Soil Nutrient Dynamics and Fertility Management for Sustained Crop Production on Oxisols In the Brazilian Amazon

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The objectives of this project were 1) to establish the patterns of soil-nutrient depletion as a function of time after clearing for a Central Brazilian Amazon Oxisol under continuous cultivation; 2) to determine the fertilizer inputs required for sustaining continous crop production on these Oxisols; and 3) to determine how a soil-fertility management system for the Manaus Oxisols would differ from one for the Yurimaguas Ultisols.

During the four years in which this study has been conducted, eight crops have been harvested in the sequence described in Table 1. Table 2 shows selected fertilizer treatments during continuous cultivation. Other treatments included a check (no fertilization), and a treatment with residue incorporation. A judicious monitoring of soil and plant nutrient levels for every crop determined when each treatment was established. Treatments for copper and lime were initiated in the second soybean crop, for sulfur in the second corn crop, for boron and zinc in the third corn crop, and for manganese in the third cowpea crop.

Topsoil nutrient-depletion patterns for this Oxisol are shown in Figure 1 and Table 3 for the absolute check treatment, which has not received any fertilizer or lime. Soil nutrient levels initially increased as a result of ash additions from burning the primary forest: The liming effect of the ash reduced Al saturation values from 73% to 18% during the first crop.

Table 1. Sequence of crops, varieties and time after burning for the cultivation of each crop.

Crop	Variety	Planting to Harvest Time
		Months After Burning
Rice	IAC 47	3.0 - 7.4
Soybeans	Tropical	8.9 - 12.6
Soybeans	Tropical	18.5 - 22.3
Cowpeas	Manaus	22.9 - 25.2
Corn	BR 5102	27.6 - 31.3
Cowpeas	VITA 3	32.7 - 34.9
Corn	BR 5102	37.2 - 41.8
Soybeans	Tropical	42.3 - 46.2

Phosphorus

Ash analysis indicated that approximately 10 kg/ha of P were added to the soil by the burn. Crop yields for the absolute check treatment (Figure 2) suggested that yields, in the absence of fertilizer inputs, would be negligible after the first crop. Despite the initial in-

