Soil Properties of a Toposequence in the Moist Semi-Deciduous Forest Zone of Ghana

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Abstract

In 1997 a semi-deciduous forest area at the University of Ghana Agricultural Research Station, Kade, was selected as a research area for ecological studies. The area is gently sloping forming a toposequence. Several activities have been initiated, e.g. six soil profiles have been described, sampled and analysed; suction cells have been installed for analysing soil solution chemistry; the water balance is determined from soil water data and climatological measurements; and for benchmark soil studies the clay mineralogy has been examined. This paper describes the basic physical and chemical status of the six soil profiles. The soil profiles were sited on the Bekwai, Nzima (upper slope), Kokofu, Kakum (middle slope), Temang and Oda (bottom slope) series. All soils are derived from Pre-Cambrian phyllite and are dominated by low activity kaolinitic clays. The toposequence shows longitudinal gradients in textures, iron content and drainage conditions and marked vertical gradient in carbon, nitrogen and phosphorus contents, soil reaction and base saturation with highest values in the topsoil due to the ion-pump effect of the natural vegetation. Upper slope soils are clayey and show distinct enrichment of clay in the subsoils. They are well drained, rich in iron oxides, strongly leached with low EC values, base saturation, and pH($CaCl_2$) (3.7-4.4) in the subsoil, but the ion-pump maintains relatively high pH($CaCl_2$) (5.4-5.9) and base saturation in the topsoil. Drainage becomes poorer towards the valley bottom, where soils generally show loamy textures and redoximorphic features, but only Oda shows high base saturation and pH($CaCl_2$) (5.8-5.9) throughout the profile.

Key words: Catena, soil series, pedology, forest, soil

Introduction

The semi-deciduous forest zone of Ghana contains some of the most productive soils of the country (Ahn, 1970; Adu, 1992). The zone, which covers some 48,000 km^2, has adequate rainfall for the cultivation of large scale plantation crops, such as cocoa [*Theobroma cacao*], oil palm (*Elaeis guineensis*) and lemon (*Citrus* spp.) as well as annual crops such as maize (*Zea mays*), cassava (*Manihot utilissima*) and plantain (*Musa sapietum*).

The soils of the forest zone are generally developed from rocks of the Birrimian system (middle Pre-Cambrian) (Adu, 1992), which consists mainly of argillaceous sediments metamorphosed into phyllite. The well-drained upland soils belong to the Forest Ochrosol Great Soil Group of the Ghanaian soil classification system (Bramner, 1962) and are generally accommodated as Acrisols in the FAO-Unesco Revised Legend (FAO, 1988) and as Ultisols in Soil Taxonomy (Soil Survey Staff, 1998).

Despite their agricultural importance and the general belief that their fertility is depleting and, hence, diminishing yields (MOFA, 1998), only cursory and rather old data are available on these soils (Brammer, 1962; Adu, 1992). Detailed physical, chemical and mineralogical data are needed to properly classify the soils and to develop improved management strategies for them.

The methodological approach for studying soils on a toposequence is well established, particularly in the tropics (Milne 1935; Moorman, 1981; Ogunkunle, 1993), although this has often resulted in stereotypic views of the tropical soil environment as, for example, the red soil-black soil toposequence.

The main aims of this work were to characterise the morphological, physical and chemical properties of the major soils on one of the most typical toposequences in the semi-deciduous forest zone of Ghana and to classify the soils according to Soil Taxonomy (Soil Survey Staff, 1998), FAO Soil Map of the World, Revised Legend (FAO, 1988) and the newly launched World Reference Base for Soil Resources (ISSS /ISRIC/FAO, 1998).

Materials and methods

The study site is at the University of Ghana Agricultural Research Station, Kade (6° 05' N; 0° 05'W) in the moist semi-deciduous forest zone (*Antiaris Chlorolophora association)* of Ghana, approximately 175 km NE of Accra, and 150 m above sea level (Fig. 1). The vegetational zoning in Ghana reflects the climate, particularly total rainfall and its distribution over the year.

