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CONTINUOUS CULTIVATION OF WEST AFRICAN SOILS: ORGANIC MATTER DIMINUTION AND EFFECTS OF APPLIED LIME AND PHOSPHORUS

by Eugene A. BRAMS

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U.S. AID/Sierra Leone, W. Africa

SUMMARY

Five years of sustained cropping of cleared ferallitic and alluvial soils in Sierra Leone reduced the organic matter originally under bush of both soils by 50 per cent and the cation exchange capacities by 30 per cent. The rate of organic matter loss was sharply reduced after the 3rd year and organic matter cycling was stabilized by the 5th year. It was predicted that this equilibrium could be sustained after the 5th year provided that other factors of soil fertility have not become degraded.

Lime applied to maize on ferallitic upland soils of pH 5.3 did not affect yields. The response to applied P was direct and significant. No interactions between lime and P were observed. At pH 5.3 exchangeable Al saturated 8 per cent of the cation exchange sites and a pH 4.4 saturated 26 per cent Soil pH and Al-saturation between these limits did not influence the maize yields or reduce the availability of applied P.

Lime applied to groundnuts on alluvial soils of pH 4.4 and Ca content of 0.2 me per 100 g soil did not influence yield or uptake of leaf P, Mn, Fe, B, Zn, Mg, K, Na, Si, and Cu but directly affected Ca uptake. Lime increased the soil pH to 5.3 at harvest, and reduced Al saturation by 65 per cent, but the effect was measurable only during the year applied.

INTRODUCTION

Sierra Leone is a verdant, tropical country encompassing 71,500 km² with a population of 2.5 million. Nearly 77 per cent of the people are farmers living in tribal units where each family operates between 1.5–2.3 ha of land every year. This segment of the population, however, shares only 31 per cent of the domestic gross product of the country [15].

The agriculture is primarily a system of shifting cultivation producing rice, groundnut, maize, sorghum, and cassava. Permanent

crops such as oil palm, pissava, cocao, kola, ginger and coffee are also produced, but not extensively, for the world markets [15].

For the past 20 years the country has been attempting a gradual transition from traditional shifting agriculture to continous cropping of food crops on arable soils that are conducive for mechanization. Presently, about 4,050 ha of low, level, riverain terrace soils, 2,630 ha of boliland, 600 ha of mangrove swamp, and 800 ha of inland swamps are continously farmed to rice under partially mechanized systems of cultivation [13]. In spite of this production a shortage of rice exists in the country and rice valued at over 4 million leones was imported in 1968 [15].

Unfortunately, during the past decade the inequality between the pressure to produce for an increasing population and the scarcity of good upland sites has reduced the revitalizing bush-fallow period, on the average, from 12 to 5 years [13]. Without the use of fertilizers, this practice has resulted in an insidious and progressive decline in yields [18].

From a cost basis to produce food, it would be logical to conclude that systems of sustained cropping (annual cropping) of only the best soils would eventually evolve as the only workable solution towards a more stable and profitable agriculture [8]. It should not be forgotten, however, that 65 per cent of the farmers live and derive their sustenance from relatively infertile upland soils. Although these may be considered marginal, a program of improved cultural practices must be developed which will enhance their means to a better livelihood [4 11].

Clearly, the only indisputable way to ascertain if sustained cropping would be feasible is to design and initiate research of long-range cropping systems [2 5 12]. They should serve as starting points for change and would encompass soil fertility and cultural practices, use of suitable varieties, plant and soil protection schemes and ecological principles to preserve the ecosystem. However, the success of any system follows from an understanding of the effects it would have on the factors of soil fertility or conversely, the effect these would have on the productivity of the system.

The maintenance of adequate levels of organic matter in upland soils is one of the most important practices which influences the productive capacity of these soils in the wet tropics [8]. Clearing and cultivation of upland tropical soils invariably reduces the organic matter content unless some type of ley period is introduced into the cropping cycle [3 7]. Nye and Greenland [16 17] had shown that after clearing of forest soils in W. Africa a rapid oxidative loss of organic matter was evidence in the 1st year but was much reduced in the 2nd year of cropping. Alternate wetting and drying of organic latisols between field capacity and drying at 100°C mineralized 63 per cent of the original level of the soil organic matter after 12 weeks of treatment [1 6].

