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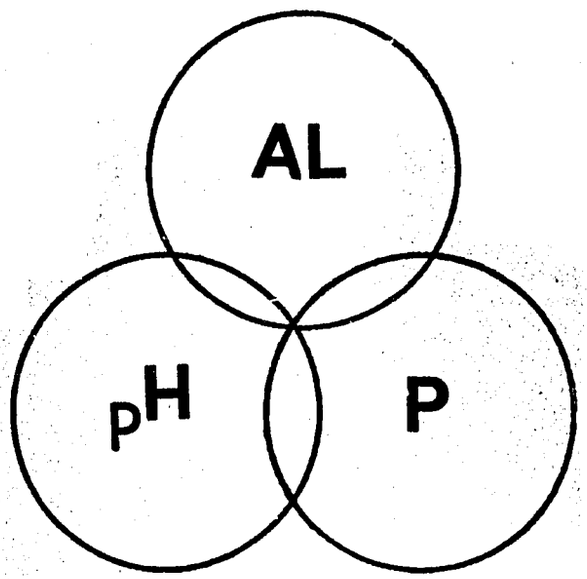

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EFFECT OF LIME ON pH, ACID EXTRACTABLE PHOSPHORUS, AND ALUMINUM IN HOCKLEY SOILS OF THE TEXAS GULF COAST PRAIRIE

J. C. Polanco and E. Brams*

The question, whether aluminum and phosphorus interactions in the soil have contributed to the degradation of pastures in the Texas Gulf Coast Prairie, has not been fully resolved. This information is not only necessary for pasture improvement innovations, but will aid in the formulation of procedures for the intensive cultivation of fruits and vegetables.

Concentrations of exchangeable Al and extractable P in the soil are functions of soil pH, particularly in acid, highly weathered soils of the tropical and sub-tropical regions. The ecosystems of the Texas Coastal Prairie, particularly the soils, have characteristics similar in many respects to the wet-dry regions of the humid tropics. In tropical soils, reduction in yields of field crops have, in part, been attributed to the fixation of souble phosphates into relatively immobile Fe and Al phosphates under acid conditions. In a limited number of cases this situation has been alleviated by heavy applications of lime.(2,7)

It is the purpose of this publication to discuss the influence of lime on the concentration of exchangeable Al and acid extractable P and the interactions between them in the soil as they affect the growth of ryegrass in a Hockley fine sandy loam.

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SITE, METHODS, AND MATERIALS

The experimental site was located on Hockley fine sandy loam of the campus farm of Prairie View A&M College. The site was a degraded Coastal Bermuda grass pasture which had not been limed or fertilized for 10 years prior to the experiment. The pH of the soil averaged 4.9, an acid extractable P level of 36 ppm, and an exchangeable Al concentration of 13.4 ppm.

The experimental design tested 5 levels of lime replicated 5 times in a randomized block design. The treatment variables consisted of 0, 3.4, 6.8, 10.2, and 13.6 M tons of lime/ha.

Lime was broadcast on August 20, 3 weeks before fertilization and planting, and was disked into the top 15 cm of soil. The lime material consisted of 95% pure $CaCo_3$ where 80% was less than 10 mesh fine.

The plots were fertilized September 20, 1971 at the rate of 560 kg/ha of 10-20-20 disked into the top 15 cm of soil.

Ryegrass was planted at a rate of 56/kg/ha two days after fertilization. The site was not disked or harrowed after seeding.

Soil samples were taken every month during the period of the test at the 0-15 cm depth. Composite samples from each plot were mixed, and a representative sample of approximately 0.5 kg of each was air-dried and stored in plastic bags.

Since root membrane systems control transport of ions from the soil into the plant, the roots can be employed as diagnostic agents in determining the soil fertility status and fertilized potential for a particular soil. (10) Accordingly, root samples from 6 sites per plot were taken, composited, and stored in plastic bags for processing. The fresh roots were washed free of soil in tap water, and rinsed in distilled water. Samples of feeder roots

were excised, rinsed in deionized water, and ashed at 600°C. The residue was solublized in 1 N HCL made to 50 ml volume and stored in leakproof plastic vials.

Soil phosphorus was determined in Bray (P1) extract (0.02 N NH_4 F 0.1 N HCL at 1:50 soil to solution ratio) and modified Morgan extract (P_2), (1.25 N CH_3COOH + 0.625 N NH_4 OH, pH 4.8) at 1:5 soil to solution ratio respectively. The phosphorus was analyzed by the reduced phosphomolybdate method and percent transmission read at 660 mu.

Soil Al was determined in a 1 N KCL extract (Al_2) and 0.1N-HCL (Al_1) extract respectively employing a 1:5 soil to solution ratio in each case. The concentration of Al was measured by the Aluminon Method and the percent transmission read at 530 mu.

Soil pH was determined by the glass electrode using a 1:1 soil/(1)N KCL ratio. (pH_2), and 1:1 soil/water ratio.

Root Al and P were analyzed in the acid solution of ashed feeder roots by the method described for the soil P and Al extracts.

Results and Discussion

The results are discussed by relating lime treatments to soil pH, P and Al and plant parameters of yields, root Al and P.

Soil pH. Lime had significantly increased the soil pH from 4.9 in the control plots to 6.2 in plots receiving 13.6 M tons of lime/ha as shown in Fig. 1. Figure 1 depicts lime requirement curves for the period between September and March and for a 12 month period beginning in September. The curvilinear slopes indicate a marked increase of soil pH up to 6.8 M tons of lime/ha after which the soil pH begins to level off about pH 6.3. Further addition of lime up to 13.6 M tons/ha only increased the pH to slightly over 6.0 for the 6th month equilibration period and to 6.4 by the 12th month.