The climate of the area is humid tropical. Average annual temperature is 28°C, with the maximum temperature in March and the minimum temperature in August. The monthly average temperature varies less than 5 °C during the year. The rainfall pattern is bimodal and the average annual rainfall during the period 1978-98 amounted to 1179 mm with about 80 per cent falling from March to mid-July and from September to November. Annual potential evapotranspiration is about 1400 mm. The soil moisture regime is udic and the soil temperature regime isohyperthermic (Van Wambeke,

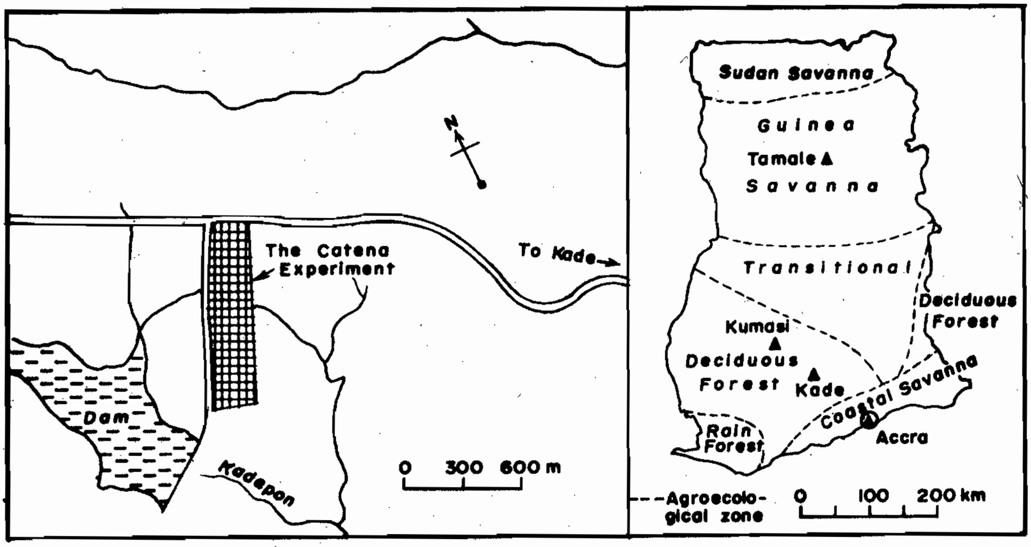

Fig 1. Location of study site (the catena experiment) at the University of Ghana Agricultural Research Station, Kade, Ghana

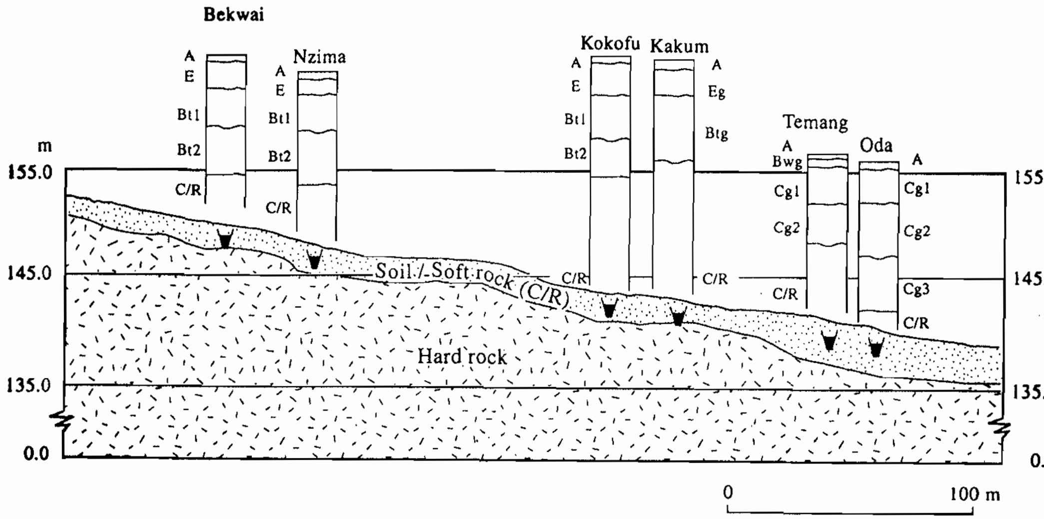

Fig 2. A toposequence of soils at the University of Ghana Agricultural Research Station, Kade. Ghana.