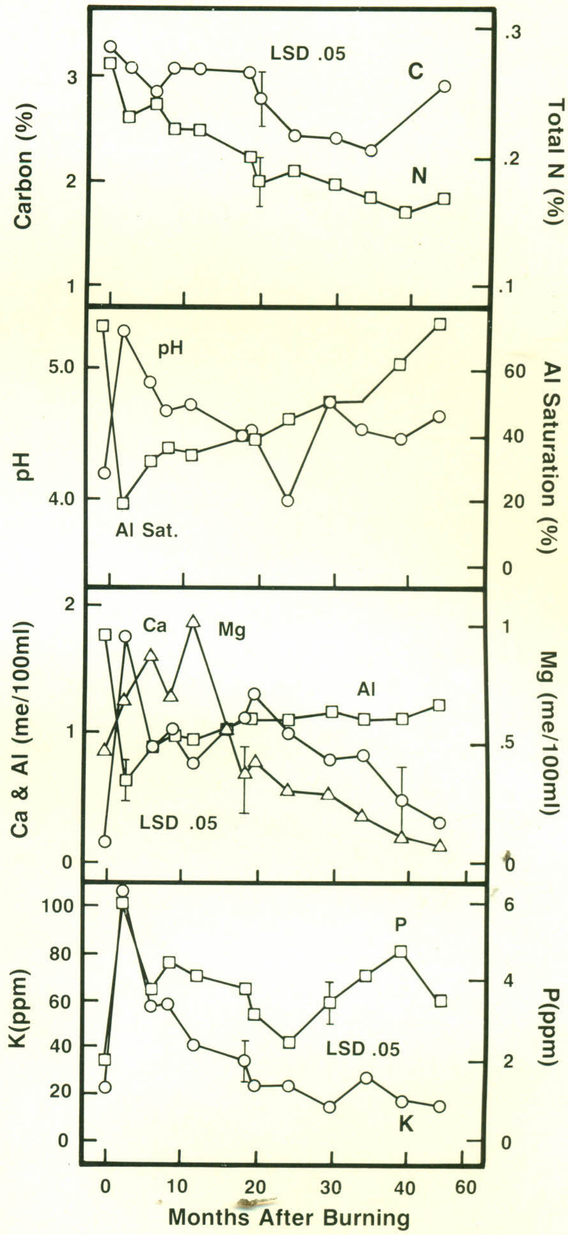

Figure 1. Soil dynamics for carbon, total N, acidity, exchangeable Al, Ca, Mg, K and Mehlich I P during the initial 44 months after clearing the primary forest on a Manaus Oxisol.

crease in Mehlich 1 extractable soil P (Figure 1), rice yields were doubled by the broadcast application of 22 kg P/ha (Figure 2). Although all succeeding crops showed a significant response to P fertilization, the optimum P rate was related to the timing of fresh P applications and crop P requirements. Relationships between crop yield and soil-test P suggested optimal Mehlich 1 P levels in the range of 5-10 ppm for corn, 8-10 ppm for cowpeas and 10-15 ppm for soybeans. Cumulative yields for the total applications of 88, 176, and 264 kg P/ha were 11.3, 13.5, and 16.7 t/ha, respectively.

Potassium

Topsoil K levels had declined from 107 to 56 ppm before planting the second crop (Figure 1). Treatments evaluating three rates of K were, therefore, initiated with this crop. Yield responses to K and the incorporation of residues from the previous crop are shown in Figure 3. The crop-residue treatment was included to evaluate the effects of returning residues when these are harvested for threshing the grain. Yield for this treatment was low on the initial soybean crop, since P was only applied prior to planting the third crop in the study (Table 2). Yields for the crop-residue treat-

Table 2. Fertilization history for selected treatments in the nutrient-dynamics study.

		Treatment								
		P_1	P_2	P_3	N_1	N_2	N_3	K_1	K_2	K_3
Crop	Fert. (kg/ha)									
Rice										
	N	60	60	60	30	60	90			
	P	22	44	66	44	44	44			
Soybeans										
	N	20	20	20	0	0	0	20	20	20
	P	22	44	66	44	44	44	88	88	88
	K	50	50	50	50	50	50	25	50	100
	Mo	.02	.02	.02	.02	.02	.02	.02	.02	.02
Corn*										
	N	54	54	54	27	54	80	54	54	54
	P	0	0	0	0	0	0	22	22	22
	K	50	50	50	50	50	50	25	50	100
	Cu	1	1	1	1	1	1	1	1	1
Soybeans										
		(no fertilizer applications in these treatments)								
Cowpeas										
	K	0	0	0	0	0	0	25	50	100
Corn										
	N	80	80	80	40	80	120	80	80	80
	P	22	44	66	22	22	22	22	22	22
	K	50	50	50	50	50	50	0	0	0
	Lime (t/ha)	2	2	2	2	2	2	2	2	2
Cowpeas										
	K	0	0	0	0	0	0	25	50	100
Corn										
	N	80	80	80	40	80	120	80	80	80
	K	50	50	50	50	50	50	25	50	100
Soybeans										
	P	22	44	66	44	44	44	44	44	44
	K	50	50	50	50	50	50	25	50	100
Cowpeas										
	K	50	50	50	50	50	50	25	50	100

* Crop failed in 43-day drought. Corn was cut and the stover incorporated.

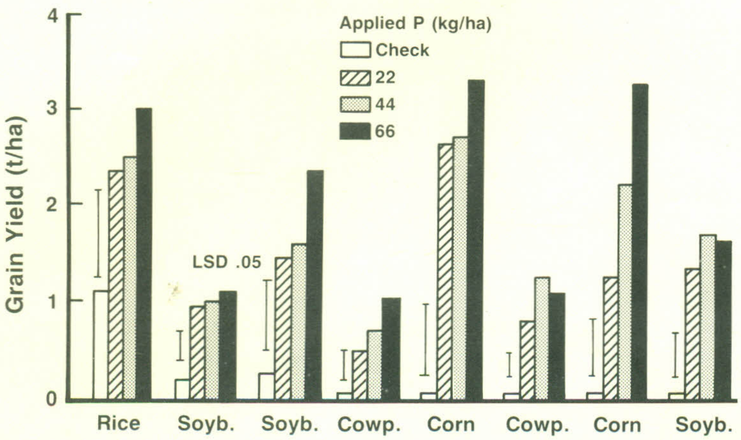

Figure 2. Grain yields for eight consecutive crops on the absolute check and P treatments.

