Review of some chemical characteristics of selected acid soils of south-western Ghana

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SUMMARY

A sound knowledge and better understanding of chemical characteristics of naturally-occurring acid soils are important for proper management practices on these soils for increased and sustained crop production. This paper reviews available data on some chemical properties of five acid soils in southwestern Ghana. The soils are highly acidic with *p*H in 0.01*M* $CaCl_2$ less than 4.5; their dominant clay mineral being kaolinite, and are generally low in basic exchangeable cations, particularly Ca, but high in exchangeable Al, with the Al saturation exceeding 60 per cent. The soils contain little organic carbon even though they occur in evergreen rain forest. They are also low in N. Availability of P seems to be a major problem of these soils. Organic P in the five soils ranged from 37 to 156 μg g^{-1} and constituted 41-70 per cent of total P. P sorption maximum values show very high trend. The inorganic sulphate and organic S accounted for 14 per cent and 86 per cent respectively of the total S in the soils. The C-bonded S and HI-reducible S constituted the bulk of the total S accounting for 52 and 45 per cent, respectively. Generally, the soils in the forest zone appear to be well endowed with available S. Both total Fe and Mn are high, and available forms occur in toxic amounts, while Zn, Cu, B and Mo levels in the soils are low to marginal. To make the soils productive, liming to decrease the detrimental effects of soil acidity and phosphate application to build up P status and improve fertility and organic matter status are proposed.

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RÉSUMÉ

Owusu-Bennoah, E. & Acquaye, D. K.: *Revue de certains caracteristiques chimiques de quelques sols acides unique de sud-ouest du Ghana.* Une parfaite connaissance ainsi qu'une meilleure compréhension de caracteristiques chimiques de sols acides qui se produissent naturellement, sont importantes, pour les pratiques d'exploitation adéquate sur ces sols, afin d'avoir une production agricole croissante et soutenue. Ce document réexamine les données disponibles sur quelques propriétés chimiques de cinq sols acides au sudouest du Ghana. Les sols sont acides avec le *p*H en 0.01*M* $CaCl_2$ moins que 4.5; leur argile minérale dominante étant kaolnite et sont généralement faibles en cation échangeable de base, particuliérement Ca, mais forts en Al échangeable avec la saturation Al dépassant 60 pour cent. Les sols contiennent un peu de carbone organique bien qu'ils surviennent dans la forêt humide é feuilles persistantes. Ils sont également faibles en N. La disponibilité de P semble être un probléme majeur de ces sols. Le P organique dans les cinq sols se sont rangés de 37 à 156 μg g^{-1} et contituen 11 à 70 pour cent de la totalité de P. Les valours maximums de la sorption de P indiquent une tendance trés élevée. La sulphate inorganique et le S organique répresentaient 14 et 86 pour cent respectivement de la totalité de S dans les sols. Le C-liaison S et le HI-reducible S constituaient le gros du S total répresentant 52 et 45 pour cent respectivement. Dans l' ensemble les sols dans la zone forestiére apparaissent être bien dotés en S disponible. Tous les deux de Fe et Mn sont forts et leurs formes disponibles se produissent en proportion toxique, alors que les sols sont faibles jusqu'au marginale. Afin de rendre les sols productifs, l'application de chaux pour réduire l'effet nuisible de l'acidité du sol ainsi que l'application de phosphate pour élever le niveau de P afin d'améliorer la fécondité et le niveau de matiére organique' sont serieusement proposées.

Introduction

The decline in soil fertility and productivity in the tropics could be attributed to, among other factors, exhaustive cropping of the soil as a result of rapid population growth and the increased demand for more food. These factors have made good farming land to be relatively scarce and expensive causing farmers to expand their farms into marginalized zones such as naturally-occurring acid soils. In Ghana, naturally-occurring acid soils are situated within the forest zone which occupies about one-third of the country. It is associated climatically with the two-peak rainfall regime of parts of southern Ghana where total annual rainfall averages 1120 - 2000 mm. Rainfall is greatest in the South-West (SW) and decreases both to the North (N) and East (E) where the forest merges into the interior and coastal savanna areas respectively.