1982).

The study site is located in a gently rolling part of the Birim basin with soil parent materials being almost exclusively Pre-Cambrian (Lower Birrimian) rocks, predominantly phyllites, greywackes, schists and gneisses (Adu, 1992). A tributary of the Kadewa, a small seasonal stream drains the site. Drainage is generally good on the uplands but becomes poor down-slope towards the streambed.

Field work

Sites for six soil profiles were selected in a patch of relatively undisturbed forest on a gentle slope. The forest shows no well-marked structural or floristic zonation along the slope. The soil profiles comprise the Bekwai, Nzima, Kokofu, Kakum, Temang and Oda series, which belong to the Bekwai-Nzima/Oda compound association (Adu, 1992). These soils occur extensively in the zone, occupying more than 55 per cent of the area. The constituent soils of the association occur in a definite topographical sequence. The soil profiles were described (Table 1) according to the FAO guidelines (FAO, 1990), and bulk samples for laboratory analyses were taken from the major genetic horizons. The length and slope of the toposequence were determined using an Abney Level instrument with readings taken at 20 m intervals.

Laboratory analyses

The soil samples were air dried and passed through a 2-mm sieve. Particle size distribution (clay < 2 µm, silt 2-50 µm, sand 50-2000 µm) was determined by seive and Sedigraph 5100 (Micrometrics Instrument Corporation). Soil pH was determined potentiometrically in water (pH H_2O) and in 0.01 *M* $CaCl_2$ (pH $CaCl_2$) at a soil-solution ratio of 1:2.5. Electrical conductivity (EC) was determined in a 1:5 soil solution ratio. Exchangeable cations were extracted with 1 *M* NH_4OAc at pH 7. Calcium (Ca) and

Table 1. Field descriptions of the soils along the toposequence.