Explicit in the data shown by these curves is the fact that a minimal rate of lime permitted to equilibrate for 12 months will induce a comparable pH effect of a greater lime rate allowed to equilibrate only 6 months. For example, it would require approximately 2.8 M tons of lime/ha to raise the pH of this soil from 5.3 to 5,8 over a 6 month period, but only 1.8 M tons/ha if the equilibration time was extended to 12 months.

Based on calculations using cation exchange capacity value of 14.3 m.e./100 gr soil for the Hockley series, slightly over 3 M tons of lime/ha would be required to saturate the cation exchange sites with Ca++ and reach the equilibrium pH range. Reference to the curve in Fig. 1 indicates however, that more lime would be required to adjust the soil to a given pH than the calculations would indicate. Several reasons may account for the soil pH not changing more. They may include failure of all of the lime to dissolve and/or a slow release of exchangeable Al. The latter situation is probably unlikely as will be shown

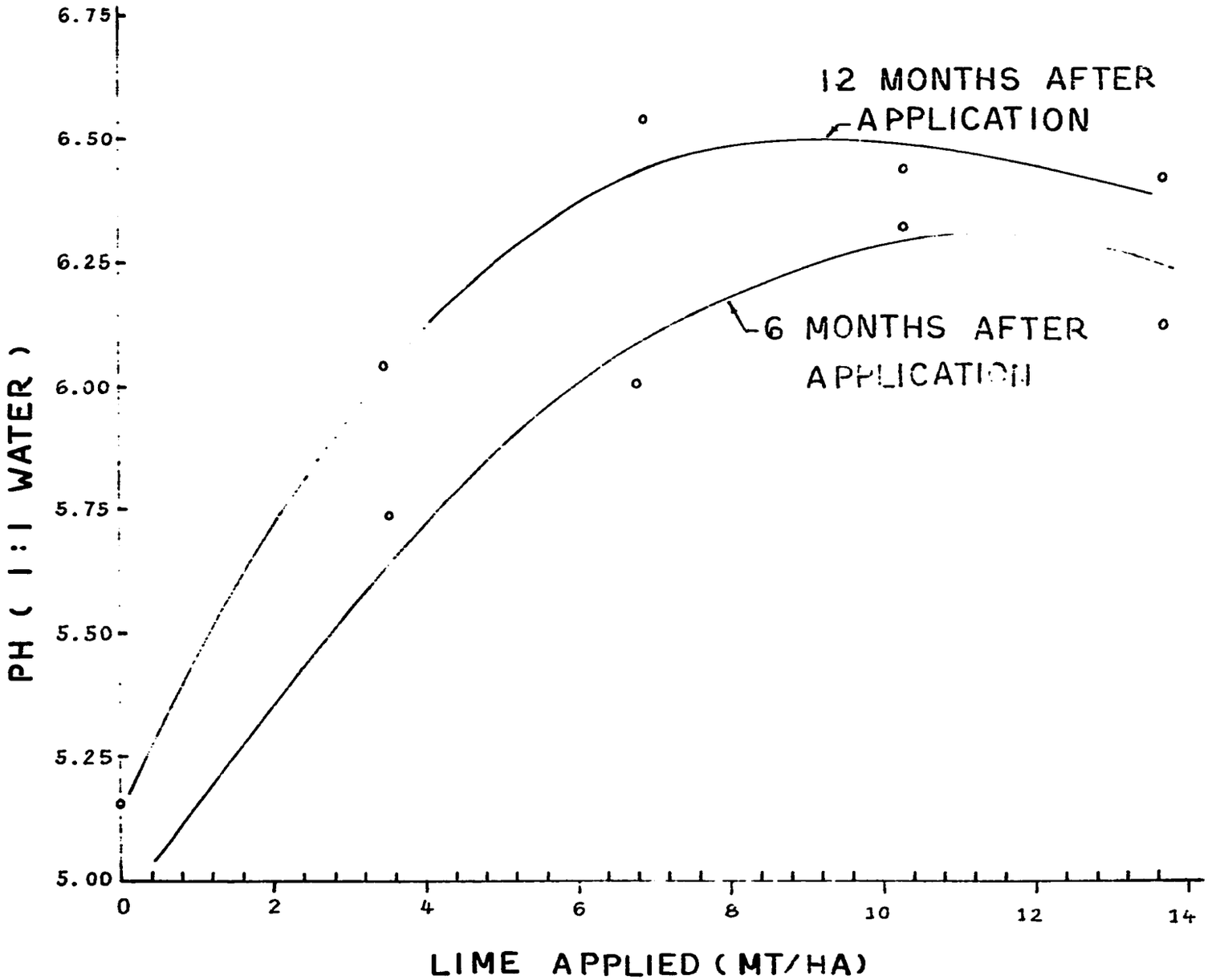

FIG.1 EFFECT OF LIME TREATMENTS ON SOIL PH

in the discussion which will follow.

The soil pH increased rapidly after the application of lime and approached equilbrium conditions in the 3rd month as shown in Figure 2. by the 6th month, the pH again continued to rise reaching new equilbrium values in the 12th month ranging from 6.0 to 6.4 for the various lime treatments excluding the check treatment which remained essentially unchanged.

The time required for a soil to achieve pH equilbrium after lime applications is a function of climatic conditions and the physical and chemical properties of the material and soil but apparently not of lime rates, at least within the rate ranges used in the experiment.

