine and medium subangular blocky. Another special feature of these soils is the presence of iron and manganese concretions in the subsoils (Table 1a and 1b).

Particle size distribution shows that while sand and silt content decreases with depth, clay content increases in the profiles examined within the two zones (Tables 2a and 2b). Depth distribution of clay shows that there is no clear clay accumulation in the Boi and Bremang profiles developed from Lower Birimian phyllites (Figure 3a) in the HRF. Though the clay increase is slight in these profiles, the increase does not meet the requirements of argillic (or argic B) horizon (Soil Survey Staff, 1999; WRB, 1998) bur rather on oxic horizon,. However, the granitic profiles (Ninisu and Ankasa) show clay accumulation (figure 3b). It can be deduced that in the HRF, soils developed from biotite granite have argillic horizon, while it is absent in those developed from lower Birimian phyllite under the same udic moisture regime.

The reverse is the case in the profiles in the MSDF. The profiles developed from hornblende granite (*Wacri* and *Kukurantumi series)* have no argillic horizon (figure 4a) whereas the three profiles developed from phyllite in the zone (B*ekwai, Nzima* and *Kokofu series*) have argillic horizons (Figure 4b). The presence of argillic horizons in these profiles indicates that they are not Oxisols. This also indicates that irrespective of geology, climate or rainfall has a significant influence on the formation of Oxisols in the two zones. Besides, the clay accumulation in these profiles which occur in a catenary sequence, decreases from summit to lower slope as drainage conditions change from well to imperfect.

This reduction in clay accumulation along the catena, gives an indication of progressive clay destruction (Lucas *et al*., 1984; Andrade *et al*., 1997).

Brinkman (1979) attributed this destruction to ferrolysis which occurs under wet climatic conditions as observed in the two zones, particularly the HRF.. The observed differences in clay accumulation among the soils developed from the two geologies can be attributed to the following:

*Udic moisture conditions exist in some parts of the MSDF where *Wacri* and *Kukurantumi series* occur.

*The phyllite soils in the MSDF occur under ustic moisture regime. Under these two moisture regimes, weathering and leaching proceed faster under udic than ustic conditions

*The more basic a mineral the less stable it is (Barshad, 1965).

These differences in relative stability of the two minerals may have accounted for the observed variation in clay distribution with depth in the granitic soils in the two zones. Chadwick and Graham (2000) also attributed such differences to processes occurring in soils depending on soil-landscape position and different climatic conditions as observed.

The silt-clay rations (Table 3 and 4) of the profiles in the two zones show that most of the soils in HRF have values below 0.7 within the subsoil and similar to those observed by Schaefer *et al.* (2002) but higher than those observed for some Puerto Rican Oxisols (Beinroth, 1982). The weathering intensity is, however, greater in the HRF, which has a higher rainfall amount than the MSDF. CEC:clay ratios show that clay mineralogy of the soils is mostly kaolinite. This further shows that soils are highly weathered.

Chemical characteristics of the soils

The soils in the HRF are extremely acidic with pH values generally <4.0 throughout the profiles (Table 2a). However, in the MSDF, pH values range from 4.0-5.4 in the B-horizon. These low pH values are conducive for the process of ferrallitization or desilication, which leads to the formation of oxisols (or ferralsols).