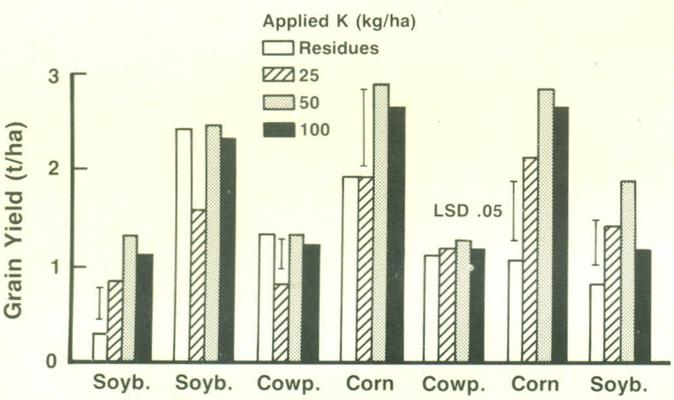

Figure 3. Effects of K fertilization and crop residue incorporation on yields of seven crops.

ment, relative to the K treatments, declined progressively following the first corn crop and were primarily related to a continual decline in soil K (Table 4) and increasing levels of soil acidity.

Yield response to fertilizer K has not exceeded 50 kg K/ha for any crop. Foliar K levels with this treatment approached the recommended values in most crops (Table 4). Topsoil K data suggested that residual effects from fertilizer K were low (Table 4). This was

Table 3. Mehlich 1 extractable soil micronutrient levels on the absolute check treatment as a function of time after burning.

Time After Burning	Melich 1 Extractable		
	Cu	Mn	Zn
months		ppm	
0	0.1	2	1.0
2.6	1.8	10	0.9
6.3	1.5	4	0.5
8.7	2.2	6	1.2
11.8	0.8	6	1.0
18.6	1.8	5	1.0
19.7	2.0	6	1.0
24.3	1.5	6	2.5
29.8	1.0	2	0.8
34.1	1.1	3	1.0
39.2		3	
44.0		2	
LSD .05	0.6	2	0.5

Table 4. Effects of K fertilization and crop-residue incorporation on soil K and foliar K levels at flowering stage during seven consecutive crops.

Applied K	Crop Sequence						
	Soyb.	Soyb.	Cowp.	Corn	Cowp.	Corn	Soyb.
kg/ha				soil K, ppm			
25	61	20	29	16	30	18	23
50	91	26	48	19	50	25	48
100	78	30	68	19	97	64	110
Crop Residues	124	32	52	24	50	21	25
LSD .05	19	9	12	ns	15	11	15
				leaf K, %			
25	1.26	1.40	0.90	1.23	1.25	1.14	1.44
50	1.85	1.70	1.16	1.68	1.56	1.50	1.63
100	1.99	1.86	1.12	1.80	1.95	1.64	1.81
CropResidues	1.64	1.92	1.09	1.93	1.44	1.29	1.45
LSD.05	0.35	0.21	0.26	0.31	0.36	0.17	0.19

particularly evident with the first corn crop, where no K was applied at planting. Data for K distribution in the profile also supported this observation (Figure 4). Between 2.6 and 39.2 months after burning, K added by the ash to the check treatment declined significantly at all depths measured. At the latter sampling date soil K levels with applications of 100 kg K/ha were significantly higher at all depths sampled than with applications of 25 kg K/ha.

