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Acid soil profiles of the semiarid and subhumid tropics in Central and West Africa

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Key words: aluminium saturation, semiarid tropics, subhumid tropics

Abstract

Soils of the semiarid and subhumid tropics of Central and West Africa are frequently strongly acid. In an investigation using soils from Cameroon in Central Africa and Mali and Niger in West Africa, selected pedons were described and classified using the U.S. soil classification system. Selected chemical and physical methods were used to analyse samples from the various profiles. Greenhouse and pot experiments were conducted to evaluate crop response to fertilizer P. The Mbomi 2 pedon from Cameroon was described and classified as clayey, kaolinitic, isohyperthermic Aeric Kandiaquult while the Cinzana Pedon from Mali and Dayobu Pedon from Niger were classified as mixed, isohyperthermic Grossarenic Paleustalf and coated, isohyperthermic Ustoxic Quartzipsamment, respectively. The pH of the profiles was strongly acid for Mbomi 2 to acid for Cinzana and Dayobu sites. All three sites have low effective cation exchange capacity. The Mbomi 2 and Dayobu sites are predominantly Al saturated and the Cinzana site is predominantly Ca saturated.

Pot and greenhouse experiments indicate that plant available P is one of the most limiting plant nutrients. Application of fertilizer P doubled rice dry matter yield for the Mbomi 2 soil, increased sorghum dry matter yield by 243 percent over the local check for the Cinzana soil, and increased millet dry matter yield by 100 percent for the Dayobu soil. Application of N, P, K and lime increased sorghum dry matter yield by 338 percent for the Cinzana site and millet dry matter yield by over 800 percent over the local check at the Dayobu site.

Introduction

Soil resources found in the semiarid region of North America are alkaline and dominated by unweathered mineralogy. Soils of the semiarid and subhumid regions of Africa are commonly acid, weathered and characterized by a dominance of sesquioxides and kaolinite. An understanding of the profile characteristics and chemistry of these soils is important in their management and productivity.

The major factors of soil formation vary across semiarid and subhumid regions of Africa. However, the similarities between many soils are their acid nature and low fertility status. A closer look at the acid and fertility status reveal differences in physical, chemical, and mineralogical properties. Kaolinitic ultisols are strongly acidic and contain low levels of available plant nutrients (Juo, 1981) such as is the case for Cameroon. Siliceous alfisols, entisols, inceptisols and ultisols are the dominant acidic soil types in Mali and Niger. (Daniels and Wilding, 1983; West *et al.*, 1984; Wilding and Hossner, 1989).

The purpose of this paper is to present selected chemical and physical data for profiles of three soils, and to demonstrate the potential these soils possess in terms of agricultural production of selected crops adapted to the ecological conditions of each site. The discussion will be based on pedons sampled from the Mbomi 2 soil in Cameroon (Central Africa), the Cinzana soil

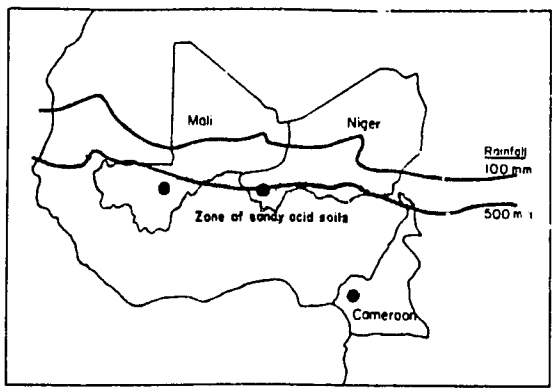

Fig. 1. Map of West and parts of Central Africa showing locations of described pedons.

in Mali and The Dayobu soil in Niger (West Africa).