Table: 1a Morphological characteristics of selected soils in the HRF

Soil Series	*Horizon Symbol*	*Depth (cm)*	*Colour (moist)*	*Structure*	*Consistence*	*Texture*	*Special features*
Ninisu	Ah	0-6	5YR 3/2	wk-fn-med-gr	friable	SL	
	BA	6-20	5YR 5/6	wk-med-sab	friable	SCL	pseudosand structure
	Btcl	20-60	5YR 5/8	wk-fn-med-sab	friable	C	pseudosandstructure; cmfinqg
	Btc2	60-105	2.5YR 5/6	mo-med-co-sab	firm	C	cfngq; mhFe/Mg conc.
	Btcv	105-150	2.5YR 5/6	mo-med-co-sab	firm	C	cfnqg; fn distinct mottles
Ankasa	Ah1	0-5	5YR 3/2	mo-fn-med.gr	friable	SL	
	Ah2	5-12	7.5YR 3/2	mo-fn-med-sab	friable	SCL	pseudosand structure
	BA	12-36	7.5YR 4/4	mo-fn-med-sab	friable	SCL	pseudosand structure
	Bts1	36-72	5YR 5/8	wk-med-co-sab	firm	C	pseudosandstructure; abfnqg
	Bts2	72-110	2.5YR 5/6	wk-med-co-sab	firm	C	common fine quartz gravel
	Bt	110-150	2.5YR 5/6	wk-med-co-sab	firm	C	
Boi	Ah	0-8	7.5YR 4/3	mo-fn-med-gr	friable	L	
	BA	8-20	7.5YR 4/4	wk-mo-med-sab	friable	L	pseudosand structure
	Btcs	20-75	5YR 5/6	wk-mo-med-sab	friable	C	pseudosandstructure; cmfnqg
	Btv1	75-130	5YR 5/6	wk-mo-med-sab	firm	C	cfnqg;absFe/Mg conc./stones
	2Btv2	130-150	5YR 5/6	wk-fn-med-sab	firm	C	cfnqg;absFe/Mg.conc./stones
Bremang	Ap	0-6	10YR 3/2	mo-med-gr	friable	CL	
	BA	6-20	10YR 4/4	mo-med-sab	friable	CL	pseudosand structure
	Bt1	20-60	10YR 5/6	mo-med-sab	friable	CL	pseudosand structure
	Bt2	60-110	10YR 5/6	mo-med-sab	firm	C	pseudosand structure
	Btv1	110-135	10YR 5/6	mo-med-co-sab	firm	C	cfnmed distinct mottles
	Btv2	135-150	10YR 5/6	mo-med-c0-sab	firm	C	ab coarse and distinct mottles

C - common; m – many; fn – fine; q – quartz; gravel; Fe/Mg conc. – iron and manganese concretions; ab – abundant; s – soft; h – hard; wk – weak; mo – moderate; med – medium; co – course; gr – gramular; sab – subangular blocky; L – loam; SL – sandy loam; SCL – sandy clay loam; CL – clay loam; C – clay

Table: 1b Morphological characteristics of the soils of the MSDF

Soil series	*Horizon Symbol*	*Depth (cm)*	*Colour (moist)*	*Structure*	*Consistence*	*Texture*	*Special features*
Wacri	Ap	0-8	7.5YR 4/2	wk-med-gr	friable	SL	
	BA	8-30	5YR 4/6	wk-med-sab	friable	SCL	
	E	30-57	5YR 4/6	wk-med-sab	firm	CL	pseudosandstructure; cqfnqg
	Btcs	57-97	2.5YR 4/6	wk-med-sab	firm	SC	pseudosand structure, fwfnqg
	Btv	97-150	2.5YR 4/6	wk-med-sab	firm	C	pseudosandstructure;csFe/Mg
Kukurantumi	Ap	0-8	7.5YR 3/2	wk-fn-gr	friable	SL	
	AB	8-28	7.5YR 4/3	wk-fn-gr	friable	SL	
	E	28-65	7.5YR 4/4	wk-med-sab	friable	SCL	pseudosand structure; fwfnqgst
	Bt	65-104	7.5YR 4/4	wk-meb-sab	firm	SCL	pseudosandstructure;fwfnqg
	CB	104-150	7.5YR 5/8	mo-med-sab	firm	SC	pseudosand structure; trdegr
Bekwai	Ah	0-9	10YR 3/3	wk-fn-gr	friable	L	
	BA	9-17	7.5YR 4/6	wk-fn-sab	friable	L	
	Btcs	17-30	5YR 4/6	wk-fn-sab	friable	CL	fw quartz gravel/stones;mhFe
	Btv1	30-61	5YR 4/8	wk-fn-med-sab	firm	C	common quartz gravel; chFe
	2Btv	261-120	2.5YR 4/8	mo-fn-med-sab	firm	C	common hard Fe concretions
	2Btv3	120-150	5YR 5/8	mo-fn-med-sab	firm	C	common hard Fe concretions
Nzima	Ap	0 – 10	10YR 3/3	wk-fn-gr	friable	SL	
	BA	10 -20	10YR 4/6	wk-fn-sab	friable	L	common hard Fe concretions
	Btcs	120-40	7.5YR 5/6	mo-med-sab	firm	CL	common quartz gravel/stone
	Btcs	240 –70	7.5YR 5/8	mo-med-sab	firm	SiC	common hard Fe concretions
	Btv1	70 – 105	7.5YR 5/8	mo-med-sab	firm	CL	cmedqg;chFe/Mn;m red mottles
	Btv2	105 – 150	10YR 5/6	mo-med-co-sab	firm	CL	fw soft Fe/Mn;mdi red mottles
kokofu	Ap	0-7	10YR 3/3	wk-med-gr	friable	SL	
	BA	7-19	10YR 4/6	wk-med-sab	friable	L	common hard Fe concretions
	E	19-40	7.5YR 5/6	mo-med-sab	firm	CL	common quartz gravel/stones
	Btcs	40-82	7.5YR 5/8	mo-med-sab	firm	SiC	common hard Fe concretions
	Btv1	82-106	7.5YR 5/8	mo-med-sab	firm	CL	cmedqg;chFe/Mn;m red mottles
	Btv2	106-150	10YR 5/6	mo-med-co-sab	firm	CL	fw soft Fe/Mn;m red mottles