Differences in rainfall within the forest zone are matched by corresponding differences in vegetation and soils. The evergreen rain forest of the SW has an average rainfall of 1750 - 2000 mm per annum and coincides fairly closely with the area in which the upland soils are classified in Ghana mostly as Oxysols, and acid Latosols (Charter, 1957), as *sol ferralitique tres lessives* of the French classification (Burridge & Ahn, 1965) and as Oxisols according to the US Taxonomy. According to Ahn (1961), all soils in the evergreen rain forest are highly weathered, usually very deep and highly leached to a common low level of fertility.

The Oxisols support mainly tree crop cultivation such as rubber and coconut and to a lesser extent oil palm and citrus. Staple food crops such as plantains and root crops grow poorly on these soils. The inherently-poor chemical properties of these soils pose very serious problems for agriculture and unless they are managed properly, sustained production of food crops will not be feasible.

Despite the low fertility status of these acid soils, they have great potential in terms of their good physical properties for development into productive agricultural lands. However, adequate knowledge and understanding of their chemical characteristics are important to their proper management. This paper is a review of the chemical properties of some of the important acids soils of south-western Ghana.

Description of the soils

The general description of the five selected naturally-occurring acid soils found in the evergreen high rain forest area is given in Table 1. A study of the mineralogy of their clay fractions indicated that kaolinite is the major clay mineral in all the soils. Mica and quartz are present but in moderate quantities while, goethite and haematite are the iron oxyhydroxide minerals present.

Chemical characteristics

pH and exchangeable Al

The soils are strongly acidic with *p*H values (0.01M CaCl$_2$ suspension) between 4.0 and 4.2 with mean value of 4.1 (Table 2). The mean value is close to that reported by Osseni (1984) for some acid soils from Cote d'Ivoire and by Acquaye & Beringer (1989) for similar soils. The low *p*H of the soils may have been caused by intensive weathering and leaching which have depleted many of their exchangeable bases leaving behind H$^+$ and exchange-

TABLE 1

General Description of the Selected Acid Soils

Soil series	*Classification*	*Parent* material*	*Vegetation*	*Texture***	*Mineralogy of clay fraction (0.002 mm)**** *Montmorillonite*	 *Illite*	 *Kaolinite*
Abenia	Typic Haplorthox	biot. gr. sch.	Forest	SCI	X	X	XXX
Ankasa	Typic Haplorthox	biot. gr. sch.	Forest	SCIL	X	X	XXX
Bio	Plinthic Eutrorthox	phyllite	Forest	SCIL	X	X	XXX
Kwabeng	Oxic Tropaquent	phyllite	Forest	CIL	X	X	XXX
Tikobo	Typic Haplorthox	Tert. sand	Forest	LS	X	X	XXX

*Bio. gr. sch. = biotite granite schists; tert. sand = tertiary sand
**SCI = silty clay; SCIL = sandy clay loam; CIL= clay loam; LS = loamy sand
***X = identifiable; XXX = strong X-ray pattern

Source: Acquaye, D. K. (1973)

TABLE 2

Chemical Characteristics of the Acid Soils

Soil series	*pH CaCl*	*Organic C*	*Total N %*	*Ca*	*Mg*	*K*	*Na*	*Al*	*ECEC*	*% Al sat.*	*Ca/Mg*	*Ca/K*	*Mg/K*
							cmol (+)/kg						*ratio*
Abenia	4.0	1.0	0.11	0.26	0.25	0.22	0.16	2.80	3.69	76	1.04	1.18	1.14
Ankasa	4.2	0.6	0.06	0.44	0.39	0.24	0.18	3.20	4.45	72	1.13	1.83	1.63
Boi	4.2	1.0	0.10	0.81	0.74	0.37	0.20	1.90	4.02	47	1.09	2.19	2.00
Kwabeng	4.1	1.1	0.13	0.64	0.23	0.25	0.18	4.50	5.80	78	2.78	2.56	0.92
Tikobo	4.2	0.8	0.10	0.50	0.34	0.10	0.18	3.00	4.12	73	1.47	5.00	3.40
Mean	4.1	0.9	0.10	0.53	0.39	0.24	0.18	3.08	4.42	70	1.50	2.55	1.82

Source: Owusu-Bennoah, E. (unpublished data)

able Al to dominate the exchange sites and the soil solution (Coleman & Thomas, 1967).