The Mbomi 2 pedon (Fig. 1) was sampled at an elevation of 720 m and is part of the Mbo plain which has a subhumid tropical climate with an annual precipitation of over 1600 mm. Maximum temperatures range from 28 to 30°C and minimum temperatures from 15 to 18°C. The vegetation is partially savannah on previously cultivated areas. Uncultivated areas are dominated by shrubs and underbrushes. Descriptions made by Gigou (1973) state that the plain was developed from old lacustrine alluvium. The lake formation on this site was probably due to a depression of tectonic origin from basaltic lava flow from the surrounding Manengouba mountains. The thickness and stratigraphy of these alluvial deposits are still unknown. These deposits are either sandy clay or clays. The north and east bound slopes are plinthite-like rocks (granitic gneiss). The southwestern slopes are of basaltic material from the Manengouba mountains. The hilly parts of the eastern portions of the plain are covered with alluvial and colluvial material which seem different from other surrounding materials. Field observations of the Mbomi 2 site, which principally is used for rice cultivation and fish farming reveal concretions of iron and manganese throughout the profile.

Cinzana (Mali) and Dayobu (Niger) pedon locations are situated in the semiarid tropics bioclimatic zone (Fig. 1). Rainfall is irregular and normally comes in the form of convective storms (West *et al.*, 1984). About one-half of the rain falls in July-August, and periodic drought is common. The mean annual rainfall is about 650 mm at the Cinzana site and about 500 mm at the Dayobu site. The mean annual temperatures at the Cinzana site range from 28 to 33°C with minimum and maximum temperatures of 8 and 40°C respectively. At the Dayobu site, the mean winter temperature is 25°C and the mean spring temperature is 33°C.

The stratigraphy and geomorphology of acidic semiarid tropical soils in Niger was reviewed by Wilding and Hossner (1989). They reported that surface deposits are a consequence of sand materials that cover ironstone caps, which in turn cover loamy miocene deposits called Continental Terminal. The sandy cover-materials are between 2 and 8 cm or more in thickness, and range from a few thousand to about 40,000 years in age. The ironstone cap can be between 20 and 100 cm or more thick, either as a continuous unit, as sequioxide blocks, or as cemented ironstone gravels. It formed during the late pliocene or early quartenary periods (about 2 million years ago). The Continental Terminal sediments are about 25 million years old, deeply weathered and exposed only in road cuts.

Materials and methods

Soil profile sites are indicated on Fig. 1, namely Mbomi 2 (Cameroon), Cinzana (Mali), and Dayobu (Niger). Pits were dug at these sites and profiles described and classified based on the U.S. soil taxonomy system (Survey Staff, 1975; 1987).

Samples from each horizon were analyzed in the soil characterization laboratory at Texas A and M University at College Station. Particle size distribution was determined by the hydrometer method of Gee and Bauder (1986). Soil pH was determined in water for all samples (1:1 soil water ratio) and 0.1 *M* KCl (1:1 soil solution ratio) for Mbomi 2 and Dayobu sites using a glass electrode and a pH meter. Exchangeable acidity and Al were extracted with 1 *M* KCl (Thomas, 1982). Exchangeable cations were extracted with *M* NH_4OAc (pH 7.0) and measured by atomic absorption (Knudsen *et al.*, 1982; Thomas, 1982). The effective cation exchange capacity (ECEC) was estimated by summing the

exchangeable acidity and exchangeable bases. Extractable Fe was determined by the citrate dithionite bicarbonate (CDB) method as outlined by Olson and Ellis (1982). Organic carbon content was estimated according to the Walkley-Black procedure as outlined by Nelson and Sommers (1982). Determination of crop response to fertilizers and amendments was in greenhouse and in field pot experiments.

Results

Classification

The Mbomi 2 profile from Cameroon was classified as a clayey, kaolinitic isohyperthermic Aeric Kandiaquult. The Cinzana profile was classified as a sandy, mixed, isohyperthermic Grossarenic Paleustalf and the Dayobu soil was classified as a coated, isohyperthermic, ustoxic Quartzipsamment.

Textural relationships

The Ap horizon of the Mbomi 2 soil is predominantly silt. The silt and sand percentages generally decreased with depth (Table 1a). The percent clay increases with depth from the Ap horizon to a depth of 200 cm (Fig. 2a).