Fw-few; c-common; m-many; fn-fine; q-quartz; gravel; Fe/Mg conc.-iron and manganese concretions; ab-abundant; s-soft; h-hard; st-stone; wk-weak; mo-moderate; med-medium; co-coarse; gr-granular; sab-subangular blocky; L-loam; SL-sandy loam;
SCL-sandy clay loam; CL-clay loam; C-clay; trdegr-traces of decomposing granite; di-distinct

Batjes (1995, 1996) observed similar pH patterns for Oxisols. These conditions are found in all the soils studied in the HRF and two (*Wacri* and *Kukurantumi series*) in the MSDF. At these low pH values, exchangeable bases are correspondingly very low throughout the profiles (Table 1 and 2). This indicates leaching of soluble bases out of the soil.

Organic carbon levels are higher in the topsoils of the HRF than the MSDF profiles. The levels range from high to very high (2.50-3.50%).

This indicates a greater accumulation of organic matter in the surface horizons of the HRF, as a result of abundant leaf fall than in the soils of the MSDF. The subsoil levels are generally very low (<0.6%). Exchangeable basic cation levels are generally lower in the HRF than the MSDF profiles, thus indicating greater leaching in the profiles of the former zone.

Table: 2a **Some physical and chemical properties of HRF soils as a function of depth**

Soil series	Horizon	Depth	Particle size distribution			pH	O.C	Exchangeable basic cations (cmol/kg)					Bray's P1 (mg/kg)	
	Symbol	(cm)	%Sand	%Silt	%clay	H_2O	(%)	Ca	Mg	K	Na	BS(%)	Av.P	Av.K
Ninisu	Ah	0-6	67	20	13	3.2	3.52	3.04	0.32	0.20	0.08	54.8	0.12	66.5
	BA	6-20	52	13	35	3.6	1.05	0.64	0.32	0.04	0.07	32.2	Trace	18.5
	Btc1	20-60	39	9	52	3.9	0.63	0.64	0.32	0.04	0.05	30.0	Trace	5.0
	Btc2	60-105	26	13	61	3.9	0.55	0.64	0.32	0.02	0.05	28.8	Trace	5.0
	Bt	105-150	23	20	57	4.1	0.36	0.48	0.32	0.02	0.21	26.2	Trace	3.5
Ankasa	Ah1	0-5	66	14	20	4.5	3.31	5.44	0.64	0.33	0.11	92.9	0.63	90.0
	Ah2	5-12	64	14	22	4.0	1.73	1.60	0.64	0.13	0.05	51.3	0.50	46.5
	BA	12-36	59	13	28	3.7	0.75	1.12	0.48	0.06	0.05	34.1	Trace	18.5
	Bts1	36-72	39	14	47	3.7	0.59	1.12	0.48	0.05	0.03	30.9	Trace	15.0
	Bts2	72-110	28	21	51	3.8	0.48	1.12	0.48	0.05	0.02	29.2	Trace	15.0
	Bt	110-150	30	23	47	3.9	0.40	1.04	0.48	0.04	0.02	28.8	Trace	13.5
Boi	Ah	0-8	44	43	13	3.6	3.71	3.68	0.12	0.28	0.05	71.9	1.62	76.5
	BA	8-20	36	37	27	3.4	1.24	1.28	1.28	0.11	0.05	40.7	0.37	33.5
	Btcs	20-75	22	28	50	3.5	0.68	1.12	1.12	0.10	0.05	39.8	Trace	31.5
	Btcs1	75-130	14	35	51	3.7	0.32	1.12	1.12	0.03	0.03	38.1	Trace	15.0
	Btv2	130-150	13	35	52	3.7	0.21	1.12	1.12	0.03	0.03	32.4	Trace	3.5
Bremang	Ap	0-6	46	28	26	3.9	1.29	3.20	1.12	0.64	0.05	78.8	0.50	36.5
	BA	6-20	42	26	32	3.7	1.26	2.24	0.80	0.13	0.02	55.6	0.12	25.0
	Bt1	20-60	37	23	40	3.6	0.44	1.44	0.64	0.05	0.02	35.8	Trace	15.0
	Bt2	60-110	33	24	43	3.6	0.38	1.28	0.64	0.04	0.01	35.8	Trace	5.0
	Btv1	110-135	41	19	40	3.6	0.36	1.12	0.48	0.04	0.01	30.8	Trace	5.0
	Btv2	135-150	30	31	39	3.6	0.29	1.12	0.32	0.04	0.01	28.2	Trace	5.0