Results have suggested that the best approach to K fertilizer management would be on an individual-crop basis. For corn and soybeans, a rate of 50 kg K/ha/crop appeared to be near optimal. Crop residue incorporation was beneficial in reducing the amounts of K exported by each crop harvest.

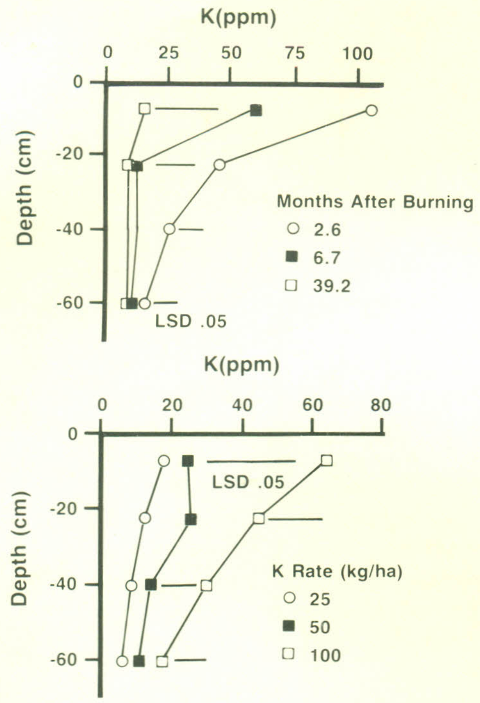

Figure 4. Potassium distribution in the soil profile for different times after burning on the check treatment, and K rates at 39 months after burning.

Table 5. Rice and corn yield and foliar N levels as a function of N fertilization rates applied to each crop.

Applied N	Yield			Leaf N		
	Rice	Corn	Corn	Rice	Corn	Corn
kg/ha	t/ha			%		
30	2.9			2.68		
40		2.7	2.2		2.33	2.24
60	3.0			2.70		
80		2.5	1.8		2.52	2.30
90	2.1			2.63		
120		2.9	2.3		2.59	2.44
LSD .05	ns	ns	ns	ns	0.25	ns

Table 6. Effects of Cu fertilization on grain yields and foliar Cu levels at flowering stage in two corn crops from a six-crop succession of soybean, cowpea, corn, cowpea corn and soybean.

Applied Cu	Corn 1		Corn 2	
	Yield	Leaf Cu	Yield	Leaf Cu
kg/ha	t/ha	ppm	t/ha	ppm
0	2.4	4	2.2	8
1	2.8	8	2.6	10
2	3.0	10	2.4	13
LSD .05	ns	2	ns	3

Table 7. Effects of B and Zn fertilization on crop yields and soil and foliar Zn levels.

Nutrient	Rate	Yield		Soil Zn		Foliar Zn	
		Corn	Soyb.	Corn	Soyb.	Corn	Soyb.
	kg/ha	t/ha		ppm			
B	0	2.1	1.3	--	--	--	--
	0.5	2.5	1.6	--	--	--	--
	1.0	2.2	1.2	--	--	--	--
Zn	0	2.3	1.8	.4	.4	16	34
	5	2.5	1.8	.8	1.3	17	43
	10	2.5	1.8	1.8	1.9	20	41
	LSD .05	ns	ns	.3	.2	3	9

Nitrogen

Yield responses to N fertilization were evaluated for rice and corn (Table 5). Nitrogen rates were split into three equal parts and applied between planting and flowering for each crop. There was no yield difference due to nitrogen rate, although the rice crop receiving 90 kg N/ha had more lodging than rice receiving 60 kg N/ha. Nitrogen supplied by previous legume-crop residues, native soil N and split applications of fertilizer N have apparently contributed to the reduction in corn's yield response to applied N. These aspects of N fertilization are being investigated further in another study.

Organic-matter dynamics for the check treatment showed that total N levels declined to 60% of initial levels, with a progressive increase in C/N ratios (Figure 1). Nitrogen fertilizer requirements may increase in future crops if these trends result in decreased soil N availability.