The average exchangeable Al was 3.08 cmol(+)/kg of soil which represents 70 per cent saturation of the effective CEC. According to Paramananthan & Eswaran (1984), Oxisols generally have low *p*H values (< 5.0) as well as high Al saturation that often exceeds 60 per cent. Sanchez & Silva (1984) have also reported the occurrence of acid soils with *p*H 4.8 and Al saturation of 64 per cent for Colombian Oxisols.

Organic carbon

Although the soil samples were taken from an uncultivated evergreen rain forest, the organic carbon content of the soils was low. It ranged between 0.6 and 1.1 per cent with a mean of 0.9 per cent (Table 2). However, the mean value obtained was 50 per cent lower than that quoted by Sanchez (1985) for some tropical forest soils from Latin America. The low organic carbon content in the soils may be the result of high rainfall and intense hot and humid conditions which create favourable conditions for rapid decomposition of organic matter (Pushparajah & Bachik, 1985).

Exchangeable bases

The mean value of exchangeable bases obtained were 0.53, 0.39, 0.24 and 0.18 cmol(+)/kg soil for Ca, Mg, K and Na respectively (Table 2). The sum total of the exchangeable bases was 1.34 cmol(+)/kg of soil. Burridge & Ahn (1965) reported a typical acid topsoil to contain 1.0-3.0 cmol(+)/kg exchangeable bases. Similar results have been reported for several acid soils located in Asia, Latin America and Africa (Garrity, Mamaril & Soepardi, 1989).

Table 2 also shows the ratios of the basic cations. The Ca/Mg ratios varied between 1.04 and 2.78 with an average of 1.50. The mean value obtained was much lower than 3.1 reported by Cochrane (1989) for 10 forest soils from Brazil. The low value may seem to suggest a possible imbalance between Ca and Mg in these Oxisols (Ritchey, Silva & Costa, 1982). It seems feasible to overcome this low Ca/Mg ratio with lime or other Ca amendments.

The mean Ca/K ratio obtained for the soils was 2.55. With the exception of Tikobo series, the soils had Ca/K ratios below the level of 5.0 which is considered generally adequate in soils (Liebhardt, 1981). Cochrane (1989) reported a ratio of 7.1 for some acid soils from Brazil. In all the acid soils, the Mg/K ratio varied from 0.92 to 3.40 with an average of 1.82 (Table 2). These values are higher than the adequacy value of 0.6 proposed by Rosalem, Machado & Brintioli (1984) for Brazilian Oxisols and the value of 0.5 suggested by the work of MacLean & Finn (1967) and Rahmatullah & Baker (1981) for various soils. Such high Mg/K ratios in many acid soils have been suggested as being due to the release of Mg from vermiculite and montmorillonite clay structure (Kamprath & Foy, 1984). These high ratios seem to suggest that the Ca/Mg ratios of the Oxisols should be examined in an agricultural context.

Effective cation exchange capacity

The effective cation exchange capacity (ECEC), defined as the sum of exchangeable bases (Ca, Mg, K and Na), H and Al, has been used as a basis for measuring cation exchange capacity (CEC) near field conditions. The ECEC ranged between 3.7 and 5.8 cmol(+)/kg soil with an average of 4.4 cmol(+)/kg soil. Similar low ECEC values have been reported by Garrity, Mamaril & Soepardi (1989) for acid soils from Onne, Nigeria (2.91 cmol (+)/kg, Suakoko, Sierra Leone (2.20 cmol(+)/kg), Philippines (4.91 cmol(+)/kg and Indonesia (1.75 cmol(+)/kg. Sanchez (1985) has also reported that about 13 per cent of the Amazon Basin of Brazil have soils with ECEC value less than 4 cmol(+)/kg soil.