Aluminum in acid soils of the tropics strongly influences the yield of crops. An interesting aspect of organic matter losses in tropical ferallitic soils is its relationship with soil Al. Mutatkar and Pritchett [14] demonstrated that accumulation of organic matter in many tropical soils was associated with

the soil's high Al content. At soil pH values above 4.8 exchangeable Al was negligible and the rate of mineralization of organic matter increased.

During the past two years, the opportunity for an exploratory study of sustained cropping was available from records of commercial plantings and demonstration sites at Njala which were under continous cultivation for 5 years. It was possible to collect data on organic matter levels and cation exchange capacities from these sites. This paper, therefore, describes the organic matter fluctuations under 5 years of sustained cropping of two Sierra Leone soils; a ferallitic upland and an alluvial river terrace soil. In addition, an experiment designed to measure the influence of lime and phosphorus applied to these soils on pH and yields during a single year is also described.

EXPERIMENTAL SITES AND METHODS

Sierra Leone is located between 7° and 10° N. latitude on the coast of W. Africa (Fig. 1). The climate is equatorial with a distinct wet and dry season (May–November and December–April) respectively. The rainfall at Njala University College where the studies were conducted averaged 272.3 cm per year of which 265.5 cm falls during the wet season. The yearly temperature fluctuates between 26.5°C and 35.0°C, maximum daily temperature. Both rainfall and temperature variations throughout the year are plotted by the month in Fig. 1.

The description of the soils of the experimental sites is given in Table 1.

At time of clearing, bush on both sites consisted primarily of *Cruelina arborea*, *Elaeis guineensis*, Albizia and *Phyllanthus discoideus*. Sites were cleared with mechanical equipment consisting of a D–4 bulldozer with blade besides native axes and cutlasses. The felled bush was removed to the periphery of sites and burned. After clearing they were cropped to rice for the first two years followed by groundnut, maize, and cassava for the remaining 3 years in that sequence. The latter 3 crops were planted in rows, weeded and harvested, with native implements. Each crop received 112 kg/ha of ammonium sulphate and superphosphate, respectively, two weeks before planting.

The regenerative cover consisting predominately of *Pueraria phaseoloides*, *Calapogonium mucunoides*, *Centrosema pubescens*, and *Pennisetum purpureum*.

The crop residues were incorporated into the top 15 cm of soil. Soil samples at each site were taken annually at random during the planting period from the 2.5 to 18 cm depth. They were collected in plastic bags, air dried, sieved through 2-mm sieves, and analyzed. The soil organic carbon was determined by the wet oxidation method. Cation exchange capacity by saturation with 1*N* NH_4Cl followed by exchange with 1*N* KCl and the ammonia determined in the leachate after distillation.