Soil P. The quantities of soil P obtained by either the Bray or Morgan extractants did not vary significantly with lime treatments as shown in Table 1; only the concentration of acid extractable P (Bray-P_1) significantly increased between September and March, but the trend was independent of lime treatments as shown in Fig. 3 and Table 1. Trends such as this suggest that climatic conditions and the concomitant mineralization of organic P might be an important factor affecting the availability of soil P as it relates to the organic-bound Al in this region (8).

Soil Al. Lime treatments did not significantly affect the quantities of soil Al extracted with 0.1 N HCL. However, the exchangeable Al, or the portion extractable with 1.0 N KCL varied inversely and significantly with applied lime as deplicted in Figure 4. The exchangeable soil Al ranged from a maximum of 23 ppm in the control plots to 3 ppm where 13.6 M tons of lime/ha were

applied. In this situation, about 2% of the cation exchange sites in the control plots were saturated with Al, a value far below the 30% Al saturation established as a minimum for good production of corn and soybeans, whereas only 0.25% of the exchange sites in the high lime plots were Al saturated; this is a reduction of 88% as a direct result of liming. It is important to note that the strong flex point in Figure 4 occurs when 70% of the exchangeable Al of the degraded pastures has been replaced after 3.4 tons of lime were applied. This suggests that replacement of approximately 3/4 of the exchangeable Al of the control plots would not achieve the maximum soil pH level but as Kamprath reported (5), it indicates the amount of lime that would create an environment optimum for plant growth with respect to exchangeable Al on the colloids and in the soil solution. The very strong relationship between soil pH and exchangeable Al is also shown in the correlation matrix of Table 2.

The concentration of exchangeable soil Al decreased to less than 5 ppm within one month after lime application and remained essentially at this level for the duration of the experiment. (Figure 5.). However, exchangeable Al in the control plots continued to increase, reaching an average of 35 ppm at the termination of the experiment. Soil pH and concentrations of exchangeable Al are correlated, a relationship also observed in Figs. 2 and 5 where these parameters reach equilibrium concentrations in the period between November and December after initial application of lime in September.

On the other hand, the concentration of acid-extractable Al progressively increased in both control and lime plots during the growing season to a level

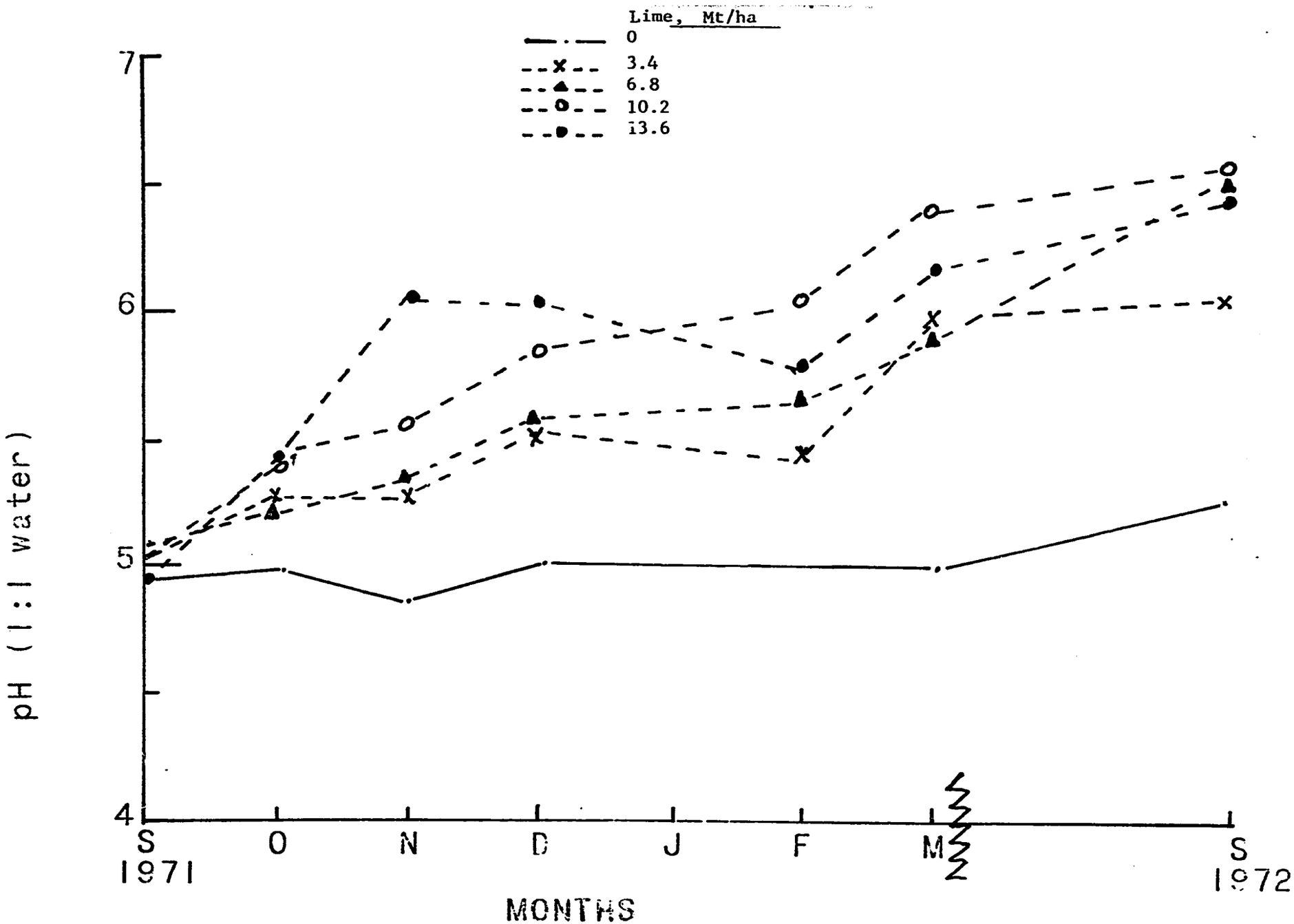

Fig.2 Influence of lime treatments on soil pH during period of experiment.