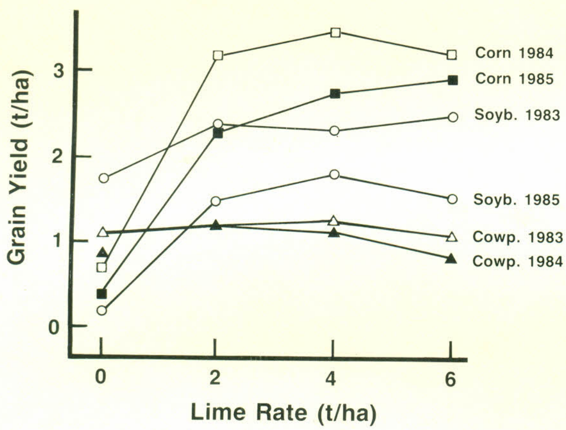

Figure 5. Yield response to four rates of lime for six consecutive crops.

Copper

Results for Cu fertilization have varied among succeeding crops. Trends for Cu response were evident in the yield- and foliar-analyses data for corn (Table 6), whereas cowpeas and soybeans have not indicated a response to Cu.

Liming

Treatments for lime were established at 18 months after burning, when Al saturation values had risen to 40%. The lime was obtained locally from a calcitic deposit (33% Ca, 0.8% Mg and 83% $CaCO_3$ equivalent). The rates of 2, 4, and 6 t/ha would be equal to 2.3, 4.6, and 6.9 t/ha, respectively, on a $CaCO_3$ equivalency basis.

Yields for corn and soybeans increased significantly to the application of 2 t/ha of lime (Figure 5). Corn and soybean yields without lime declined with each succeeding crop, as Al saturation levels increased from 52 to 77%. Relationships between relative yields and Al saturation for these lime treatments indicated a decline in corn and soybean yields for Al saturation levels greater than 20% (Figure 6). In the range of 0-60% Al saturation, cowpeas have not demonstrated a response to lime. Soybean and cowpea yield reductions with 6 t/ha of lime were associated with a decrease in foliar Mn levels.

Yield data for the lime treatments have indicated a prolonged residual effect to applications as low as 2 t/ha. Topsoil chemical properties support this observation (Figure 7). Lime treatments have maintained higher levels of pH and Ca and lower levels of Al during the initial 26 months. During this period, Al levels for the no-lime treatment have fluctuated between 1.1 and 1.4 meq/100 ml. Consequently, increases in Al saturation have resulted from a progressive decline in the levels of exchangeable bases. Topsoil levels of Ca and Mg have also declined during the initial 20 months

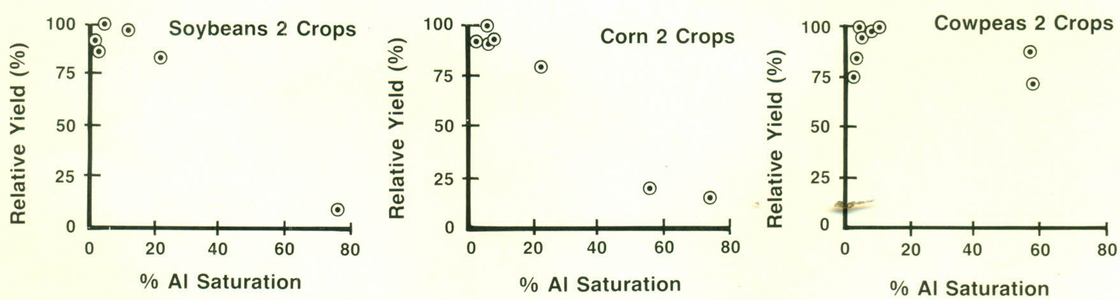

Figure 6. Relationships between relative yield and soil Al saturation for six consecutive crops grown on treatments with four lime rates.

on the three lime rates. Profile data for these lime treatments at 21 months after liming indicated that Ca had increased and Al had decreased in the subsoil (Figure 8). Liming, therefore, should also improve the proliferation of roots in the subsoil for acid-sensitive crops.