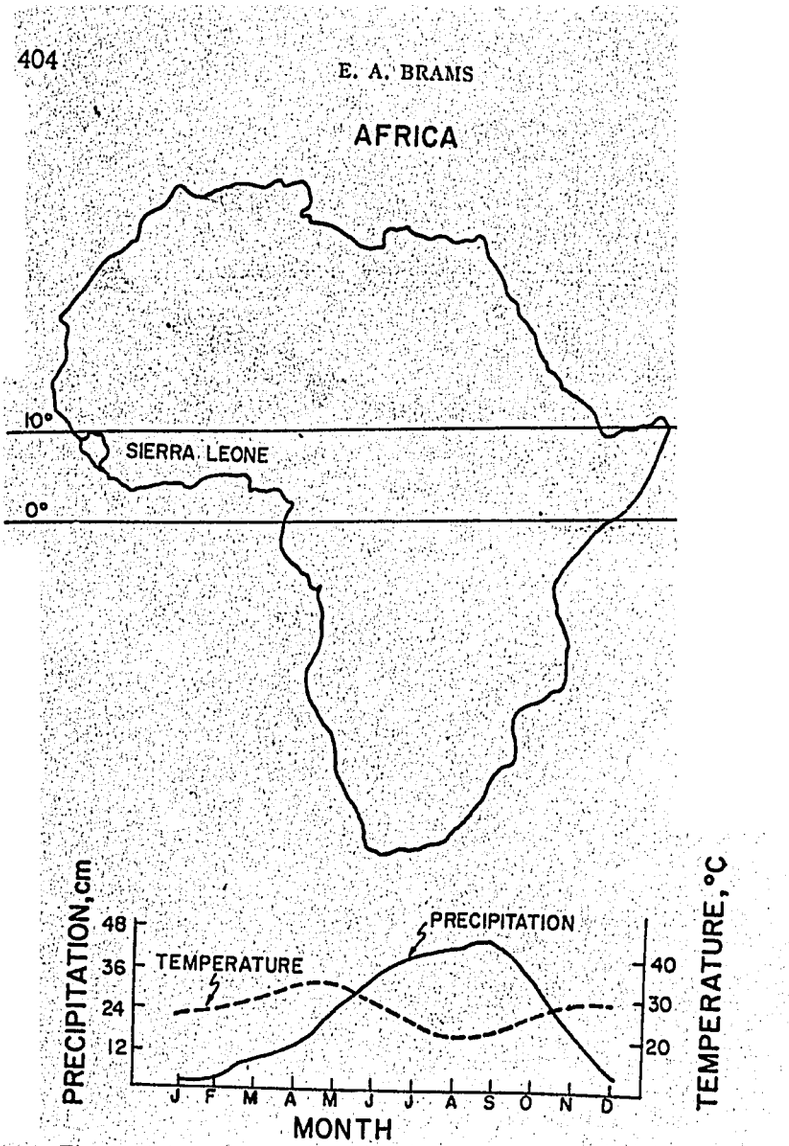

Fig. 1. Njala rainfall and temperature for a 12-year average.

The lime-phosphorus experiments were situated on Njala soils (ferallitic upland) and conducted in the 1st year after clearing of 6-year bush. The lime source was derived from a mixture of coarse ground (< 2 mm) oyster shell and finely ground (< 0.01 mm) commercial limestone in equal proportions. Lime was applied to maize at 0, 563, 1125, and 1689 kg/ha and 20% superphosphate at 0, 112, 225, and 336 kg/ha in a factorial combination of lime and phosphorus treatments replicated 4 times in a randomized block design. The lime was applied 12 days before planting and raked into the top 4 cm of

TABLE 1

Physical and chemical properties of soils under forest*. (3–18 cm depth)

Classification	Particle size distribution: gravel >2 mm	sand 2–0.05	silt 0.05–0.002	<2 mm in % clay <0.002	**Clay type	Exch. cations me/100 g soil: Ca	Mg	K	Na	Al	C.E.C. me/100 g	Base sat. %	pH 1:1 H_2O	Org. C
1 *Njala gravelly fine sandy loam* Plinthic Haplustox	45	53	22	25	K,G,C	0.34	0.20	0.06	0.06	3.31	12.5	5.4	4.3	2.10
2 *Nyawama sandy clay loam* Typic Haplustox	0	52	20	28	K,G	0.11	0.09	0.06	0.04	1.50	9.0	4.0	4.7	1.60

* From Soil Survey Report. J. C. Dykerman and H. Breteler, Njala, U.C.
** K-Kaolinite, G-Gibbsite, C-Chlorite in order of abundance.

soil by native implements. The superphosphate was broadcast and racked into the soil (4 cm depth) at planting. Each plot received an application of 112 kg/ha of ammonium sulphate, potassium sulphate, and magnesium sulphate respectively in a split application, ¼ broadcast at planting and the remainder side-dressed 4 weeks after emergence. Hybrid corn (Dekalb 1110) was planted in June at a density of 36,000 plants/ha in rows 0.9 m wide and 0.3 m in the row. The maize was harvested in late November, shelled, dried to 14% moisture and wieghed.