Table 2b Some physical and chemical properties of MSDF soils as a function of depth

Soil Series	Horizon Symbol	Depth (cm)	Particle size distribution			pH	O.C	Exchangeable basic cations (cmol/kg)					Bray's P1(mg/kg)	
			%Sand	%Silt	%clay	H_2O	(%)	Ca	Mg	K	Na	BS(%)	Av.P	Av.K
Wacri	Ap	0-8	67	19	14	5.8	1.45	6.40	0.96	0.38	0.22	98.8	1.25	109.5
	BA	8-30	54	17	29	5.2	0.35	2.88	0.32	0.22	0.07	92.3	0.12	63.5
	Bt	30-57	49	15	36	5.1	0.32	2.88	0.32	0.17	0.05	94.7	Trace	86.5
	Btcs	57-97	44.0	17	39	4.3	0.35	2.56	0.32	0.17	0.05	94.2	0.37	48.5
	Btv	97-150	31	26	43	4.4	0.10	2.08	1.12	0.13	0.21	89.7	Trace	41.5
Kukurantumi	Ap	0-8	76	15	9	6.1	1.14	5.12	0.96	0.21	0.17	98.5	5.37	123.5
	BA	8-28	68	14	18	5.3	0.33	3.04	0.16	0.14	0.13	94.6	0.37	36.5
	Bt1	28-65	63	16	21	5.4	0.27	2.56	0.32	0.14	0.13	95.5	0.12	28.5
	Bt2	65-104	58	17	25	5.2	0.26	2.24	0.16	0.14	0.17	96.4	Trace	25.0
	CB	104-150	49	14	28	5.2	0.23	3.52	0.32	0.13	0.17	97.6	Trace	21.5
Bekwai	Ah	0-9	50	42	8	5.2	2.52	9.00	2.10	0.29	0.18	94.0	1.00	145.5
	BA	9-17	46	37	17	4.6	0.98	3.60	1.30	0.13	0.12	87.0	0.50	52.5
	Btcs	17-30	31	35	34	4.1	0.69	1.90	0.90	0.10	0.13	61.0	0.30	50.5
	Btv1	30-61	25	25	50	4.3	0.58	1.60	0.60	0.08	0.11	48.0	0.30	30.0
	2Btv2	61-120	27	19	54	4.2	0.41	0.70	0.30	0.09	0.11	27.0	Trace	25.0
	2Btv3	120-150	37	15	48	4.1	0.24	0.50	0.30	0.09	0.12	23.0	Trace	20.0
Nzima	Ap	0-10	56	38	6	4.7	3.13	6.30	2.50	0.78	0.27	92.0	6.00	300.0
	BA	10-20	49	34	17	4.0	0.87	1.50	0.70	0.24	0.18	60.0	0.60	99.0
	Bt1	20-40	36	31	33	4.0	0.55	1.00	0.40	0.10	0.21	39.0	0.30	99.0
	Bt2	40-70	18	40	42	4.0	0.42	0.50	0.40	0.05	0.17	24.0	0.30	45.0
	Btv1	70-105	23	38	39	4.0	0.32	0.20	0.50	0.08	0.11	19.0	Trace	22.0
	Btv2	105-150	25	44	31	4.0	0.21	0.40	0.10	0.08	0.19	18.0	Trace	42.0
Kokofu	Ap	0-7	55	40	5	4.4	2.28	4.20	2.10	0.19	0.15	87.0	6.00	100.0
	BA	7-19	50	34	16	4.0	1.19	0.90	0.20	0.14	0.16	44.0	1.10	15.0
	Bt	19-40	45	30	25	4.0	0.48	1.10	0.40	0.13	0.21	46.0	0.50	15.0
	Btcs	40-82	34	34	32	4.1	0.43	1.20	0.20	0.13	0.21	38.0	0.60	10.0
	Btv1	82-106	33	32	35	4.1	0.39	0.60	0.40	0.06	0.17	42.0	0.50	7.0
	Btv2	106-153	43	27	30	4.1	0.25	0.50	0.10	0.09	0.20	30.0	0.50	10.0