According to Pushparajah & Bachik (1985), most Oxisols and Ultisols of southeastern Asia have ECEC less than 10 cmol(+)/kg soil. They explained that the low ECEC is due to the dominance of low-activity kaolinite clay and low organic matter content of the soils. Another reason for the low ECEC of the acid soils may be that a large part of the negative charge of organic matter is countered by chelation with Al ion species (Juo & Kamprath, 1979). Severe leaching caused by heavy rainfall in the area may also contribute to the lowering of the base saturation of the ECEC (Uehara & Gillman, 1981). The low ECEC of the soils may create potential nutrient imbalance problem in the use of fertilizers. For example, Villachia (1978) found that in Peruvian Oxisols, K application may lower the Mg/K ratios and cause Mg deficiency by decreasing Mg uptake by crops.

Nitrogen

The total N content varied from 0.06 to 0.13 per cent with an average of 0.1 per cent (Table 2). The mean value obtained, however, is much lower than 0.35 per cent reported by Ling, Tan & Sofie (1979) for acid soils in Malaysia and 0.18 per cent for soils in the humid tropics of Latin America. The low total N values obviously stem from the low organic matter content (Table 2). The mean C/N ratio of the soils was 9.1 as compared with 11.3 reported by Sanchez *et al.* (1982) for other tropical soils.

The organic fractions of N have not been studied extensively on acid soils even though N is mainly in the organic form. Setsoafia (1973) estimated the different organic N fractions in the acid soils of Ghana by hydrolysis of the soil samples with 6 *N* HCl according to the method of Bremner (1965). The data presented in Table 3 show that the ammonium-N in the soils ranged from 88 to 372 μgg^{-1} (average 257 μgg^{-1}), the amino acid-N from 214 to 336 μgg^{-1} (average 256 μgg^{-1}); the hexose-amine-N ranged from 87 to 263 μgg^{-1} (average 153 gg^{-1}) and serine and threonine-N from 77 to 120 μggl^{-1} (average 92 μgg^{-1}).

TABLE 3

Contents of Ammonium and Different Organic-N Fractions in the Acid Soils (mgg^{-1})

Soil series	*Ammonium N*	*Amino acid-N*	*Hexose-amine-N*	*Serine threonine-N*	*Sum of fractions*	*Total hydrolysable-N*
Abenia	295	336	263	104	998	1088
Ankasa	356	248	147	77	828	975
Bio	88	240	160	77	565	686
Kwabeng	372	241	109	120	842	945
Tikobo	172	214	87	83	556	588
Average	257	256	153	92	758	856

Source: Setsofia, K. M. (1973)

The data seem to suggest that most of the organic N or total hydrolysable-N in the acid soils was in the amino acid-N (30-36 %), followed by hexose amine-N (15-24 %). Abenia series contained the highest level of total hydrolysable-N (1088 μgg^{-1}) while Tikobo series contained the least amount (588 μgg^{-1}). Based on amounts of the relatively most available forms of ammonium-N and amino acid-N, all the soils could be considered as being deficient.

Phosphorus

Phosphorus availability in acid soils has been extensively investigated in Ghana and in other humid tropical countries (Acquaye & Oteng, 1972; Pushparajah & Bachik, 1985; Garrity, Mamaril & Soepardi, 1989). The data in Table 4 show that the available P (0.5 *M*NaHCO$_3$-P i.e. Olsen-extractable P) varied from 2.42 to 5.22 gg^{-1} (average 3.41 μgg^{-1}). The mean value is lower than 5.0 μgg^{-1} reported by Pushparajah (1977) for Oxisols in Malaysia. Although 10 μgg^{-1} of Olsen-extractable P is generally accepted as the critical threshold for adequacy, Tandon & Kanwar (1984) reported that in India, a soil is considered deficient if it contains less than 5 μgg^{-1} Olsen-extractable P. Based on all these, the acid soils could be considered as being medium to serious deficient in P. Pushparajah & Bachik (1985) and Wada, Sue-yuen & Moody (1989) have concluded that phosphorus availability is one of the major problems in the management of Oxisols.

The range of organic P in the soils is 37-156 μgg^{-1}. The organic P constitutes between 41-70 per cent of the total P (Table 4). These values are similar to values published for Nigerian soils (Kang *et al.*, 1981).