In a second study, ground oyster shell was applied to groundnut (Mares variety) growing on alluvial upland soils in a site cleared that year of 20-year secondary forest. Lime was applied one week before planting in July at the rate 0, 2350, 4700, and 7050 kg/ha, the lime rates replicated in a 4 × 4 latin square. The lime was raked into the soil 6 days before planting. Each plot also received 235 kg/ha of superphosphate at planting and 112 kg/ha of ammonium sulphate side-dressed 4 weeks after emergence. The groundnuts were not ridged.

Soil samples from 2.5 cm to 18 cm were taken at planting and before harvesting.

Soil pH of a 1:1 water suspension of fresh soil was determined by glass electrode.

The Bray extractant (0.3N NH_4F and 0.025 *N* HCL) was used and the P determined spectrometrically by molybdenum – blue method.

Soil Al was determined in a neutral 1*N* KCl extract of soil by the Aluminon method.

RESULTS AND DISCUSSION

The diminution of humified organic materials in the Nyawama alluvial soils resulting from clearing of secondary forest followed by successive cropping of rice and intertilled crops for 5 years is depicted in Fig. 2. Two months after the site was cleared in March, but not yet planted to rice, the organic matter level diminished from 3.5 to 3.1 per cent – a loss of 11.4 per cent. Following two years of rice it decreased to 40 per cent of the original and after 3 more years of cropping to intertilled crops the level was further reduced by 10 per cent. The production of organic material derived from crop residues and regenerative cover measured in the 3rd, 4th and 5th year of sustained cultivation in the month of March averaged between 16 to 26 tons per ha per year of fresh top growth material. Each year this material was physically incorporated into the top 14 cm of soil using native tools. Thus, after 5 years of annual cropping in which residues

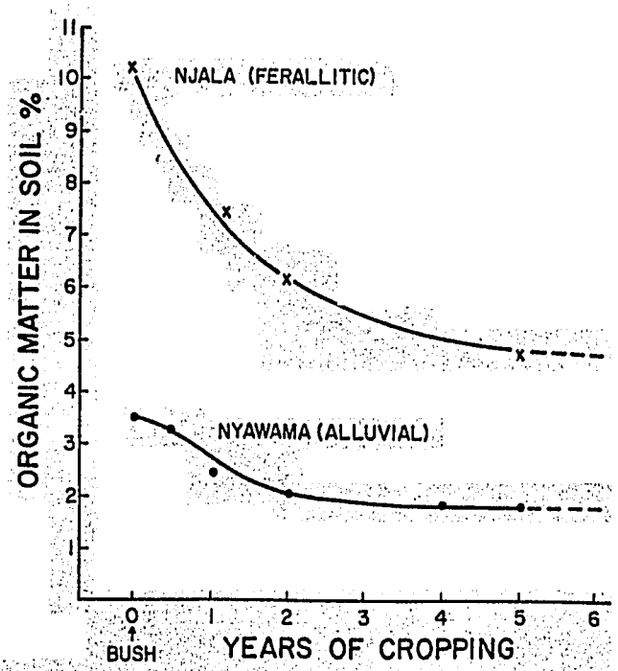

Fig. 2. Organic matter diminution in ferallitic and alluvial tropical soils of experimental sites under sustained cultivation of agronomic crops.

and regenerative cover were returned to the soil each year, the original status of humified soil organic matter under bush was reduced by nearly 50 per cent.

It is important to note, however, that the declining rate of humified organic matter loss after the 2nd year, as evidenced by the levelling of the curve in Fig. 2, indicated that an equilibrium was being attained between the raw plant material returned each year, the material undergoing mineralization and/or moving into deeper soil horizons, and the organic matter originally developed under bush. In the 5th year, the cycle of organic matter in the soil apparently became stabilized.