Soil series	Horizon	Depth (cm)	Colour (moist)	Texture	Structure	Consistence	Roots	Boundary	Notes
Bekwai									
	A	0-7	10 YR 3/4	Clay	Weak fine crumb	Friable	Common very fine roots	Clear smooth	Few fine angular quartz fragments
	E	7-34	7.5 YR 3/4	Clay	Moderate medium subangular blocky	Friable	Few very fine roots	Abrupt broken	Abundant fine angular soft concretions
	Bt1	34-71	2.5 YR 4/6	Clay	Moderate medium subangular blocky	Moderate medium subangular blocky	Very few very fine roots	Gradual smooth	Very few fine spherical hard ferrugenous concretions
	Bt2	71-119	2.5 YR 4/6	Clay	Moderate medium subangular blocky	Firm	Very few very fine roots	Gradual smooth	Very few fine spherical hard ferrugenous concretions
Nzima									
	A	0-8	10 YR 3/3	Clay	Weak fine crumb	Friable	Common very fine roots	Clear smooth	-
	E	8-23	10 YR 4/4	Clay	Moderate medium subangular blocky	Friable	Few very fine roots	Abrupt smooth	-
	Bt1	23-60	5 YR 5/6	Clay	Massive medium subangular blocky	Firm	Very few medium and few very fine roots	Abrupt wavy	Few coarse subrounded quartz fragments
	Bt2	60-113	2.5 YR5/6	Clay	Moderate to strong medium subangular blocky	Firm	Very few fine and very fine roots	Gradual smooth	Very few angular hard iron-manganese nodules
	C/R	113-135	2.5 YR 5/6	Clay	Moderate to strong medium subangular blocky	Very firm	Very few very fine roots	nd	-
Kokofu									
	A	0-7	10 YR 3/2	Clay loam	Weak fine crumb	Very firm	Few medium common very fine and very fine roots	Clear smooth	-
	E	7-39	10 YR 5/6	Clay loam	Moderate fine subangular blocky	Firm	Very few fine, common very fine few fine roots	Diffuse smooth	Few termite channels
	Bt1	39-82	2.5 Y 6/8	Clay loam	Strong coarse angular blocky	Firm	Very few fine few very fine roots	Diffuse smooth	Very few coarse angular quartz fragments
	Bt2	82-120	2.5 Y 5/4	Clay	Strong medium subangular blocky	Firm	Few fine and very fine roots	nd	-
Kakum									
	A	0-10	10 YR 2/2	Loam	Weak fine crumb	Very friable	Very few fine-medium and few medium – coarse roots	Clear smooth	-
	Eg	10-64	2.5 Y 6/3	Loam	Weak fine and medium angular and subangular	Friable	Very few fine medium and few fine roots	Gradual smooth	Few fine faint brownish mottles
	Bwg	64-105	2.5 Y 6/2	Sandy clay loam	Moderate fine and medium angular and subangular	Firm	Very few fine roots	nd	Many medium distinct red mottles
Temang									
	A	0-5	10 YR 2/1	Loam	Weak fine crumb	Friable non sticky(wet) and non plastic(wet)	Many fine roots	Clear smooth	-
	Bwg	5-13	10 YR 4/1	Loam	Weak fine and medium subangular blocky	Slightly sticky non plastic(wet)	Many fine-medium and few coarse roots	Gradual smooth	Common fine faint reddish brown mottles
	Cg1	13-50	2.5 Y 5/2	Clay loam	Moderate medium subangular blocky	Slightly sticky non plastic(wet)	Few fine and very few very fine roots	Abrupt smooth	Common coarse prominent brownish mottles
	Cg2	50-90	2.5Y 5/1	Clay	Moderate medium subangular blocky	Non sticky(wet) non plastic(wet)	Very few fine and very fine roots	nd	Common medium prominent brownish and abundant yellowish brown mottles
Oda									
	A	0-8	10 YR 2/1	Sandy clay loam	Weak fine crumb	Friable non sticky(wet) and non plastic(wet	Many fine medium and few very fine roots	Clear smooth	
	Cg1	8-42	2.5 Y 6/2	Sandy clay loam	Weak fine subangular blocky platy	Slightly sticky non plastic(wet)	Very few fine and very fine roots	Gradual smooth	Very few fine angular quartz fragments
	Cg2	42-69	2.5 Y 6/2	Clay loam	Weak fine and medium subangular blocky	Slightly sticky non plastic(wet)	Very few very fine roots	Abrupt and wavy	Common fine distinct yellowish brown mottles
	Cg3	69-96	5 Y 6/2	Clay	Strong medium subangular blocky	Very firm	Very few very fine roots	nd	Common medium distinct yellowish brown mottles

magnesium (Mg) were determined by atomic absorption spectrophotometry while potassium (K) and sodium (Na) were determined by flame photometry. Exchangeable acidity (H^+ and Al^{3+}) was extracted with 1 *M* KCl and determined by titration with NaOH before and after addition of NaF (Sims, 1996). The cation exchange capacity CEC at pH 7 was determined by the NH_4OAc method. The effective cation exchange capacity (ECEC) was determined as the sum of exchangeable cations and exchangeable acidity. Total carbon (C) was determined by measuring the carbon dioxide evolved by igniting the soil in an induction - operating like the LECO furnace (Tabatabei & Bremner, 1970). Total nitrogen (N) was determined by the Kjeldahl method. Total phosphorus (P) was determined spectrophotometrically by the molybdenum blue method using ascorbic acid as a reductant after heating the soil to 550 ^{0}C and extraction with 6*M* sulphuric acid. Free iron (Fe_d) and aluminium (Al_d) were determined by the dithionite-citrate-bicarbonate method of Mehra & Jackson (1960).

Results and discussions

General soil properties

The six profiles (Fig. 2) were developed *in situ* by intensive chemical weathering under humid and warm conditions. The upper slope soils (Bekwai and Nzima), middle slope (Kokofu and Kakum) and the bottom slope (Temang and Oda) vary from clay loams to sandy clay loams. The bottom slope soils are temporarily submerged during the rainy season and their sand content may be due to mixing with alluvial sediments. The soils are highly weathered and leached (EC<0.05 dS m^1) (Table 2), gradually merging into soft saprolite or hard rock at depths varying from 150 to 200 cm. Clay mineralogical analyses show that kaolinite is predominantly clay mineral in all the soils (Owusu-Bennoah, in prep). Substantial amounts of iron oxides (goethite and hematite) occur in soils on the upper slope Bekwai series in accordance with the profile descriptions (Table 1). Each profile shows a systematic increase in clay content with depth, presumably as a result of clay migration, while the sand content decreases with depth. Very little variation in the silt content is observed with depth in all the profiles. All topsoil structures are weak granular while subsoil structures are moderate to strong subangular blocky, which is typical for mature stable landscapes (Okusami *et al.*, 1997).