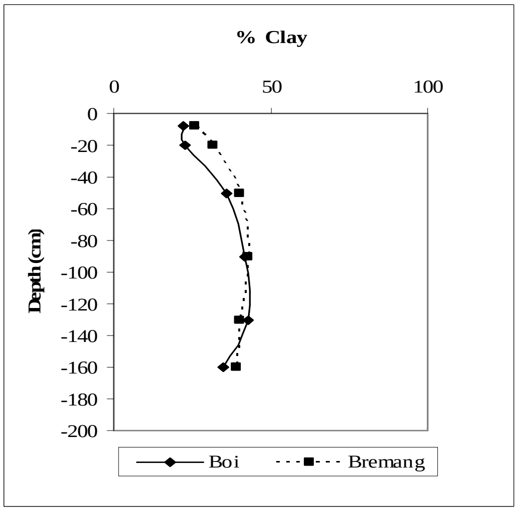

Figure 3a: Depth distribution of clay in phyllitic profiles of HRF

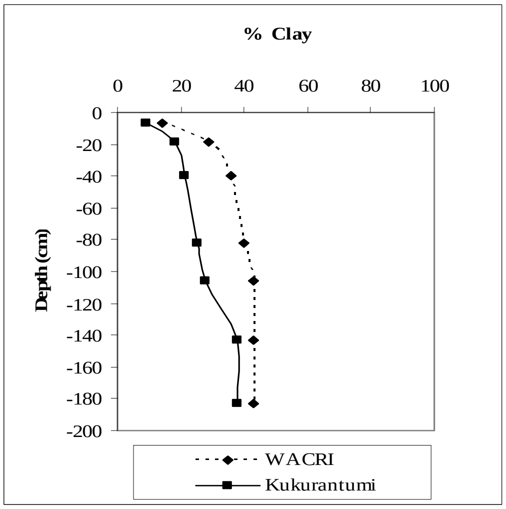

Figure 3b: Depth distribution of clay in granitic profiles of HRF

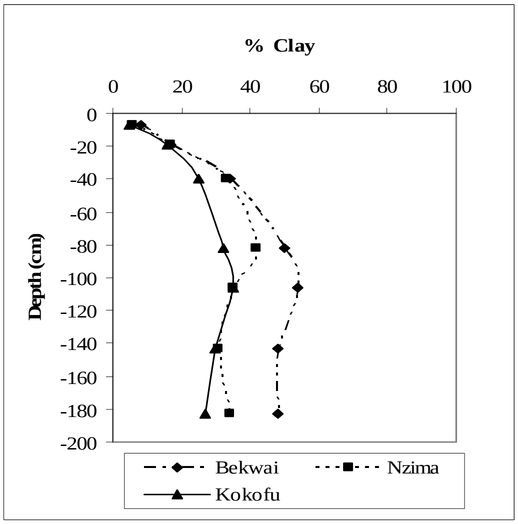

Figure 4a: Depth distribution of clay in phyllitic profiles of MSDF

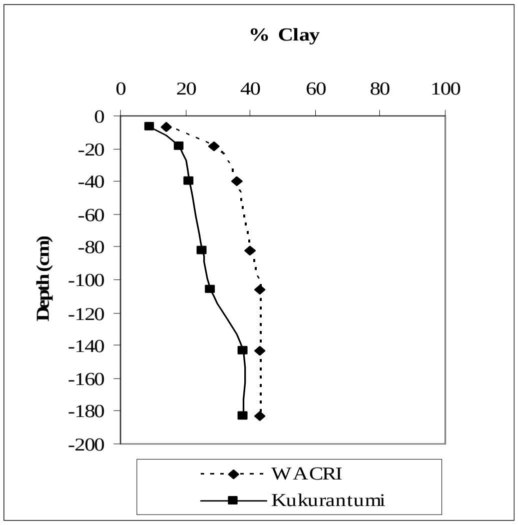

Figure 4b: Depth distribution of clay in granitic profiles of MSDF

Base saturation is <50% in the subsoils of the HRF profiles and the soils developed over phyllite in the MSDF. This is a further reflection on the low base status of these soils. It is, however, very high (>80%) in the two profiles developed over granite in the MSDF (Tables 1 and 2). Available P is very low (<3 mg/kg soil) and occurs in traces in most of the profiles examined in the two zones. These levels may be due to the low soil pH levels which normally result in P fixation, thus making it unavailable for plant uptake.

Available K levels are moderate (50-100 mg/kg soil) in the topsoil of Ninisu, Ankasa and Boi profiles.

The levels are very low (<40 mg/kg soil) in the subsoil of these profiles and throughout the Bremang profile.

In the case of the MSDF profile, moderate to very high levels occur in the top 10 cm of all the profiles. Moderate levels occur within 10-40 cm of the Wacri, Bekwai and Nzima profiles. Very low levels occurred in a greater part of the Kokofu profile. These low nutrient levels show that the soils are intensely leached, particularly in the HRF.

Effective cation exchange capacity (ECEC) levels are very low (<5 cmol(+) /kg soil) throughout the profiles examined, especially in the B-horizons. Correcting for OM influence on the ECEC, weathering intensity values range from 4.2-5.4 cmol(+)/kg clay and 7.0-8.9 cmol (+)/kg clay for the HRF and MSDF soils respectively. These values are below or less than 12 cmol(+)/kg clay, thus indicating very strongly weathered soils. Weathering intensity is, therefore, higher in the HRF than MSDF.