A situation similar to that in the alluvial soils was observed in the Njala ferrallitic soils (Fig. 2). During the first two years, after clearing, the humified organic matter level was diminished by 30 per cent. After 3 more years, the level of humified organic material was reduced another 21 per cent so that after 5 years of annual cropping the soil organic matter concentration attained a level which was 49 per cent of that developed under secondary forest. As in the alluvial soils, the rate of organic matter loss was substantially reduced after the 2nd year. After the 5th year, the organic cycling in the soil appeared to have become stabilized.

It is interesting to note that the rate of mineralization of organic matter after clearing and cropping in both soils was essentially the same (Fig. 2).

A strong correlation between the organic matter content of the soils and the cation exchange capacities was also observed (Fig. 3). A 50 per cent reduction in the level of organic matter was reflected by a 30 per cent reduction in the cation exchange capacity. The relationship may, in part, be a direct one, but can also be attributable to changes in soil pH, clay content and movement, and Al–Fe/Si ratios particularly in longer term experiments.

It is reasonable to conclude that after the 5th year of continuous cropping of the upland sites the organic matter level would stabilize at about 50 per cent of that attained before clearing under bush and the cation exchange capacity would remain at 70 per cent of the original levels.

However, the factors of soil productively are inextricably related to each other, and the conclusions derived from this study would be more valid for periods exceeding 5 years provided that one or more

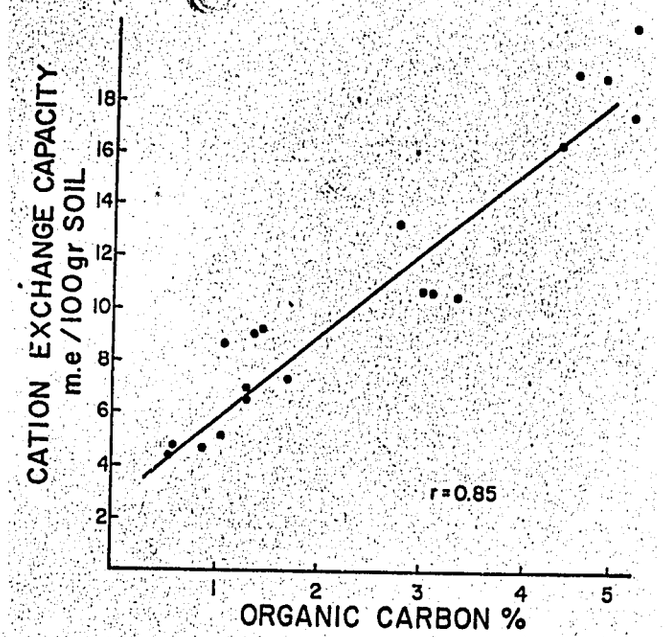

Fig. 3. Relationship between organic carbon and cation exchange capacity of the experimental soils.

of the other soil factors have not deteriorated. Thus, the case for long-period studies of the effects of cropping systems on soil fertility factors would be justifiable and must be done before committments can be advanced as to the kind of agriculture that would improve or replace the traditional practices.

Lime–phosphorus studies

Application of P to Njala soils during the 1st year after clearing increased the maize yield over the control (Table 2). Superphosphate (20%) at 225 and 336 kg per ha gave higher yields than 112 kg per ha but there were no significant differences in yields between the higher rates. The yield increase attributable to the lower level of P (112 kg per ha) demonstrated the low available P status of newly-cleared, but unburnt, ferallitic soil. The P concentration after clearing and in the control plots averaged 14 kg per ha as determined in the Bray extract. Apparently, at this level the soil potential for P was not great enough to support adequate yields of maize. The positive re-

TABLE 2

Effect of applied lime and phosphorus on yields (grain, kg/plot) of maize

Treatment†	Average maize yields††
All lime treatments	
P_0	1.7 a
P_1	6.5**b
P_2	8.6 c
P_3	9.5**c
All P treatments	
L_0	6.1 a
L_1	6.2 a
L_2	7.3* b
L_3	6.6 a

* Significant at 0.05 level.
** Significant at 0.01 level.
† P_0–P_3 represents 0, 112, 225, and 336 kg/ha superphosphate.
L_0–L_3 represents 0, 563, 1125, and 1689 kg/ha lime.
†† Values are averages of 4 replicates or 16 plots respectively.
Values with the same letters within respective treatments are not significantly different.

sponse to application of P suggested that the fixation of P by soluble Al and Fe into unavailable forms did not occur to any appreciable extent.