Table 1 Analysis of Variance of Lime Treatments and Soil and Plant Parameters by Months

Parameters	Months					
	September (1)	October	November	December (2)	February	March
	F Values					
Treatments and P_1 (3)	1.03	1.06	1.29	2.66	0.51	1.37
Treatments and P_2	0.73	0.11	2.11	0.79	1.13	1.07
Treatments and Al_1	0.83	0.80	2.03	0.90	0.21	2.23
Treatments and Al_2	1.41	8.48*	11.69*	17.24*	14.27*	22.67*
Treatments and pH_1	1.10	8.06*	9.77*	11.34*	15.16*	21.04*
Treatments and pH_2	1.19	14.77*	1.82	15.90*	15.78*	27.07*
Treatment and Yield						0.85
Treatment and Root Al						1.78
Treatment and Root P						9.40*

*Significant at 5% level

(1) First sampling; no lime and fertilizer applied

(2) Janaury values not available

(3) P_1 in Bray Extractant, P_2 in modified Morgan Extractant, Al_1 in 0. INHCL extractant, Al_2 in INKCL extract, pH_1 in water extractant, pH_2 in 1.0NKCL extractant

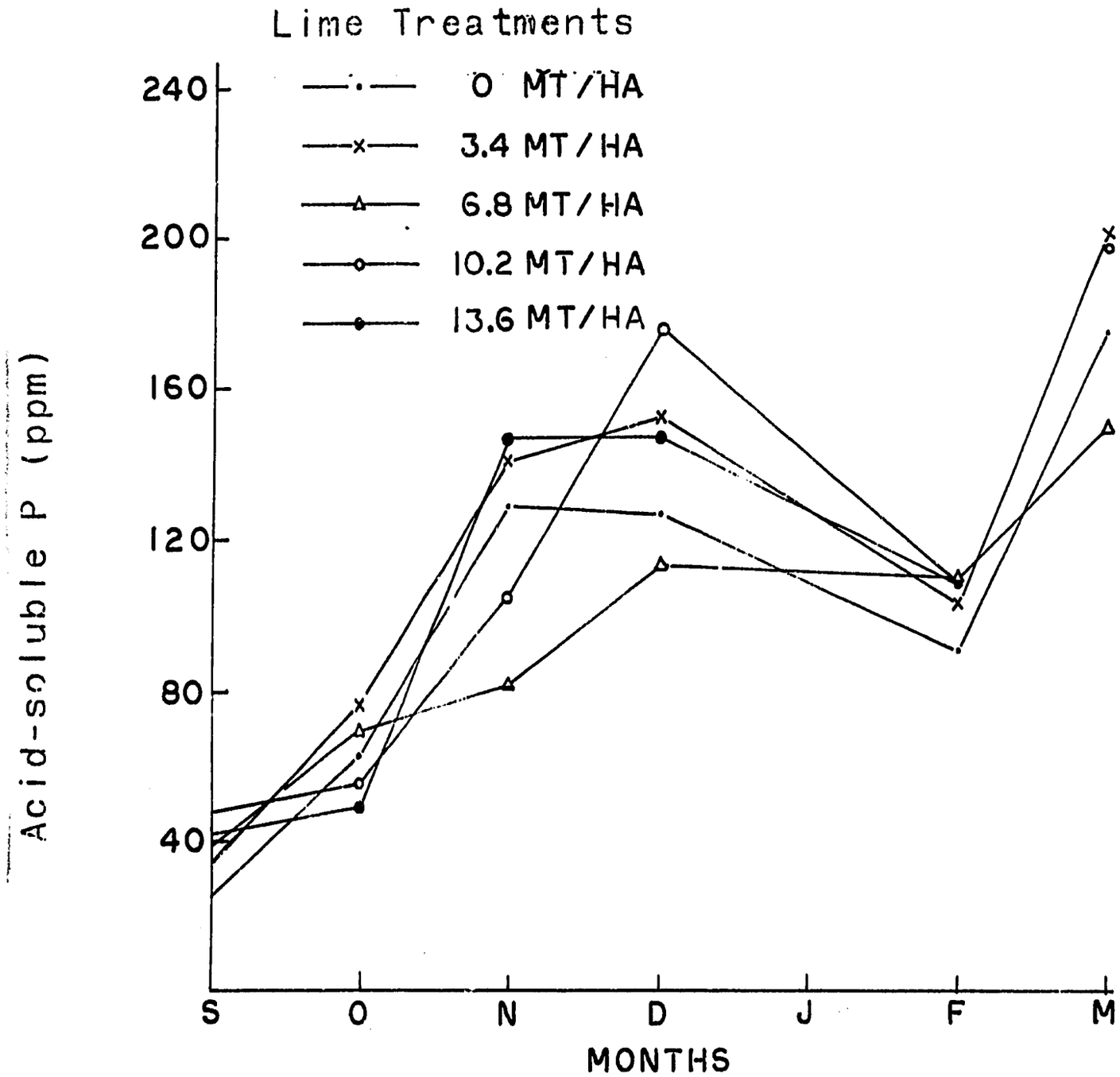

FIG.3 FLUCTUATIONS IN ACID-SOLUBLE P IN TIME AFTER LIME APPLICATION

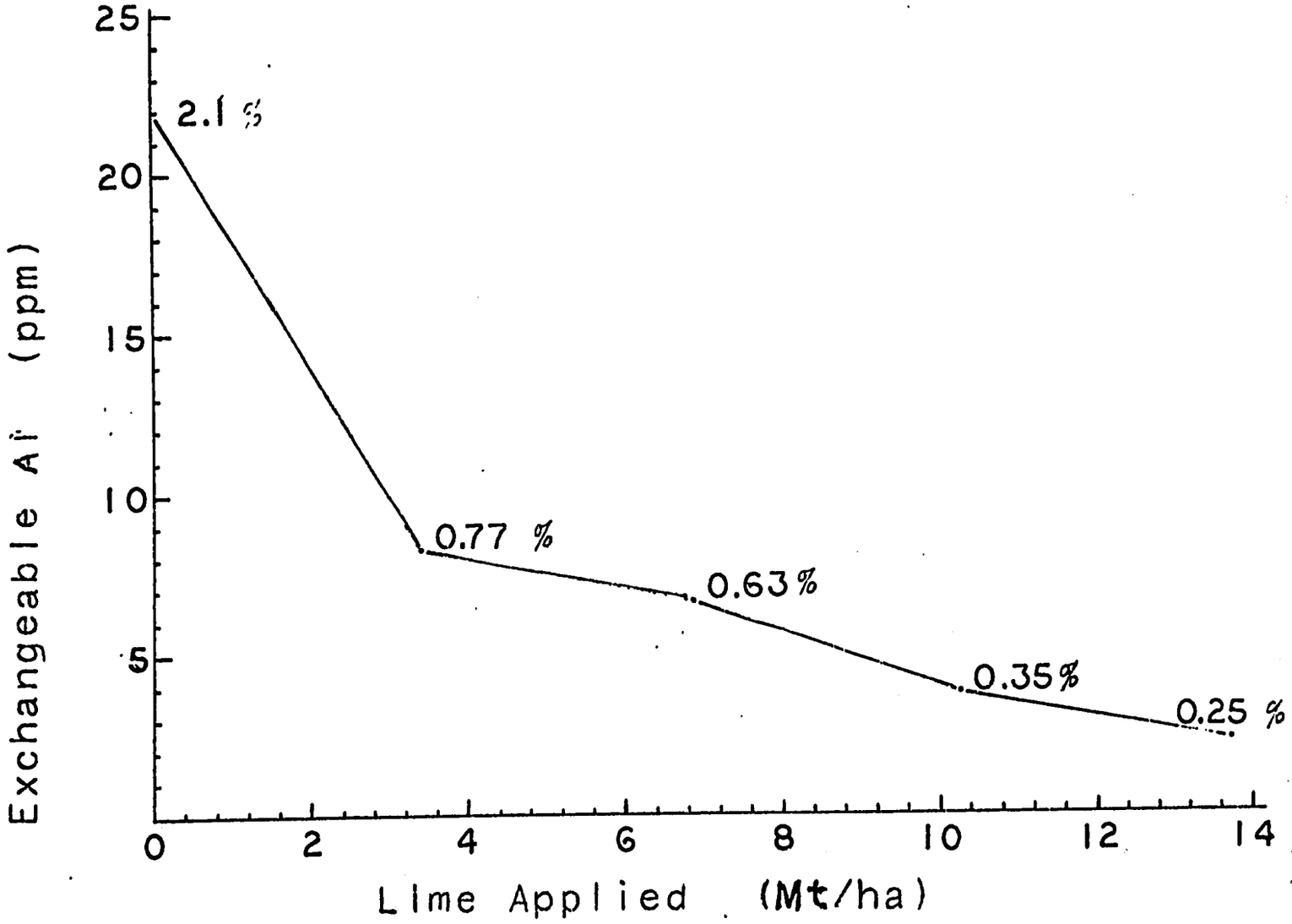

Fig 4. Exchangeable soil Al as a function of lime treatments. Values given on the curve show percent Al saturation of cation exchange sites under different levels of applied lime.