Soil Classification

The nine soils studied are placed in two international systems of classification (Table 5) currently used in Ghana and the Ghanaian Classification system (Brammer, 1962). The international systems are Soil Taxonomy (soil Survey Staff, 1998) and World Reference Base for Soil Resources (WRB) (1998). In the Soil Taxonomy, Oxisols and Ultisols, which are Ferralsols and Acrisol in the World Reference Base were identified. The criteria and rationale used in the classification are briefly discussed below:

Table 3:Some weathering intensity parameters and clay activity classes of profiles examined in the HRF

			Weathering intensity parameters				
Soil Name	**Horizon**	**Depth (cm)**	**ECEC**	**Corrected ECEC x 100 % Clay**	**Silt:Clay**	**CEC:Clay**	**Clay activity class**
Ninisu Series	Ah	0 – 6	6.64	8.40	1.60	0.50	Mixed Kaolinitic
	BA	6 – 20	3.32	4.00	0.36	0.09	
	Btcs1	20 – 60	3.50	4.60	0.18	0.07	“
	Btcs2	60 – 105	3.58	4.20	0.21	0.06	“
	Bt	105 – 150	3.93	5.40	0.35	0.07	“
Ankasa Series	Ah1	0 – 5	7.02	6.77	0.73	0.36	Mixed Kaolinitic
	Ah2	5 – 12	4.72	7.68	0.61	0.21	
	BA	12 – 36	5.01	6.11	0.46	0.18	“
	Btcs	136 – 72	5.43	9.43	0.30	0.12	“
	Btcs	272 – 110	5.72	9.55	0.36	0.10	“
	Bt	110 – 150	5.48	10.17	0.49	0.12	“
Boi Series	Ah	0 – 8	7.12	5.84	3.48	0.60	Mixed Kaolinitic
	BA	8 – 20	4.72	9.70	1.24	0.17	
	Btcs	20 – 75	4.40	5.19	0.56	0.09	“
	Btcs	175 – 130	4.36	7.30	0.68	0.08	“
	Btcs2	130 – 150	4.14	7.26	0.68	0.08	“
Bremang Series	Ah	0 – 6	3.36	4.57	1.10	0.13	Kaolinitic
	BA	6 – 20	5.74	11.03	0.82	0.18	“
	Bt1	20 – 60	6.00	13.00	0.59	0.15	“
	Bt2	60 – 110	5.82	12.19	0.57	0.14	“
	Btv1	110 – 135	5.35	11.89	0.46	0.13	“
	Btv2	135 – 150	5.29	12.34	0.80	0.14	“