Sulfur

Fetilizers have been applied in concentrated forms in order to reduce transportation costs. Sulfur-carrying fertilizers, with the exception of Cu and Zn, have therefore been excluded thus far. Sulfur treatments, with rates of 0, 10, 20 and 30 kg/ha, were established with the first corn crop by adding varying proportions of ammonium sulfate to the fixed N rate. Yield data for four successive crops have not shown a significant response to these single S applications. Corn yields ranged from 2.4 to 2.8 t/ha, soybean yields from 1.4 to 1.6 t/ha, and cowpea yields from 1.1 to 1.3 t/ha. Although foliar S levels in general were low, from .15 to .18%, S applications did not increase leaf S concentrations.

Boron and Zinc

Treatments for these elements have been evaluated during the last two crops. Yield data and soil and leaf Zn data are shown in Table 7. Neither crop presented a significant yield response to B or Zn, although foliar Zn levels for corn were below the normal sufficiency range in the treatment without Zn.

Conclusions

Results from this study have provided insight into the timing and quantities for fertilizer inputs required for sustaining continuous crop production on these Oxisols. When compared with similar data obtained on Ultisols in Yurimaguas, inputs were noted to vary both in quantity and time of application. In summary:

1) Fertilizer P requirements were higher and occurred at an earlier stage in this clayey Oxisol, when compared to those on the Ultisols.

2) Lime applications for this Oxisol were delayed for a longer period in cultivation than for the Yurimaguas Ultisol.

3) Yield responses to micronutrients on the Manaus Oxisol have not been as consistent as those observed for the Ultisols in Peru.

Implications

The study shows, in general, that a farmer growing food crops in an ecosystem like that at Manaus will need to apply phosphorus immediately after slash and

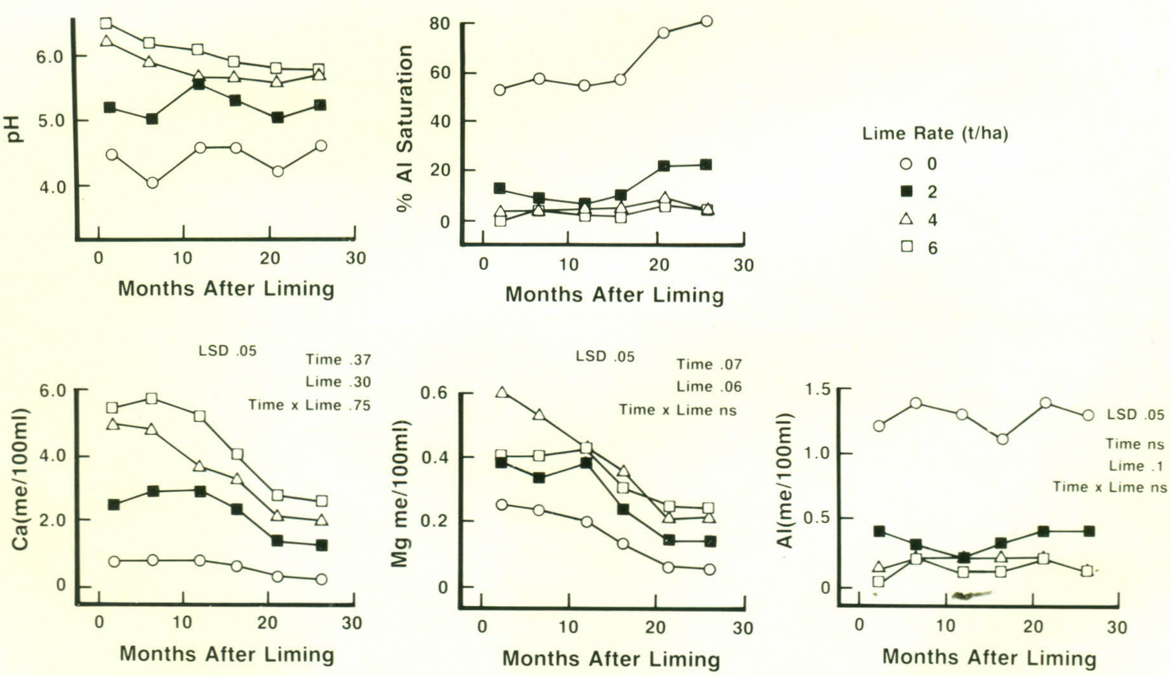

Figure 7. Topsoil acidity dynamics as a function of time after lime was applied to the Manaus Oxisol.

burn, potassium by the third crop, and lime at or before the 18th month after burning. Yields under this management system will be high by local standards, and comparable to those at Yurimaguas. Differences in the patterns of nutrient dynamics at Manaus and Yurimaguas point to the need for obtaining similar information on other major soil types in the humid tropics.