TABLE 4

Contents of Different Forms of Phosphorus and P Sorption Maximum of the Acid Soils (mgg^{-1})

Soil series	*Available P (0.5* M *NaHCO$_3$)*	*Inorganic P*	*Organic P*	*Total P*	*Sorption maximum*
Abenia	2.42	34	71	105	2500
Ankasa	3.10	16	37	53	1430
Bio	5.22	82	83	165	980
Kwabeng	2.83	104	156	260	2300
Tikobo	3.50	54	64	158	650
Average	3.41	58	82	148	1570

Source: Acquaye, D. K. & Oteng J. W. (1972)

The total P contents (mean value 148 μgg^{-1}) in the acid soils are generally low. The values seem generally lower than the values (250-350 μgg^{-1}) quoted for some acid soils of Brazil by Le Mare (1982).

Phosphorus sorption maximum values obtained using the Langmuir sorption isotherms for the soils ranged between 650 and 2500 μgg^{-1} (average 1570 μgg^{-1}). The data confirm the well-documented results that acid soils have high P sorption capacity (Wada, Sue-yuen & Moody, 1989). The high P sorption capacity, coupled with the inherent low native P status of these acid soils, generally make crops such as rubber, oil palm and cassava to respond to phosphate fertilizer application (Corley & Mok, 1972; Pushparajah, 1977).

Sulphur

Table 5 shows that the average total S ranged between 122 and 318 μgg^{-1} with an average of 245 μgg^{-1}. The average total content is considerably close to the value of 273 μgg^{-1} reported for Nigerian forest soils (Kang *et al.*, 1981) but higher than the 166 μgg^{-1} quoted for Brazilian soils (Neptune, Tabatabai & Hanway, 1975). Generally, the values do not support the documented view of Blair, Mamaril & Ismunadji, 1980) that highly weathered soils in the tropics have low total S. It should be pointed out, however, that these are forest soils and generally, forest soils tend to have higher total S content than savanna soils by virtue of their higher organic matter content (Acquaye & Kang,

TABLE 5

Distribution of Sulphur (mgg^{-1}) in the Acid Soils

Soil series	*Total S*	*Inorgainc SO$_4$-S*	*Org. S fractions HI-reducible*	*C-bonded*	*Total Org. S*	*C:N:S*
Abenia	318	38	117	163	280	93:7..9:1
Ankasa	122	17	50	55	105	147:9.5:1
Kwabena	295	51	115	129	244	161:12.7:1
Average	245	35	94	210	116	

Source: Acquaye, D. K. & Beringer, H. (1989)

1987).

The inorganic S, extracted SO_4-S from the soils, ranged from 17 to 51 μgg^{-1} (average 35 μgg^{-1}). On the average, the inorganic S accounted for 14 per cent of the total S in the surface soil. This compares closely with average of 11 per cent reported for Brazilian soils (Neptune, Tabatabai & Hanway, 1975). According to Bettany & Stewart (1983), the inorganic SO_4-S usually accounts for less than 10 per cent of the total S in the surface soils. Based on the critical value of 6.0 μgg^{-1} proposed by Fox, Olson & Rhodes, (1964), the SO_4-S status of these soils could not be considered deficient.

The total organic S, calculated from total S by subtracting inorganic S, varied between 105 and 280 μgg^{-1} with an average of 210 μgg^{-1}, representing 86 per cent of the average of the total S content.

According to Bettany & Stewart (1983), current available analytical techniques only permit fractionation of the total organic S into two broad groups, namely: carbon-bonded S, in which S is bonded directly to C, e.g. S containing amino acids and sulphonates and HI-reducible S, in which S is linked to C through an oxygen or nitrogen atom, e.g. sulphate esters. The HI-reducible S fraction and a portion of the C-bonded S fraction have been found to be labile and could, therefore, be significant sources of mineralized S in these soils (Freney & Williams 1983; Acquaye & Beringer, 1989). In this study, the mean concentration of HI-reducible S in the surface soils was 94 μgg^{-1}, accounting for 45 per cent of the total organic S. The average amount of C-bonded S was 116 μgg^{-1}, representing 52 per cent of the total organic S in the soils. According to Biederbeck (1978), the correlation between the two organic S fractions and organic C and total N suggests that the fractions form relatively consistent proportions of soil organic matter. The HI-reducible S and C-bonded S fractions have been found to be well correlated to organic C and total N in Ghanaian soils (Acquaye & Kang, 1987; Acquaye & Beringer, 1989).