Topsoil colours are predominantly dark brown (10 YR 3/4 moist) to black (10 YR 2/1 moist) at all slope positions (Table 1). Subsoil colours range from uniformly red (2.5 YR 5/6 moist) in the well-drained upper slope soils to light brownish grey (2.5 Y 6/2 moist) with red mottling on the middle slope and to uniformly light brownish grey (2.5 Y 6/2 moist) in the valley bottom, where drainage is poor. Almost all the horizons on higher landscape positions show low colour values and high chromas whereas the opposite is observed for the soils at the valley bottom. The main variation in Fe_d values is along the toposequence, showing a decrease of values towards the poorly drained bottom gradients. The rather high content of Fe_d in the upper slope soils is in agreement with the occurrence of substantial amounts of goethite and hematite as shown by x-ray diffractions of Bekwai samples. In contrast, Al_d is low indicating low Al for Fe substitution in the iron oxides (Owusu-Bennoah *et al.*, 1997).

While drainage and colours show a clear gradient along the toposequence, most other soil variables are strongly influenced by forest vegetation bio-cycling and show well-

Table 2. Physical and chemical properties of the soils along the toposequence.

Soil series	Horizon	Depth cm	Particle size fractions µm ------% of < 2 mm ------ < 2	2-50	50-2000	C %	N %	C/N	Total P ppm	Fe_d ppm	Al_d ppm	pH H_2O	pH $CaCl_2$	EC 1:5 dS m^{-1}	Exchangeable cations ---- cmol(+) kg^{-1} ---- Ca^{2+}	Mg^{2+}	K^+	Na^+	H^+	Al^{3+}	CEC pH 7 -- cmol(+) kg^{-1} --	ECEC	BS %	Al sat %
Bekwai	A	0-7	48	26	26	3.69	0.32	12	499	3280	400	6.4	5.4	0.440	10.01	3.69	0.56	0.04	0.07	0.03	12.76	14.40	112	0
	E	7-34	51	23	26	0.81	0.10	8	295	5730	550	5.4	3.9	0.053	0.98	0.91	0.34	0.03	0.04	1.45	6.25	3.75	36	39
	Bt1	34-71	62	24	14	0.59	nd	-	245	8200	710	5.2	3.8	0.038	0.77	0.87	0.16	0.04	0.04	2.84	10.59	4.72	17	60
	Bt2	71-119	60	28	11	0.40	nd	-	200	7310	780	4.9	3.7	0.028	0.17	0.33	0.05	0.02	0.04	3.82	11.86	4.43	5	86
	C/R	150-160*	52	35	14	0.23	nd	-	224	7740	680	4.8	3.7	0.027	0.05	0.04	0.04	0.03	0.03	5.35	9.09	5.54	2	97
Nzima	A	0-8	44	25	31	4.14	0.39	11	399	2080	400	6.6	5.9	0.609	15.06	4.04	0.52	0.05	0.04	0.11	16.86	19.82	117	1
	E	8-23	42	24	34	1.00	0.13	7	279	2450	480	5.8	4.6	0.061	3.00	1.55	0.21	0.02	0.02	0.06	7.04	4.86	68	1
	Bt1	23-60	55	19	26	0.60	nd	-	210	3720	730	5.8	4.3	0.037	2.58	1.68	0.11	0.04	0.02	0.14	7.54	4.57	58	3
	Bt2	60-113	65	21	14	0.53	nd	-	176	7670	940	5.9	4.4	0.036	2.74	2.79	0.09	0.05	0.02	0.36	13.24	6.05	43	6
	C/R	113-135	64	24	12	0.47	nd	-	201	8300	880	5.8	4.3	0.033	2.31	2.76	0.08	0.05	0.03	0.39	13.31	5.62	39	7
	C/R	230-240*	25	57	17	0.07	nd	-	244	5880	410	5.0	3.7	0.051	0.29	0.43	0.05	0.04	0.03	4.28	5.47	5.12	15	84