There were no significant interactions between lime and phosphorus at any level of either component and these data were not included in Table 2. The effect of lime on maize yields was not significant at the 536 or 1685 kg per ha level but a slight increase in yield was attributable to lime applied at 1125 kg per ha.

It is well known that the effects of lime or phosphorus on plant growth in acid, mineral soils of the tropics are closely associated with exchangeable soil Al the solubility of which in turn is strongly influenced by soil pH [10]. This latter relationship is borne out by the regression curve between soil pH and exchangeable Al (Fig. 4).

Because such a relationship exists there is an increasing awareness that the lime requirements of such soils should be based on the levels of exchangeable Al or that portion of the Al pool extractable with unbuffered neutral salt solutions. Liming should be practiced only to

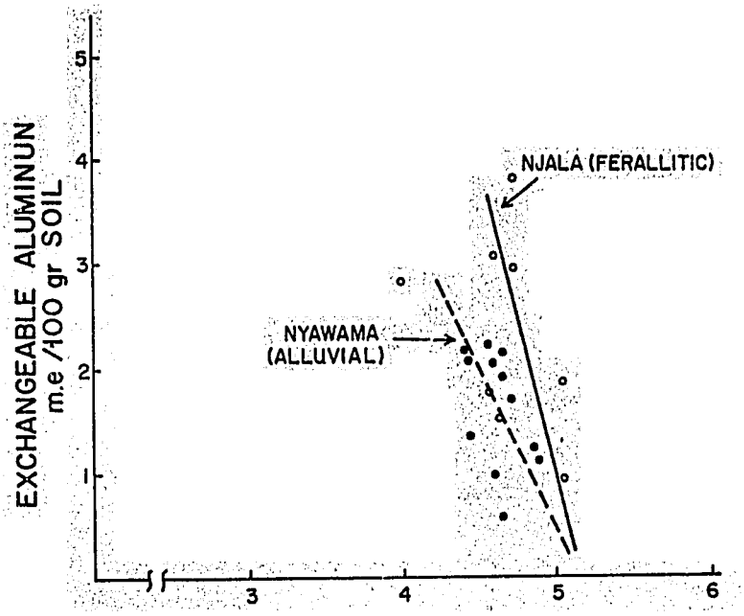

Fig. 4. Relationship between soil pH and exchangeable aluminum in two tropical soils of Sierra Leone.
Nyawama — 0.73 r value
Njala — 0.47 r value.

the extent of neutralizing the exchangeable Al to a predetermined percentage of the cation exchange capacity, depending on the tolerance of the crop to soluble Al [9].

The situations described above are applicable to the present study. The Njala (ferallitic) soils are highly buffered, the buffering capacity primarily a function of the clay and sesquioxodes fractions and the exchangeable Al associated with these fractions, and to a limited extent, the organic matter.

Based on the relationship between exchangeable Al and soil pH (Fig. 4), only 8 per cent of the cation exchange capacity was saturated with Al at pH 5.3, the exchangeable Al averaged less than 1.0 me per 100 g soil. At pH 4.3 the exchangeable Al averaged 3.2 me per 100 g soil and involved 26 per cent of the cation exchange sites. A pH increase of 1.0 unit reduced the Al saturation of the cation exchange sites by 70 per cent. This striking reduction concomitantly

with the increase in soil pH confirms the views expressed by Kamprath [10] that the buffering capacity of mineral soils at pH values below 5.6 directly involved neutralization of exchangeable Al.

The lack of response to lime, the absence of interactions between lime and P, and the pronounced response to applied P was attributable to an adequate supply of soil Ca (averaging 160 kg per cent ha) and to the relatively low levels of exchangeable Al, of a concentration which presumably did not affect the maize growth directly or immobilized sufficient P to cause deficiencies.