* Significant at the 5% level
** Significant at the 1% level

Table 2. Correlation matrix of soil parameters by months

Soil Parameters	Months	P_2	Al_1	Al_2	pH_1	pH_2
P_1	September	0.78**	0.39*	0.23	-0.37	-0.25
	October	0.53**	0.21	0.15	-0.08	-0.07
	November	0.86**	0.51**	-0.01	0.40*	0.41*
	December	0.45*	0.28	-0.21	0.05	0.22
	February	0.21	0.50**	-0.12	0.23	0.25
	March	0.72**	-0.01	-0.19	0.07	0.13
P_2	September		0.32	0.16	-0.53**	-0.36
	October		0.36	-0.10	0.20	0.16
	November		0.29	-0.28	0.69**	0.56**
	December		-0.02	-0.28	0.35	0.45*
	February		0.00	-0.06	0.25	0.19
	March		0.14	-0.33	0.30	0.40
Al_1	September			0.19	-0.46*	-0.48*
	October			0.01	-0.11	0.28
	November			0.30	-0.25	-0.19
	December			0.17	-0.12	-0.18
	February			0.18	-0.03	-0.05
	March			0.06	0.11	0.14
Al_2	September				-0.08	-0.22
	October				-0.53**	0.58**
	November				-0.59**	-0.49*
	December				-0.70**	-0.74**
	February				-0.71	-0.79**
	March				0.79**	-0.82**
pH_1	September					0.89**
	October					-0.21
	November					0.80**
	December					0.91**
	February					0.93**
	March					0.98