Kokofu	A	0-7	32	40	28	2.54	0.28	9	239	830	190	5.7	4.8	0.296	5.78	1.47	0.44	0.05	0.05	0.03	7.47	7.82	104	0
	E	7-39	29	34	37	0.48	0.06	8	145	1170	300	5.6	4.1	0.038	1.21	0.50	0.06	0.03	0.04	0.69	3.94	2.53	46	27
	Bt1	39-82	37	31	32	0.32	nd	-	84	1500	400	5.9	4.2	0.035	2.25	0.90	0.03	0.05	0.04	0.47	5.01	3.74	64	13
	Bt2	82-120	44	26	30	0.35	nd	-	85	3070	450	6.1	4.4	0.030	2.68	1.34	0.04	0.05	0.02	0.23	6.48	4.36	63	5
	C/R	210-220*	50	23	27	0.26	nd	-	80	3300	550	5.8	4.2	0.036	1.88	2.10	0.09	0.06	0.03	0.75	8.43	4.91	49	15
Kakum	A	0-10	21	41	38	2.62	0.28	9	289	440	90	5.2	4.2	0.251	3.05	1.41	0.16	0.02	0.07	0.26	7.21	4.97	64	5
	Eg	10-64	17	41	42	0.34	0.04	9	86	470	150	5.1	3.7	0.021	0.33	0.22	0.03	0.01	0.04	1.05	1.81	1.68	33	63
	Btg	64-105	29	28	43	0.18	nd	-	45	1160	280	5.0	3.6	0.025	0.25	0.38	0.03	0.02	0.04	1.82	3.62	2.54	19	72
	C/R	150-160*	Nd	nd	nd	0.16	nd	-	nd	nd	nd	5.1	nd	0.053	0.30	1.08	0.05	0.03	0.10	2.53	1.48	4.09	98	62
Temang	A	0-5	22	37	42	2.75	0.28	10	289	260	50	5.9	4.8	0.230	5.82	1.85	0.23	0.07	0.07	0.01	6.79	8.05	117	0
	Bwg	5-13	18	34	48	0.83	0.10	8	215	240	80	5.7	4.3	0.078	1.75	0.95	0.05	0.08	0.03	0.03	2.89	2.89	98	1
	Cg1	13-50	29	24	47	0.28	nd	-	93	980	240	5.8	3.6	0.090	1.40	1.40	0.03	0.33	0.03	1.07	4.59	4.26	69	25
	Cg2	50-90	41	26	34	0.27	nd	-	81	790	270	5.6	3.8	0.164	1.03	3.22	0.04	0.95	0.03	2.94	8.33	8.21	63	47
Oda	A	0-8	29	23	48	2.62	0.24	11	175	nd	nd	7.0	5.9	0.369	11.98	4.03	0.15	0.03	0.05	0.02	10.49	16.26	154	0
	Cg1	8-42	25	29	46	0.20	0.03	6	87	nd	nd	7.4	5.9	0.061	3.19	2.72	0.04	0.04	0.02	0.00	5.60	6.01	107	0
	Cg2	42-79	31	27	43	0.06	nd	-	51	nd	nd	7.5	5.9	0.056	3.61	5.99	0.06	0.13	0.01	0.01	9.92	9.81	99	0
	Cg3	79-96	41	25	35	0.04	nd	-	50	nd	nd	7.6	5.8	0.042	4.46	9.09	0.06	0.30	0.02	0.00	13.65	13.93	102	0
	C/R	150-160*	42	28	30	0.05	nd	-	64	nd	nd	7.5	5.8	0.083	6.01	10.07	0.08	0.56	0.01	0.01	16.53	16.74	101	0
	C/R	210-220*	43	51	27	0.09	nd	-	598	nd	nd	7.6	5.8	0.063	10.35	9.68	0.04	0.42	0.04	0.07	8.41	20.60	244	0

* auger samples, approximate depth; nd = not determined

marked vertical gradients. Generally, the topsoil of all the profiles show high organic-C, P and N contents as compared with the horizons below (Table 2). This contrast is particularly expressed in the well-drained upper slope soils where, for example, topsoil C contents are about 4 per cent and decrease to about 0.5 per cent in the subsoil. A major role of soil organic matter is it serves as a store and slow release source of nitrogen (N), phosphorus (P), and sulphur (S) and potassium (K). The C:N ratio of the surface soils is on the average 10:1, which is within the range of 10-12 suggested by Nye & Stephens (1958) for tropical forest soils, and shows that mineralisation of organic residues is advanced.