The Cinzana profile is predominantly sand (82–85%) throughout. Clay percentage is relatively low in the surface horizons but increases with depth of profile (Fig. 2b).

The Dayobu soil is extremely high in sand ranging from 91.7 to 94.6 percent. The distribution of sand increased with depth of profile (Table 1c). The clay percentage is low (less than 5.1%) and decreases with increasing depth (Fig. 2c).

Mineralogy

Mineralogically, Mbomi 2 soils could be considered residual systems dominated by kaolinite and

Table 1a. Particle size distribution and organic carbon content of Mbomi 2 soil of Cameroon (Aeric Kandiaquult; clayey, kaolinitic, isohyperthemic)

Depth (cm)	Horizon	Particle size distribution (%)			Organic C	Silt/Clay ratio
		Sand	Silt	Clay		
0–15	Ap1	26.7	37.4	35.9	1.55	1.0
15–26	Ap2	27.3	37.4	35.3	1.32	1.1
26–41	BA	15.5	25.5	59.0	0.84	0.4
41–60	Bt	34.3	17.7	48.0	0.61	0.4
60–79	Btg1	27.3	17.5	55.2	0.49	0.3
79–100	Btg2	30.3	14.6	55.1	0.37	0.3
100–130	Btg3	21.6	12.4	66.0	0.29	0.2
130–165	Btg4	14.6	12.7	72.7	0.25	0.2
165–200	Btg5	12.7	14.5	72.8	0.21	0.2

Table 1b. Particle size distribution and organic carbon content of Cinzana soil (Mali) [Arenic Paleustalf; sandy, mixed, hyperthermic]

Depth (cm)	Horizon	Particle size distribution (%)			Organic C	Silt/Clay ratio
		Sand	Silt	Clay		
0–14	Ap1	82.4	13.7	3.9	0.1	3.5
14–43	Ap2	85.0	10.9	4.1	0.2	2.7
43–57	Bt1	85.2	9.9	4.9	0.2	2.0
57–73	Bt2	85.0	9.3	5.7	0.2	1.6
73–85	Bt3	84.5	9.5	6.0	0.1	1.6
85–102	Bv1	84.9	8.1	7.0	0.1	1.2
102–125	Bv2	85.0	7.1	7.9	0.1	0.9
125–160	Bv3	83.4	5.1	11.5	0.1	0.4

Table 1c. Particle size distribution and organic carbon content of Dayobu soil of Niger (Ustoxic Quartzipsamment: isohyperthermic). (Source: Wilding and Hossner, 1987)

Depth (cm)	Horizon	Particle size distribution (%)			Organic C	Silt/Clay ratio
		Sand	Silt	Clay		
0–15	A1	92.5	3.0	4.5	0.25	0.7
15–27	A2	91.7	3.2	5.1	0.15	0.6
27–44	Bt1	92.1	3.2	4.7	0.11	0.7
44–62	Bt2	92.7	3.0	4.3	0.08	0.7
62–80	Bt3	93.0	2.5	4.5	0.08	0.6
80–103	BW	92.5	3.2	4.3	0.07	0.7
103–126	Bw	93.4	2.5	4.1	0.09	0.6
126–150	BC	94.5	1.9	3.6	0.06	0.5
150–173	BC	95.0	2.0	3.0	0.05	0.7
173–200	C	94.6	2.9	2.5	0.04	1.2