Kamprath reported [9], in acid mineral soils, the presence of exchangeable Al would not affect the growth of maize provided that 44 per cent or less of the cation exchange capacity was saturated with Al. If this holds true for ferallitic soils, in the present experiment, then the percentage cation saturation with exchangeable Al between pH 4.3 and 5.3 was not high enough to affect the yields of maize or bring about a response to lime. The results in Table 2 substantiates this conclusion. This is an important fact because the success of sustained cropping of upland mineral soils high in sesquioxides depends, in part, on the direct and indirect effects of soluble Al. Further studies are necessary to ascertain the effects of Al at pH values 4.3 and lower in tropical upland soils.

In another trial, oyster shell was applied to groundnuts growing on alluvial upland soil. There were no significant increases in yields for any increment of applied lime (Table 3). Yields were reduced at the high lime level, a situation similar to one reported by Reeves [19] for sorghum growing in Oxisols.

The pH of the soil during the growing season averaged 4.7 and

TABLE 3

Response of groundnut to lime on tropical alluvial soils

Treatment Lime – kg/ha	Yields* shelled nut, kg/ha
0	355a
2,350	342a
4,700	364a
7,050	245b

* Average of 4 replicates. Values having the same letter are not significantly different.

contained 0.20 me Ca per 100 g soil and 1.3 me Al per 100 g soil. The cation exchange capacity averaged 12.0 me per 100 g soil and the exchangeable Al saturated 11 per cent of the C.E.C. The roots were in a healthy condition and did not exhibit symptoms of Al toxicity.

The lack of response to lime in this experiment reflected two situations – a low Al saturation of the cation exchange sites and an adequate level of Ca. The ion uptake (Table 4) suggested that the availability of P to the plant was not affected by the presence of exchangeable Al in the concentrations existing during the growing period. The uptake of P, and other ions (excepting Ca) was also not influenced by the lime applications. The uptake of Ca, however, was directly affected by the applied lime, and was indicative of a root environment that was subjected to the influence of lime.

Another interesting aspect of this experiment concerned the buffering capabilities of the alluvial soil to resist a change in pH. At the inception of the lime trials in May, the soil pH averaged 4.4. Three months after the lime applications, at harvest, the soil pH averaged 5.4 and the exchangeable Al dropped to less than 0.5 me per cent 100 gr soil – a reduction of 61 per cent. However, 10 months later at the start of the next planting season in May, the soil pH was reduced to 4.5 and the Al concentrations rose to 2.3 me per 100 g soil. This observation alludes to the high reserve acidity of these soils, the rapid rate of hydrolysis of Al compounds, and the increase in organic acids during the rapid mineralization period at the onset of the rains.

The important conclusions derived from the lime-phosphorus trials indicate that in ferallitic and alluvial upland soils the saturation of cation exchange sites with Al between pH 4.3 to 5.3 ranged from 26 to 8 per cent and that within this range Al did not directly or

TABLE 4

Relationships between ion concentrations* in groundnut leaves and lime treatment

Lime kg/ha	Zn	B	Fe	Mn	Na	Cu	Mg	Ca**	P	K	Si
	ppm			ppm			%			%	
0	29	50	395	101	293	11	0.30	0.80c	0.20	3.47	3.24
2350	33	60	397	113	332	13	0.28	0.82c	0.22	3.32	3.16
4700	30	54	400	110	384	12	0.29	0.91b	0.21	3.89	2.82
7050	28	58	395	93	288	12	0.24	1.10a	0.21	3.71	2.85

* Values for each ion are means of 4 replicates.

** Values in Ca column with the same letter are not significantly different at the 0.05 level.

indirectly affect the growth of maize or groundnuts. On alluvial soils, an Al saturation of 11 per cent of the cation exchange sites at pH 4.3 was not great enough to adversely affect the yields. It appears that liming these soils would have no influence on yield of these crops within the soil pH ranges of 4.3 to 5.5 providing the Ca concentration remains at 0.2 me per 100 g soil or greater.

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