Except for the low-lying Oda soil, all the soils show strongly acidic subsoil pH ($CaCl_2$) values, which range from 3.6 to 4.4. The relatively high pH 5.9 observed in the surface of the Oda soil may be due to accumulation of bases leached from the soil located at the upper slope and also to release of OH^- from iron reduction processes (Hoyt & Turner, 1975; Hue, 1992). Due to the bio-cycling of base cations, surface soil pH (both methods) is markedly higher than that in the subsoil of all the soils except Oda. With the exception of the Oda series, variation in pH values along the slope is not marked. Exchangeable acidity (H^+ and Al^{3+}) follows the same pattern as pH; Al^{3+} is very low in the topsoil of all the profiles but tends to increase with depth. This trend is particularly marked in the profiles located at the upper slope. Exchangeable acidity of the Oda series at the bottom slope is almost zero. A similar pattern is observed for aluminium saturation or percent base saturation (BS), of the soils.

As shown in Table 2, base saturation of the surface horizons is more than 100 per cent. This may be attributed to the high and sustained bio-cycling power of the forest vegetation, resulting in an excess of exchangeable base cations over the CEC at the beginning of the rainy season, when litter, accumulated during the dry season, decomposes and large amounts of base cations are released. Later in the rainy season base saturation is expected to be lower due to plant uptake of exchangeable bases and some leaching. It is possible that base saturation of surface horizons could drastically decline under continuous cultivation of short rooted crops that are not efficient in intercepting leached nutrients and also not capable of recycling nutrients from lower horizons. The exceptionally high base saturation in the bottom horizons of the Oda series could be attributed to the presence of a soft rock, which solubilizes to release base cations when treated with NH_4OAc.

The effective cation exchange capacity (ECEC) of the topsoils ranges between 4.96 and 19.80 cmol (+) kg^{-1} with an average of 11.86 cmol (+) kg^{-1}. The values decrease sharply in the horizons below the topsoil in all the soil profiles and decline down the slope from the upper (Nzima series) to the middle slope (Kakum series). The ECEC values increase with depth in the soils of the bottom slope as shown by both Temang and Oda series. The main contributor to the increasing ECEC is the content of exchangeable Mg in the C-horizons of these profiles. Calcium and Mg constitute the dominant base cations in the soils. Except for Bekwai series all the soils contain small to very small amounts of exchangeable K, especially in the subsoils. Apart from the Oda series, the amounts of Ca, Mg and K decrease with depth. From a depth of about 60 cm and below, all the soils tend to contain more Mg than Ca.

The amounts of Na are almost constant

with depth, except for Temang and Oda series in which exchangeable Na increases in the bottom horizons. These distributions show that Ca, Mg, and K are nutrients, which are taken up by tree roots and re-circulated to the surface via plant residues and subsequently released when organic matter is mineralized. The calcium/magnesium ratios are > 1 in the upper 60 cm of the soils, whereas these ratios are < 1 below this depth, suggesting that the parent material is rich in Mg. Even though rainfall is heavy and leaching is intense in the study area, it appears that the forest vegetation is a major buffer in nutrient cycling. The vegetation builds up a store of nutrients (N, P, Ca, Mg, K and probably other nutrients) in the organic materials that accumulate on top of the soils and bases are recycled after decomposition. Thus, it is likely that cultivation of the soils, which will lead to removal of topsoil litter, may reduce the nutrient cycling capabilities of the soils.