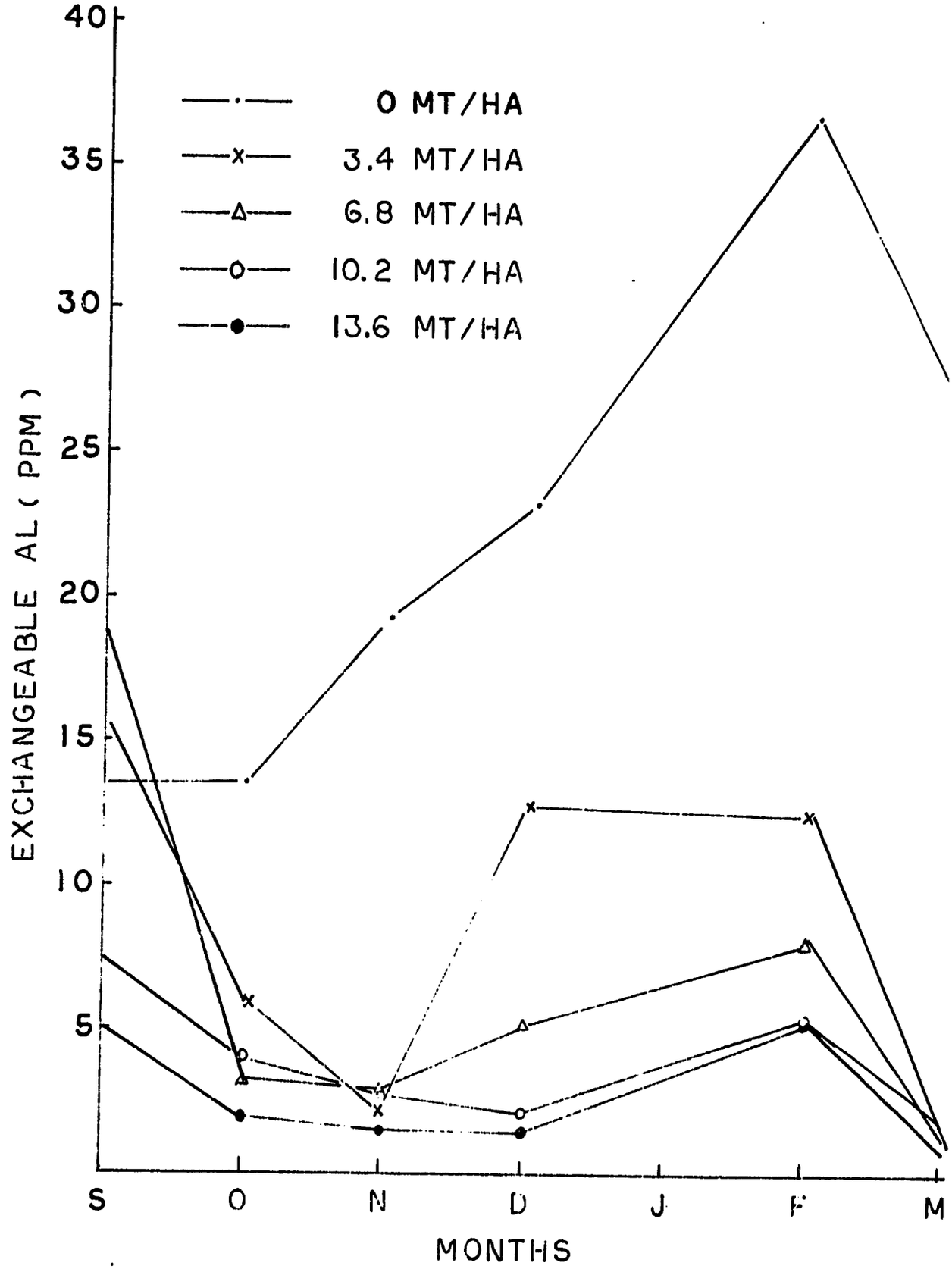

FIG.5 FLUCTUATION OF EXCHANGEABLE AL AS FUNCTION OF TIME AFTER LIMING

of 500 ppm (Fig. 6). This increase was not a function of lime treatments but apparently was attributable to warm and moist climatic conditions enhancing the mineralization of organic matter following the cultivation of the degraded pasture.[8]

Yields of Ryegrass - No significant yield differences were measured for any level of applied lime (Table 2). Yields over all plots averaged 9270 kg/ha and represented only a single cutting at the termination of the experiment in March. Conclusions relative to the effect of lime on yields cannot be established for this length of study.

Root Al and P. - Lime treatments did not significantly affect the concentration of root Al at harvest (Table 1). Although exchangeable soil Al did vary with treatments the total concentration of available Al in the soil was too low to materially affect the uptake and accumulation of Al in the root.

At the time of sampling in March, the Al concentration in the root over all plots averaged 1400 ppm. This is a relatively high level for forage crops, but apparently Al levels of this magnitude were not a yield - limiting factor under the conditions of this experiment (3,10).

The concentration of accumulated P in the root, did, however, vary directly with lime treatments as shown in Fig. 7 and Table 1. Apparently, lime increased the proliferation of grass roots and enhanced the uptake of P. Since grass yields did not vary with treatments, the concentration of root P which averaged 180 ppm in ryegrass roots growing in the 0-lime plots was adequate to meet the requirement of the grass and higher P concentrations in the root did not elicit greater yields.

