TRACING THE MINERAL FROM THE SOIL TO THE PLANT TO THE ANIMAL BLOOD

Part III—The Effect of Phosphorus and Lime on the Mineral Composition of the Soil and Grass

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INTRODUCTION

A field experiment was started on June 25, 1943 in soil type Fajardo clay, at the Agricultural Experiment Station, Río Piedras, to study the effect of the application of lime on the mineral composition of the soil and of the grass. To raise this acid soil to about pH 6.5, the limed plots received applications from eight to ten tons of limestone per acre. The field was planted to a mixture of Para grass *Panicum purpurascens* and Carib grass *Eriochloa polystachya* and seven consecutive crops were harvested in a period of three years and two months up to August 23, 1946. The yields and the mineral analyses for the second, third, and fourth grass crops, and for the soil samples, taken 15 and 23 months after liming, were reported by Bonnet (1) and then by Bonnet and Riera (2). In the latter paper, the methods used and the protein contents for the five crops, as well as the yield of the fifth crop, are also given. The mineral analyses comprise calcium, magnesium, manganese, phosphorus and iron. The results obtained (1) were as follows: "The increase of available calcium and phosphorus and the decrease of available iron in the soil due to liming was highly significant 15 and 23 months after the lime was applied to the soil. The decrease of available manganese in the soil due to liming was highly significant 15 months after liming and significant 23 months after liming. The difference between the available magnesium content of the limed and unlimed soil was not significant.

"The increase of calcium and the decrease of manganese in the grass due to liming was highly significant for the second and third crops; the increase of calcium was significant for the fourth crop, and the decrease of manganese was not significant. The increase of phosphorus in the grass due to liming

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was highly significant for the second and fourth crops but was not significant for the third crop. There was no significant change in the iron content of the grass due to liming in the three crops and in the magnesium content of the second and fourth crops. The increase of magnesium in the grass crop due to liming was highly significant for the third crop.

"The increase in the grass yield due to liming was significant for the first and third crops. The difference between the respective yields of the unlimed and limed soil for the second, fourth and fifth crop, and for the total of five crops, was not significant."

EXPERIMENTAL WORK

The same field used previously by Bonnet and Riera (1, 2), was selected for the experiment.

Each of the original 18 plots, half of which received lime, were subdivided. The field consisted then of 36 plots, each with an area of two-tenths of an acre. The four treatments were: check, unlimed, phosphorus and lime-phosphorus. Superphosphate at the rate of 200 pounds P_2O_5 per acre was applied in the row, on November 7, 1945.

Soil samples were taken to a six-inch depth from each plot on February 18, 1946, 32 months after the lime or 3.4 months after the phosphorus applications. Samples were taken again on September 13, 1946, 39 months after the lime or 10.3 months after the phosphorus applications.

Two other crops were harvested; the sixth, in the middle of March 1946 when about eight months old; and the seventh, in the third week of August 1946 when about five months old. The latter crop received an application of ammonium sulphate at the rate of 500 pounds to the acre.

PRESENTATION AND DISCUSSION OF DATA

The pH and the amounts of available calcium, magnesium, manganese, phosphorus and iron, in the soil samples taken 32 and 39 months after liming or 3.4 and 10.3 months after the phosphorus application, are reported in table 1. The table contains also the mineral data reported previously (1, 2) for the soil samples taken 15 and 23 months after liming, but this time the figures are expressed in terms of pounds to the acre rather than in parts per million.

TABLE 1.—SOIL pH AND AVAILABLE CALCIUM, MAGNESIUM, MANGANESE, PHOSPHORUS AND IRON, IN FAJARDO CLAY (dry basis).