Soil management considerations

Soil management practices to be considered for the study area should provide for minimum physical and chemical degra-dational processes. The traditional slash and burn agriculture practised in the area would accelerate the decline of organic matter in the topsoil and expose the soils to heavy rainfall, which may lead to soil degradation. Although Al vulnerability shows high variability between different crops, almost all of the soils may not need liming to be productive. Liming is, however, necessary in Bekwai and Kakum series, which show more than 40 per cent Al saturation in their subsoil horizons.

Juo (1977) concluded from a study of some Ultisols from agro-ecological zones similar to the ones in this study that relatively low levels of exchangeable Al would suggest that nutrient deficiencies are probably more critical limiting factors than Al toxicity for crop growth. Total P is high in all the A horizons and in the soils at the upper slope (Bekwai and Nzima), but its availability for plants is unknown. Medium to high P availability was, however, found in the A horizons of other strongly leached Ghanaian soils with total P contents comparable to those in the Kade soils (Owusu-Bennoah *et al.* 1997). Nevertheless, Duah-Yentumi *et al* (1997) concluded that microbial growth was limited mainly by P in a cocoa stand at Kade.

Soil classification

Table 3 shows how the locally established soil series names correlate with the international soil classification systems Soil Taxonomy (Soil Survey Staff, 1998), FAO Soil Map of the World, Revised Legend (FAO, 1988) and World Reference Base for Soil Resources (WRB)(ISSS/ISRIC/FAO, 1998). According to Soil Taxonomy, Bekwai series is allocated as a Typic Paleudult as a result of the < 35 % BS argillic horizon in which the clay content does not decrease relative to the maximum with more than 20 per cent. The argillic horizon of the Nzima series shows BS > 35 % and the lack of decreasing clay content of the argillic horizon, which shows an apparent CEC of < 24 cmol (+) kg^{-1} clay, allocates it as Kandic Paleudalf. Both Kokofu and Kakum series show kandic horizons. However, the BS criteria (35 %) of Soil Taxonomy separate them as Udic Kandiudalf and Aquic Kandiudults, respectively. The valley bottom soils (Temang and Oda) show no distinct soil development and the redoximorphic features place them both as Aeric Endoaquents.

According to FAO the Bekwai, Nzima and Kokofu series show argic horizons with CEC

TABLE 3.
Classification of soils on a toposequence at Kade, Ghana

Slope position	*Ghanaian soil series*	*Soil taxonomy (1998)*	*FAO revised legend (1988)*	*World Reference Base for Soil Resources (1998)*
Upper slope	Bekwai	Typic Paleudult	Ferric Acrisol	Alumic Acrisol
Upper slope	Nzima	Kandic Paleudalf	Haplic Acrisol	Chromic Acrisol
Middle slope	Kokofu	Udic Kandiudalf	Haplic Lixisol	Haplic Lixisol
Middle slope	Kakum	Aquic Kandiudult	Gleyic Acrisol	Gleyic Acrisol
Bottom slope	Temang	Aeric Endoaquent	Eutric Gleysol	Eutric Gleysol
Bottom slope	Oda	Aeric Endoaquent	Eutric Gleysol	Eutric Gleysol

values < 24 cmol (+) kg^{-1}clay at pH 7. Bekwai series shows ferric properties and keys out as Ferric Acrisol. Nzima series keys out as Haplic Acrisol, while 50 per cent of Kokofu places it as a Haplic Lixisol. Kakum series shows gleyic properties within 50 cm and the presence of an argic horizon accommodates it as a Gleyic Acrisol.Temang and Oda series both show gleyic properties within 50 cm and high base saturation and key out as Eutric Gleysols.

In the newly launched WRB system, Bekwai series keys out as Alumic Acrisol due to Al saturation in excess of 50 %. Nzima series keys out as Chromic Acrisol, whereas Kokofu series keys out as Haplic Lixisol. The Kakum series is a Gleyic Acrisol, while the Temang and Oda series are Eutric Gleysol.

During the field work the depth to the saprolite was examined by augering at various places on the toposequence. This revealed that the depth varies from 140 to 175 cm, which might affect the classification of the soils, particularly in Soil Taxonomy. Therefore, to validate and extrapolate the classification of the soil series in the study area the Ghanaian soil database should be consulted in order to analyse variability ranges of these series.

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