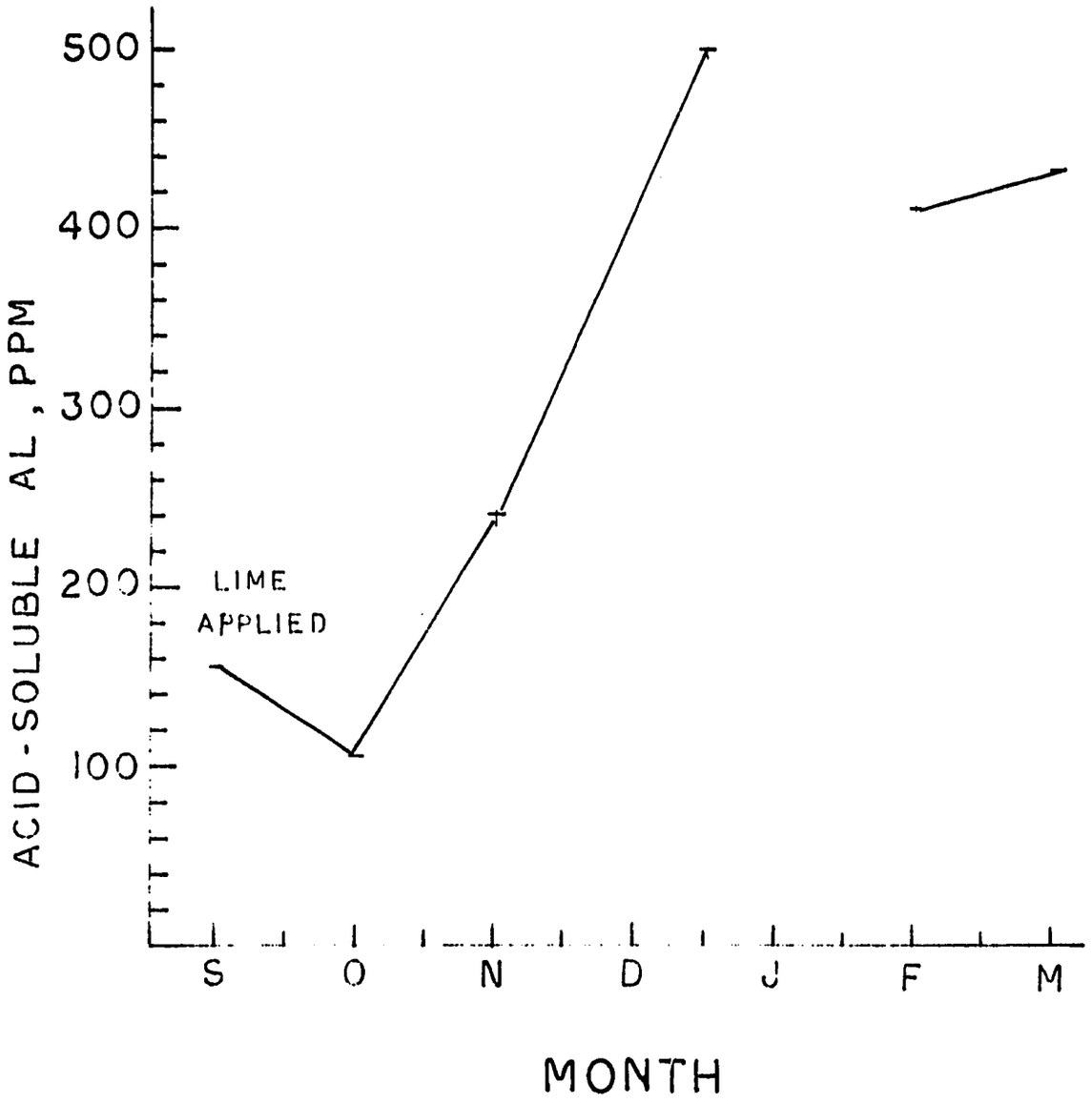

FIG. 6 CONCENTRATION OF ACID-SOLUBLE SOIL AL AS A FUNCTION OF TIME

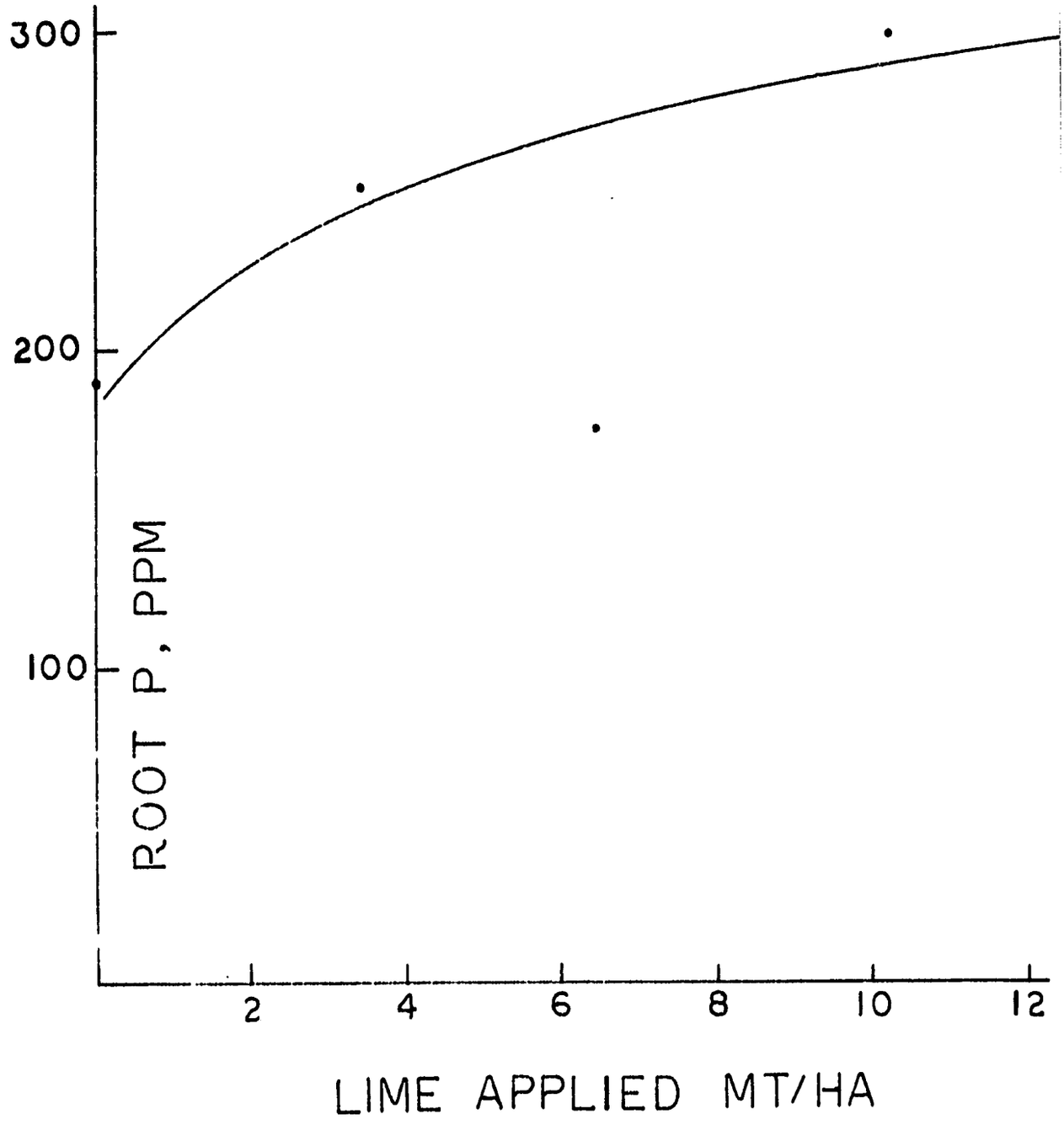

FIG. 7 ACCUMULATION OF ROOT P IN RYE-GRASS AS A FUNCTION OF LIME TREATMENTS

Correlations Between Soil Parameters and Lime Treatments

The significant, negative correlation between exchangeable Al and soil pH previously referred to corroborates the documented evidence (1, 2, 7, 4) that moderate applications of lime can reduce exchangeable Al to extremely low base saturation levels.

The lack of correlations between exchangeable soil Al and soil P (Table 2) tends to modify the prevalent assumption that, in highly weathered acid soils, particularly of the tropics, P-fixation by Al is a dominant reaction which contributes significantly lower crop yields. The fact that correlations between these soil parameters were not detected in the Hockley soils suggests that if P deficiencies should occur, they probably would be the result of a reduction in the pool of labile P, which could easily be corrected by the addition of soluble and inorganic fertilizer. Evidence that residual P was not fixed in acid soil was also obtained in studies of acid, relatively young soils in the humid tropics (1)

SUMMARY AND CONCLUSION

The application of 6.8 tons of lime/ha to Hockley fine sandy loam raised the pH of a degraded Coastal Bermuda grass pasture from 4.8 to 6.0 while further additions of lime up to 13.6 M tons/ha increased the pH only 0.4 unit to a maximum of 6.4. Equilibrium of the soil pH to the above levels was achieved 4 months after lime application while pH values increased approximately 0.3 unit if the equilibration time was extended for 12 months.