Table 4: Some weathering intensity parameters and clay activity classes of profiles examined in the MSDF

Soil Name	Horizon	Depth (cm)	*Weathering intensity parameters* ECEC	Corrected ECEC x 100 % Clay	Silt:Clay	CEC:Clay	Clay activity class
Wacri	Ah	0 - 8	8.06	39.71	1.30	0.60	Mixed
	BA	68– 30	3.92	11.45	0.57	0.14	Kaolinitic
	Bt	30 – 57	3.75	8.87	0.42	0.11	“
	Btcs	57 – 97	3.42	7.14	0.42	0.09	“
	Btv	97 – 150	3.90	8.17	0.61	0.09	“
K'tumi	Ap	0 – 8	6.56	51.24	1.74	0.70	Mixed
	BA	8 – 28	3.67	17.06	0.79	0.20	Kaolinitic
	Bt1	8 – 65	3.30	13.16	0.74	0.15	“
	Bt2	65 – 104	2.80	9.20	0.68	0.11	“
	CB	104 – 150	4.24	0.24	0.49	0.15	“
Bekwai	Ah	0 – 9	12.37	-	5.25	1.50	Vermiculite
	BA	9 – 17	5.95	25.76	2.24	0.36	Mixed
	Btcs	17 – 30	5.05	11.32	1.01	0.15	Kaolinitic
	Btv1	30 – 61	4.99	7.98	0.50	0.10	“
	2Btv2	61 – 120	4.50	7.04	0.35	0.08	“
	2Btv3	120 – 150	4.31	8.23	0.32	0.09	“
Nzima	Ap	0 – 10	10.65	95.45	6.90	1.90	Vermiculite
	BA	10 – 20	4.37	17.39	2.10	0.26	Kaolinitic
	Btca1	20 – 40	4.41	10.49	0.97	0.14	“
	Btcs2	40 – 70	4.67	9.57	0.98	0.11	“
	Btv1	70 – 105	4.64	11.13	1.12	0.13	“
	Btv2	105 – 150	4.32	12.65	1.42	0.14	“
Kokofu	Ap	0 – 7	7.49	72.00	7.90	1.50	Vermiculite
	BA	7 – 19	3.15	6.60	2.13	0.20	Kaolinitic
	Bt	19 – 40	4.04	13.22	1.24	0.16	“
	Btcs	40 – 82	4.54	12.00	1.06	0.14	“
	Btv1	82 – 106	4.18	10.10	0.93	0.12	“
	Btv2	106 – 150	3.84	11.47	0.88	0.13	“

A. Soil Taxonomy

1. *Oxisols*

The subsurface horizons of *Ninisu*, *Ankasa*, *Boi*, *Bremang*, *Wacri* and *Kukurantumi series* qualify for oxic horizons as defined by soil Survey Staff (1998). They are classified as Oxisols. They key out as Udox under the suborder level sice they occur under udic moisture regime. At the great group level, Ninisu, Ankasa and Boi series qualify as Kandiudox. *Bremang series* qualifies as Hapludox. *Wacri* and *Kukurantumi* series key out as Eutrudox as base saturation by NH_4OAc is greater than 35% throughout the two profiles. At the subgroup level, *Ninisu*, *Ankasa* and *Boi series* are Plinthic Kandiudox, while *Bremang* series is Plinthic Hapludox on account of the occurrence of plinthite within 125 cm of the soil surface.

Wacri series is a Plinthic Eutrudox owing to the presence of plinthite within 125 cm of the soil surface. *Kukurantumi series* is a Typic Eutrudox.

2. *Ultisols*

Bekwai, *Nzima* and *Kokofu series* have argillic horizons with base saturation less than 35% within 125 cm of the soil surface. They therefore qualify as Ultisols. At the suborder level, they are Ustults as they occur under an ustic moisture regime. They key out as Plinthustults at the great group level in having plinthite within 150 cm of the mineral soil surface. They are all Typic Plinthustults at the subgroup level.