Micronutrients

Investigations into micronutrient contents viz. Cu, Zn, Fe, B, Mn and Mo have been made by Acquaye, Ankoma & Kanabo (1972), using both chemical and biological methods. The total analysis was carried out by fusion with sodium carbonate followed by colorimetric estimation. The results (Table 6) show that total Fe was the dominant micronutrient in the soils and the least was Mo in the following decreasing order: Fe > Mn > Zn > Cu > B > Mo. This confirms the observation made by Lopes, Smyth & Curi (1985) that Fe and Mn tend to be toxic in acid soils while Zn, Cu, B and Mo tend to be deficient. The available micronutrient levels follow almost the same trend (Table 6).

TABLE 6

Micronutrient Status of the Acid Soils

Soil series	Total* (μgg^{-1})						Available ** (μgg^{-1})					
	Cu	*Zn*	*Fe*	*B*	*Mn*	*Mo*	*Cu*	*Zn*	*Fe*	*B*	*Mn*	*Mo*
Abenia	38	116	15500	45	325	59	0.85	4.57	21.6	0.52	2.54	1.02
Ankasa	21	33	5750	25	150	12	0.33	3.77	22.0	0.08	0.55	0.83
Boi	115	72	1250	10	1950	22	0.71	2.38	17.2	0.06	15.15	1.17
Kwabeng	30	35	8000	70	550	26	2.33	2.00	17.4	0.38	3.54	0.68
Tikobo	30	41	7000	65	150	20	0.71	1.00	15.8	0.20	2.05	0.35
Average	47	59	7500	43	625	28	0.99	2.74	18.8	0.25	4.77	0.84

* Total micronutrients were determined after fusion with Na_2CO_3

** Available copper, iron, manganese, zinc, boron and molybdenum were extracted with 0.1*N* HCl, NH_4OAc *p*H 4.8 NH_4OAc *p*H 7.0, dithizone, hot water, and NH_4-oxalate respectively.

Source: Acquaye *et al.* (1972)

The total Cu levels in the soils varied between 21 and 115 μgg^{-1} with an average content of 47 μgg^{-1}. According to Swaine (1955), the total Cu in most soils is in the range between 2 and 100 μgg^{-1}. Burridge & Ahn (1965) obtained an average value of 25 μgg^{-1} for some acid soils from Ghana.

The available Cu extracted with 0.1 *N* HC*l* also ranged from 0.33 to 2.33 (average 0.99) μgg^{-1}. The average value is lower than the figure of 1.90 μgg^{-1} reported by Sillanpaa (1982) as the available Cu content of most Ghanaian soils. Avaliable Cu contents in acid soils have been given by Sanchez & Silva (1984) as follows: 1.7 μgg^{-1} for Columbia; 4.6 μgg^{-1} for Ecuador and 1.3 μgg^{-1} for Peru. These values are all higher than the average available Cu level (0.99 μgg^{-1}) obtained for the acid Ghanaian soils implying that Cu deficiency, acute or hidden seems to be more likely in the soils. This conclusion is supported by the data obtained by Lopes (1980). However, it should be noted that Kang & Osiname (1972) did not obtain maize yield response to Cu application on some acid soils of Nigeria with available Cu content ranging from 0.4 to 1.60 μgg^{-1}.

The total Zn content ranged between 33 and 116 μgg^{-1}, with an average of 59 μgg^{-1}. The range of total Zn cotent fell within 10 and 300 μgg^{-1} reported by Mitchell (1964). The available Zn extracted with dithizone also ranged between 1.00 and 4.57 μgg^{-1}, which fell within the range of 0.2-8.4 μgg^{-1} obtained by Trierweiler & Lindsay (1969). The mean value of 2.74 μgg^{-1} was lower than the 4.3 μgg^{-1} given by Sanchez & Silva (1984) for Oxisols that were low in available Zn.