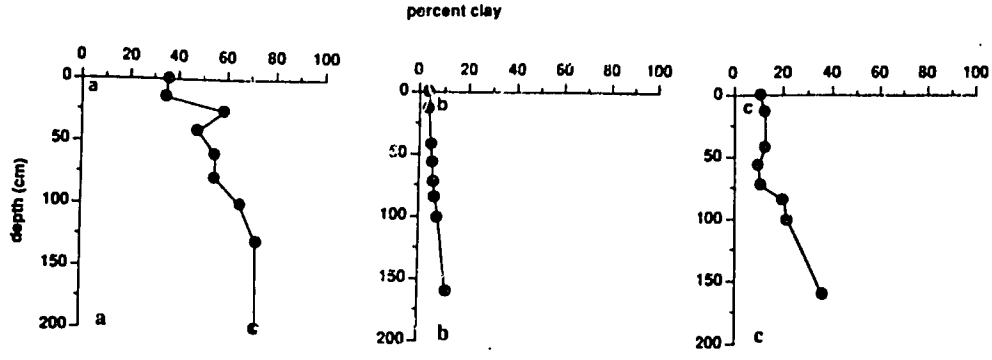

Fig. 2. Percent clay profiles of Mbomi 2(a), Cinzana (b), and Dayobu (c).

quartz. Visual observations and laboratory analysis indicate that the soils also contain significant amounts of Fe-oxides. The Cinzana and Dayobu soils are considered residual systems dominated by quartz (hence high sand percentages) with kaolinitic mineralogy. These two profiles contained lower concentrations of iron oxides (Table 2c).

Chemical properties

Chemically, these soils have some common properties. The soils are acidic and have low organic carbon content and cation exchange capacity (CEC).

Mbomi 2 soils are acid to strongly acid with pH (water 1:1) ranging from a low of 4.5 to a high of 4.9 (Fig. 3a). The base saturation is low and is generally less than 23% in the upper 200 cm (Table 2a). Extractable Al (1 *M* KCl) is relatively high (2.9–7.5 cmol/kg) and Al saturation is greater than 54% (Table 2a). Besides the high Al saturation, the Mbomi 2 soil is also high in free iron oxides (Table 2a). The difference between ECEC and CEC is relatively high in the Mbomi 2 soil and in the upper part of the Dayobu profile. This indicates substantial pH dependent charge (Tables 2a and Table 2c).

Chemically, the Cinzana soil is different from the Mbomi 2 soil. The pH is acid to slightly acid and soil pH decreases with depth of profile though not sequentially (Fig. 3b). The Al saturation percentage is moderately low compared to the Mbomi 2 and Dayobu soils (Fig. 4b).

The Dayobu soil pH values were lower than those of the Cinzana soil but similar to those of the Mbomi 2 soil (Table 2c). The pH of the surface horizon ranged from 4.9 to 5.1. A difference of 0.5 to 1.1 pH units exists between pH in water and pH in KCl (Table 2c). Aluminium saturation percentage increased with depth while soil pH decreased with depth. Percent Al saturation ranged from 57 to 86 and was inversely related to percent base saturation.

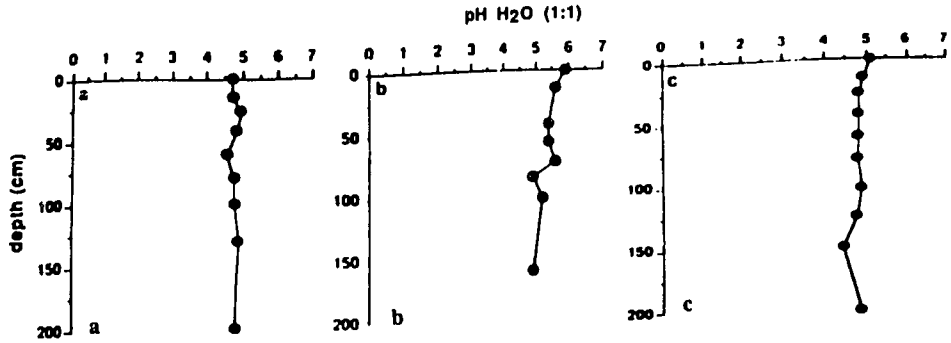

Fig. 3. pH profiles of Mbomi 2(a), Cinzana (b), Dayobu (c).