B. World Reference Base (WRB)

1. *Ferralsols*

Ninisu, Ankasa, Boi, Bremang (HRF profiles), *Wacri* and *Kukurantumi series* (MSDF profiles) key out as Ferralsols. They have pseudosand structure and are friable in the subsoil indicating ferralic horizon. All the HRF profiles were classified as Plinthic Ferralsols because they have plinthic horizons in the subsoil. With the MSDF profiles, *Wacri series* was classified as a Rhodi-Lixic Ferralsol. It had dark red colours with munsell hues of 5YR and 2.5YR, low ECEC and high base saturation. *Kukuran tumi series,* on the other hand, was a Xanthic Ferralsol with a munsell hue of 7.5YR throughout the profile and a colour value, moist, of 4 or more.

2. *Acrisols*

Bekwai, *Nzima* and *Kokofu series* are Acrisols. They have an argic horizon, CEC < 24 cmol(+)/kg clay and a base saturation <50% in some parts of the profile. They are Plinthic Acrisols as plinthite occurs in the subsoil. However, *Bekwai* and *Nzima series* are Ferri-Plinthic Acrisols by the occurrence of a ferric horizon characterized by iron concretions, thus distinguishing them from *Kokofu series* which is classified at this level as Gleyi-Plinthic Acrisol due to the presence of gleyic colour pattern in the subsoil.

C. Ghana Soil Classification System

In the system, the main determinants of soil formation in the forest zone are climate and vegetation. On the basis of these two factors, the soils studied in the HRF

Table 5: Classification of the soils into World Reference Base and Soil Taxonomy

Soil series	*WRB (1998)*	*Soil Taxonomy (1998)*	*Ghanaian System*
Soils in the HRF			
Ninisu	Plinthic Ferralsol	Plinthic Acrudox	Forest Oxysol
Ankasa	Plinthic Ferralsol	Plinthic Acrudox	Forest Oxysol
Boi	Plinthic Ferralsol	Plinthic Acrudox	Forest Oxysol
Bremang	Plinthic Ferralsol	Plinthic Acrudox	Forest Oxysol
Soils in the MSDF			
Wacri	Rhodi-Lixix Ferralsol	Typic Eutrudox	Forest Oxysol
Kukurantumi	Xanthic Ferralsol	Typic Eutrudox	Forest Oxysol
Bekwai	Ferri-Plinthic Acrisol (endoskeletic;	Typic Plinthustult	ForestOchrosolrhodic)
Nzima	Ferri-Plinthic Acrisol (endoskeletic)	Typic Plinthustult	Forest Ochrosol
Kokofu	Gleyi-Plinthic Acrisol	Typic Plinthustult	Forest Ochrosol

and MSDF keyed out as climatophytic earths. The criteria we used were low exchangeable bases, low CEC, low pH values and deep to very deep profiles. In this order, we differentiated two groups of soils as Forest Oxysols and Forest Ochrosols. The former group is dominant in the HRF and the latter in the MSDF. The system uses colour to distinguish between the two groups of soils at the Great Soil Group level.

1. *Forest Ochrosols*
   On the basis of the criteria stated above, *Bekwai*, *Nzima* and *Kokofu series* were classified as Forest Ochrosols (Table 5). The characteristics colours ranged from red, reddish brown on the summits and upper slopes (*Bekwai series*) through brown on the middle slopes (*Nzima series*) to yellowish brown on the lower slopes (*Kokofu series).*

2. *Forest Oxysols*
   Wacri and *Kukurantumi series* in the MSDF and all the profiles of the HRF were classified as Forest Oxysols (Table 5). These soils were distinguished from Forest Ochrosols by their very deep profiles, very low exchangeable bases and paler colours indicating higher rainfall regime. The differentiating colours used were orange brown to yellow rather than red or reddish brown for the Forest Ocsols.

CONCLUSIONS

The preliminary assessment of some key and easily measurable soil properties show that Oxisol (or Ferralsol) development is not limited to the HRF but also occurs in some parts of the MSDF, under udic moisture regimes.

Other conducive climatic variables like evapotranspiration being higher than rainfall in some parts of the year and rainfall exceeding the soil's water retention capacity at certain times in the year also promote Oxisol development in the two agro- ecological zones. The soils examined in the two zones are highly weathered, with the intensity being higher in the HRF than the MSDF. Soils in the HRF have lower silt:clay and CEC:clay values. The occurrence of Oxisols in the MSDF should, therefore, be taken into account in the management of soils, especially their pH levels (which give reflection of their basic cation levels) in the zone, where most of the upland soils are considered as Acrisols. Further detailed chemical, mineralogical and micromorphological studies are necessary to establish the pedogenetic changes and differences in soils studied in the two agro-ecological zones.

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