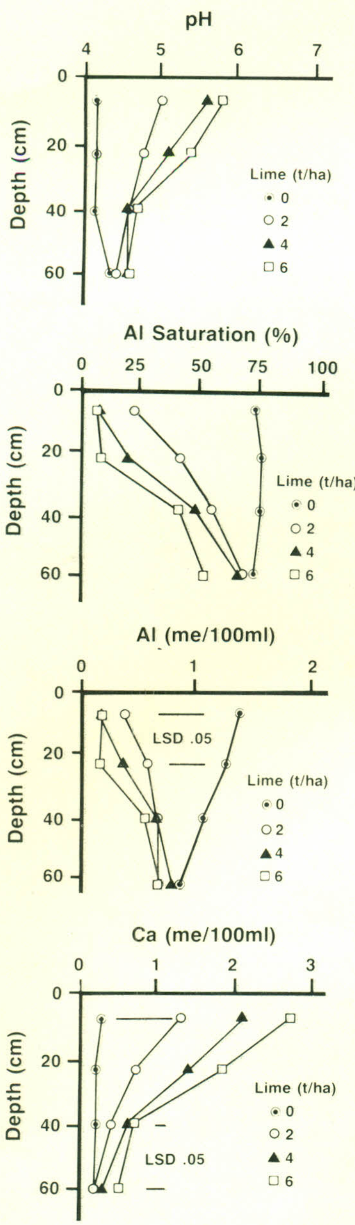

Figure 8. Soil-profile acidity acidity characteristics for the lime treatments at 21 months after liming.

Phosphorus Management In Humid Tropical Oxisols

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Phosphorus deficiency is common in Oxisols of the Brazilian Amazon. For clayey Oxisols, P fertilization could become an important economic factor, as their P sorption capacities are high, in the same range as those in Oxisols of the Cerrado region. Although several studies have demonstrated marked yield responses to P fertilization with annual crops on these soils, information has been needed on soil-test calibrations and the long-term effects of different strategies for P fertilization.

The objectives of this project were: 1) to obtain detailed P response curves and soil-test calibration data for the main annual crops cultivated in the region; 2) to obtain a description of the residual P fertilizer value, and 3) to provide indications of appropriate maintenance P fertilizer rates for sustaining adequate crop yields.

Eight consecutive crops of the annual corn-cowpea rotation have been harvested in this study. The ex-

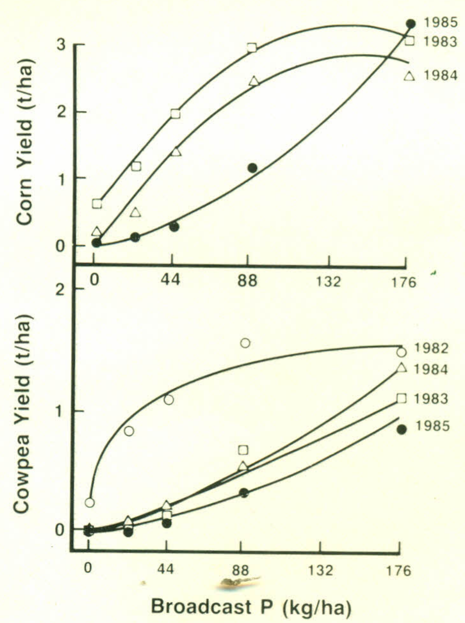

Figure 1. Corn and cowpea yield responses to initial broadcast P applications during the first four years.