The total Fe content of the acid soils ranged from 7,000 to 15,500 μgg^{-1} with 7,500 μgg^{-1} as the average value. The available Fe extracted with NH_4OAc also varied between 15.8 and 22 μgg^{-1} (average 18.8 μgg^{-1}) This high level of available Fe in the soils could create problems of nutritional imbalance with Mn and P (Lopes, Smyth & Curi, 1985).

As shown in Table 6, the average total B and available B were 43 and 0.2 μgg^{-1} respectively. The average B status of 0.25 μgg^{-1} in the acid soils may be considered to be very low as Raychaudhuri and Datta Biswas (1964) proposed 0.50 μgg^{-1} while Singh (1970) suggested less than 0.70 μgg^{-1} as the critical limit for available B. According to Jones & Wild (1975), B occurs in organic matter in the soil solution and as weakly adsorbed form on clay surfaces. Thus, the generally low amounts of organic matter (Table 2) in these soils mean that the danger of deficiency may be widespread in these soils. Matin (1969) indicated that oil palm which thrives on acid soil in the high rainfall areas of the tropics responds to B application if the available B content falls below 0.1 - 0.2 μgg^{-1}.

The total Mn ranged from 150 to 1950 μgg^{-1} with a mean value of 635 μgg^{-1}. The data show that the total Mn was the second dominant micronutrient after Fe in the soils (Table 6). Boi series contained the highest level of total Mn (1950 μgg^{-1}) while Ankasa and Tikobo series contained the least amount (150 μgg^{-1}). Generally, the mean value was higher than the value of 280 μgg^{-1} quoted by Coulter (1972) for Malaysian acid soils. Allen (1966) recorded higher mean content of total Mn (1350 μgg^{-1}) in the topsoil (0-5 cm) and 740 μgg^{-1} in the subsoil (5-30 cm) of some Malaysian acid soils as compared with the mean of 600 μgg^{-1} reported by Burridge & Ahn (1965) for acid soils in Ghana.

The available Mn extracted with NH_4OAc also ranged from 0.55 to 15.15 μgg^{-1}. Using the same extracted method, Mohapatra & Kibe (1971) reported a mean value of 46.35 μgg^{-1} for two acid soils from India. Judging by the critical level of 3.0 μgg^{-1} of available Mn reported by Sherman & Harmer (1943) for healthy soils, only Boi series with 15.2 μgg^{-1} could be considered as being well supplied with available Mn.

Molybdenum is the least micronutrient in the soils. Total Mo in the soils varied from 12 to 59 μgg^{-1} (average 28 μgg^{-1}). Burridge & Ahn (1965) reproted 3 μgg^{-1} total Mo in some acid soils of Ghana. The available Mo content of the soils varied widely, ranging from 0.35 to 1.17 μgg^{-1}. Based on the critical limit of 0.14 μgg^{-1} available Mo for soils with *p*H less than 6.3 proposed by Grigg (1953), the acid soil of the evergreen rain forest area of Ghana could be considered as well as endowed.

Conclusion

The review has indicated that there is a fair accumulation of scientific knowledge on the chemical characteristics of the Oxisols of south-western Ghana to enable formulation of good management options that can lead to improved productivity of these acids soils. The low organic matter content of the soils coupled with the highly acidic nature, low Ca/Mg ratios, presence of toxic level of Al, Fe and Mn and deficient levels of available P contribute to the poor crop yields on the soils. With appropriate soil management strategy, agricultural development to support sustainable farming is feasible. The constraint of soil acidity can be solved by the application of agricultural lime or other Ca amendments. In addition to the changes in *p*H, alleviation of Ca and Mg deficiencies and reduction of Al, Fe and Mn toxicities, liming may also result in a significant increase in the ECEC. The large deposits of limestone at Nauli in the region make such recommendation economically feasible.

The total P contents of the soils are low and the available P exctracted by the routine Olsen method is much lower than the 8-10 μgg^{-1} level required for most crops. The performance of all crops without addition of external inorganic P fertilizers is expected to be poor. To increase P fertilizer efficiency on these soils, perhaps investigations should be made into the following:

a) the economic ways to minimize P fixation,
b) determine the best fertilizer rates and placement method,
c) efficient use of the locally available rock phosphate and
d) enhancement of P uptake by plants through vesicular-arbuscular mycorrhizal inoculation.

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