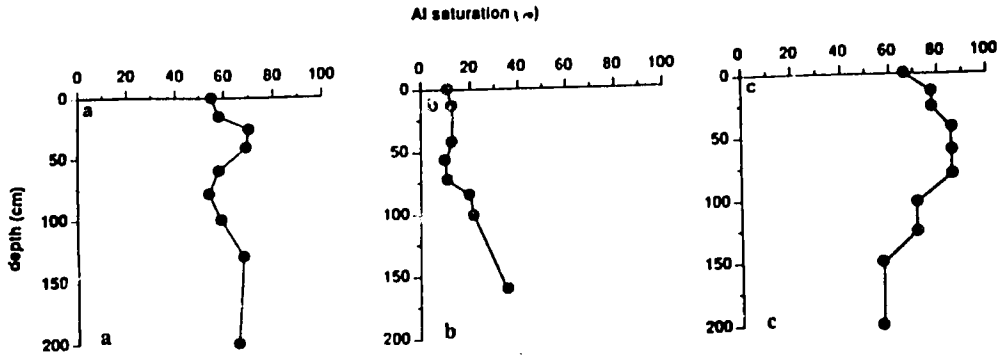

Fig. 4. Percent Al saturation of Mbomi 2(a), Cinzana (b), and Dayobu (c) soils.

Percent calcium saturation decreased with increasing depth of profile for the Mbomi 2 soil (Table 3). In the Cinzana soil, there was a high percent calcium saturation in the Ap horizon, a relatively high pH and low Al saturation percentage. The Dayobu soil had a low Ca saturation percentage.

Response to applied nutrients

Although these soils can be strongly acidic, they have potential for agricultural production if properly managed. In a pot experiment using Mbomi 2 soil, application of 50 kg of P per hectare gave a 200 percent increase in rice dry matter yield over the control treatment.

Phosphorus application alone to the Cinzana soil yielded a 243 percent dry matter increase over the no-P treatment when sown to sorghum. There was a 100 percent increase in dry matter yield of millet over the control treatment when P was applied alone to the Dayobu soil. When N was applied alone, dry matter yield of sorghum in the Cinzana soil decreased by 86 percent while millet dry matter yield in the Dayobu soil was reduced by 42 percent. A combination of N and P in the Cinzana soil tripled dry matter yield of sorghum while application of N, P, K and a lime amendment increased dry matter yield by 338 percent over the control treatment. Dry matter yield of millet in the Dayobu soil increased 800 percent over the control treatment following the application of lime in combination with N, P and K.

Table 3. Percentage calcium saturation of soil horizons of Mbomi2, Cinzana, and Dayobu soils

Mbomi2(Cameroon)		Cinzana(Mali)		Dayobu(Niger)	
Horizon	Ca(%)	Horizon	Ca(%)	Horizon	Ca(%)
Ap	29	Ap	65	A	17
BA	20	Bt	67	Bt	8
Bt	20	Bv	50	Bw	14
Btg–	21			BC	14
–	–			C	17

Discussion

Lal (1981) reported that texture of most soils of the subhumid and semiarid tropics is predominantly sand. This is the case for the Cinzana and Dayobu soils (Tables 1b and 1c). However, the Mbomi 2 soil in Cameroon is more clayey than sandy (Table 2a). The coarse nature of the Cinzana and Dayobu soils may be attributed to the influence of the parent materials being derived from sandy sediments while the fine textured subhumid soil (Mbomi 2) was derived mainly from granites and gneisses.

Soils with kaolinitic clay mineralogy occur more frequently in the tropics than elsewhere (Uehara and Gillman, 1981). The clay mineralogy of the three soils in this study was predominantly kaolinitic. The greater abundance of kaolinite clay in the Mbomi 2 soil is attributed to the soil parent material. Lal (1981) further reported that the relative magnitude of the silt/clay ratio at different depths has a special significance in terms of the degree of weathering. In general, the silt/clay ratio for most soils will decline exponentially with the depth of profile. A pattern of decreasing silt/clay ratio was found for the Mbomi 2 and Cinzana soils. There is an alternate decrease and increase in the silt clay ratio, though not exponentially, for the Dayobu soil.