Lime, up to 13.6 M tons/ha, did not affect the quantities of acid soluble soil P (Bray P_1) extracted. However, soil P levels had increased progressively during the growing season. It is probable that mineralization of organic matter enhanced by rainfall and relatively high temperatures, had contributed to the liberation and the steady increase in concentration of acid soluble P from these soils (6, 9).

Exchangeable soil Al in the degraded pasture at pH 4.8 averaged 23 ppm and was reduced to less than 8 ppm one month after the application of 3.4 M tons of lime/ha. After liming, the percent Al saturation of the cation exchange sites fell from 2.8 to less than 1%, (far below the 33% Al saturation level advocated by Kamprath (4), above which Al begins to interfere with the growth of agronomic plants, particularly in acid, mineral soils. Concentration of exchangeable Al in the unlimed plots was at a level too low to affect the growth of ryegrass in these soils or induce an interaction with acid extractable soil P.

However, the acid-extractable Al steadily increased during the growing season, the effect was probably attributable to mineralization of organic

matter and not to lime treatments. Neither the yields of ryegrass nor the accumulation of Al in the feeder roots of 6 month old ryegrass were influenced by lime treatment. Concentration of 1400 ppm of Al in the ryegrass feeder roots apparently did not affect yields or the growth patterns. The concentration of root P, however, did vary significantly and positively with lime treatment, suggesting that an increase in proliferation of the root system and an enhancement of P accumulation in the root had occurred, but in concentrations exceeding the requirements for optimum yields. Apparently, soil P levels (Bray P_1) of 150 ppm were adequate to sustain good yields of ryegrass.

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