The low pH for the Mbomi 2 soil can be associated with low base saturation and high Al saturation percentage. The Cinzana soil has a Ca saturation percentage greater than 50 percent in all three horizons (Ap, Bt and Bv) (Table 3). The Dayobu soil, has a moderately acid pH and a relatively high percentage Al saturation with depth. This could be attributed to an acid parent material combined with contemporaneous weathering.

The ECEC for Mbomi 2 and Dayobu soils is relatively low and predominantly Al saturated. The ECEC of the Cinzana soil is predominantly Ca saturated indicating a lower degree of weathering.

Acidity in all three soil profiles is attributed to the indigenous acidity of the parent material (ex. Cinzana and Dayobu), development in soils weathered in wetter paleoclimates (Mbomi 2) and leaching of bases from shallow soils systems in contemporaneous climates (Wilding and Hossner, 1989). It is probable that soil acidity in these profiles reflects multiple processes.

Table 4. Effect of fertilizer on relative dry matter production of rice, sorghum and millet

Fertilizer treatment	Rice Mbomi2 relative yield(%)[b]	Sorghum Cinzana	Millet Dayobu
N	–	–86	–42
P	204	243	100
NP	–	300	–
Lime + NPK		338	808

[b] Control treatment was assigned a value of 0 relative yield.

Although, these soils are acid, their production potential for adapted crops is high if properly managed. Many authors have examined these soils for P sufficiency as it influences crop growth and yield (Enwezor and Moore, 1966; Goldsworthy, 1967; Nye and Greenland, 1960; Pichot and Roche, 1986; Pieri, 1989; Poulain, 1976). They found that P is the most limiting nutrient in these soils. Jones and Wild (1975) documented that P deficiency could be so acute that plant growth stopped once the seed reserve of P had been depleted. Davis-Carter (1989) found that Al and P were the soil chemical variables most related to uneven stand establishment and crop growth in acid, sandy Nigerian soils. The same situation apparently applies to Mbomi 2 and Dayobu soils (Table 4). For the Cinzana soil, Al saturation percentage is not high enough to be considered critical for plant growth. Optimum crop growth and yield is largely controlled by lack of an adequate level of available P. Application of N and P is necessary in the semiarid tropics to make use of available rainfall more efficiently.

Because of the acid nature and apparent low buffering capacity of these soils, care must be taken in the application of acid forming fertilizers. Application of acid forming fertilizers will render soils more acidic and less productive. In these situations lime amendments have proven beneficial.

Conclusions

Soils of the semiarid and subhumid tropics of Central and West Africa are frequently strongly

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acid. The three pedons viz. Mbomi (Cameroon), Cinzana (Mali) and Dayobu (Niger) are acid throughout the profiles.

The major cause of acidity is apparently an acid parent material coupled with paleoclimate and contemporaneous leaching. Aluminium saturation of the Mbomi 2 and Dayobu soils is greater than 54 percent for the entire profile and may result in Al toxicity to many plants.

Phosphorus is one of the most limiting nutrients in these soils hence application of optimum levels of this nutrient results in substantial increases in dry matter yield of major cereals (rice, sorghum, millet). Because of the fragile nature of these soils, care must be exercised in the application of acid forming fertilizers. Lime amendments have proven beneficial in reducing the soil acidity.

References

Daniels R B and Wilding L P 1983 Report of soil/geomorphological relationships in areas surrounding ICRISAT Sahelian Center. Texas A & M University, College Station, TX.

Davis-Carter J G 1989 Influence of spatial variability of soil physical and chemical properties on the rooting patterns of pearl millet and sorghum. Ph.D. dissertation. Soil and Crop Sciences Dept., Texas A & M University, College Station. TX.

Enwezor W O and Moore A W 1966 Phosphorus status of some Nigerian soils. Soil Sci., 102:322–328.

Gee G W and Bauder J W 1986 Particle size analysis. Eds. A L Page *et al.* *In* Methods of Soil Analysis. Part 1. 2nd ed. Agronomy 9, 383–411.

Gigou J 1973 Morphopedological studies of the Mbo plain (Cameroon). Institute of Tropical Agriculture and Food Crops Research. Ministry of Agriculture. Annual report.

Goldsworthy P R 1967 Responses of cereals of fertilizers in Northern Nigeria. Expl. Agric. 3(1): 29–40.

Jones M and Wild A 1975 Soils of the West African Savanna: The maintenance and improvement of their fertility. Technical Communication No. 55 of the Commonwealth Agricultural Bureaux, Franham Royal, UK.

Juo A S R 1981 Chemical characteristics. *In* Characterization of Soils in Relation to Their Classification and Management for Crop Production: Examples from Some Areas of the Humid Tropics Ed. D J Greenland. Clarendon Press, Oxford.

Knudsen D, Peterson G A and Pratt P F 1982 Lithium, sodium, and potassium. *In* Methods of Soil Analysis. Part 2. 2nd ed. Eds. A L Page *et al.* Agronomy 9, 225–245.

Lal R 1981 Physical properties. *In* Characterization of Soils in Relation to Their Classification and Management for Crop Production: Examples from Some Areas of the Humid Tropics. Ed D J Greenland. pp 135–148.

Nelson D W and Sommers L E 1982 Total carbon, organic carbon, and organic matter. *In* Methods of Soil Analysis. Part 2. 2nd ed. Eds. A L Page *et al.* Agronomy 9, 539–579.

Nye P H and Greenland D J 1960 The Soils under Shifting Cultivation. Commonwealth Bureaux Soils Techn Comm 51, Harpenden, UK.

Olson R V and Ellis R Jr 1982 Iron. *In* Methods of Soils Analysis. Part 2. 2nd ed. Eds. A L Page *et al.* Agronomy 9, 301–312.

Pieri C 1986 Fertilization of crops and fertility of soils in subsahara subsistent agriculture. Agron. Trop. (France) 29, 1–20.

Pieri C 1989 Fertility of Savannah Soils: Thirty Years of Research and Agricultural Development in South of the Sahara. Ministry of Cooperation and CIRAD-IRAT, France.

Pichot J and Roche P 1972 Phosphorus in tropical soils. Agron Trop. (France) 27, 939–965.

Poulain J F 1976 Improvement of the fertility of agricultural soils in Mali: Thirteen years of research (1962–1974). Agron. Trop. (France), 31, 402–416.

Survey Staff 1975 Soil taxonomy. A basic system of soil classification for making and interpreting soil surveys. Soil Conservation Service, U.S. Department of Agriculture, Agriculture Handbook No. 436.

Survey Staff 1987 Keys to soil taxonomy. Agency for International Development, United States Department of Agriculture, Soil Management Support Services (SMSS), SMSS technical monograph No. 6. 3rd. printing, Cornell University, Ithaca, NY.

Thomas G W 1982 Exchangeable cations. *In* Methods of soil analysis. Part 2. 2nd ed. Eds. A L Page *et al.* Agronomy 9, 159–164.

Uehara G and Gillman G 1981 Mineralogy. *In* The Mineralogy, Chemistry, and Physics of Tropical Soils with Variable Charge Clays. Westview Press Boulder, CO.

West L T, Wilding L P, Landeck J K and Calhoun F G 1984 Soil Survey of the ICRISAT Sahelian Center. Texas A & M University System/Tropsoils, College Station, TX.

Wilding L P and Hossner L R 1989 Causes and effects of acidity in Sahelian soils. *In* ICRISAT. Soil, crop, and water management systems for rainfed agriculture in the Sudano-Sahelian zone: proceedings of an international workshop, 7–11 Jan. 1987. ICRISAT Sahelian Center, Niamey, Niger. Patancheru, A.P. 502324, India: ICRISAT.