Time of Sampling	Treatment	pH	Pounds to the Acre				
			Ca	Mg	Mn	P	Fe
15 months after liming	Unlimed	4.6	1,698	360	84	26	34
	Limed*	6.3	13,662	344	16	122	4
23 months after liming	Unlimed	4.4	1,984	312	58	42	90
	Limed	6.3	10,702	312	10	112	24
32 months after liming or 3.4 months after phosphorus was applied	Unlimed	4.4	1,780	334	188	82	102
	Limed	6.3	11,412	442	42	156	16
	Phosphorus**	4.3	1,902	288	148	82	104
	Lime & Phosphorus	6.0	11,108	326	56	164	22
39 months after liming or 10.3 months after phosphorus was applied	Unlimed	4.6	1,580	346	80	52	74
	Limed	6.0	9,360	344	14	74	10
	Phosphorus	4.5	1,920	294	82	62	90
	Lime & Phosphorus	6.3	11,500	292	12	110	10

* Limestone, 8 to 10 tons to the acre.
** Superphosphate, 200 lbs. P_2O_3 to the acre.

The soil reaction varied from pH 6.0 to 6.3 in the limed soil, 32 and 39 months after the lime was applied. That of the unlimed soil varied from pH 4.3 to 4.6.

The effect of the lime on the mineral composition of the soil, 32 and 39 months after liming, was similar to that reported by Bonnet and Riera (1, 2) for the soil samples taken 15 and 23 months after liming. That is, there was a highly significant increase in the available calcium and a highly significant decrease of the available manganese and iron, of the soil, and no significant difference for the magnesium. There was also a highly significant increase in the soil available phosphorus, 32 months after the lime application, but this time, there was no significant increase of the soil available phosphorus during the 39 month period.

When phosphorus was applied, without lime, there was no significant difference in the soil available phosphorus. When phosphorus was applied with the lime there was a highly significant increase in the soil available phosphorus, 3.4 and 10.3 months after the phosphorus application. At the 3.4 month period, the lime treatment was as effective as the phosphorus-lime treatment, toward increasing the soil available phosphorus. But seven months later, the phosphorus-lime treatment was significantly better with regard to the increase of soil available phosphorus.

The addition of phosphorus, without the lime, had no significant effect in changing the available calcium, magnesium, manganese, phosphorus, and iron, of the soil.

The time of sampling and the mineral composition of the seventh grass crop are given in table 2 together with that for the second, third and fourth crops reported previously by Bonnet and Riera (1, 2).

TABLE 2.—TOTAL CALCIUM, MAGNESIUM, MANGANESE, PHOSPHORUS AND IRON IN FOUR CROPS OF PARA-CARIB GRASS GROWN IN SOIL TYPE FAJARDO CLAY (air dry basis).

Crop Numbe	Time of Sampling	Treatment	Parts per Million				
			Ca	Mg	Mn	P	Fe
Second	14 months after liming	Unlimed	2,199	1,509	229	2,100	149
		Limed	2,811	1,638	137	2,430	158
Third	17 months after liming	Unlimed	2,008	1,824	156	2,749	196
		Limed	3,351	2,212	84	3,047	160
Fourth	22 months after liming	Unlimed	2,919	2,166	243	2,450	124
		Limed	3,381	2,088	181	2,929	121
Seventh	38 months after liming or 9.6 months after phosphorus application	Unlimed	2,973	2,328	220	1,566	175
		Limed	3,839	2,171	125	1,991	111
		Phosphorus	3,229	2,216	247	1,829	126
		Lime & Phosphorus.	3,762	2,170	129	2,082	130

The results obtained with the seventh grass crop due to the lime application were similar to those obtained with the second, third and fourth crops, as reported by Bonnet and Riera (1, 2). When lime or lime and phosphorus were applied, there was a highly significant increase of calcium and phosphorus and a highly significant decrease of manganese in the grass but the iron and magnesium contents were not affected. When phosphorus was applied without lime, there was a significant increase of phosphorus in the grass, but no significant change in the other minerals. There was also a significant difference between the phosphorus content of the grass that received phosphorus and that with calcium and phosphorus. The latter treatment had the higher content. There was no significant difference between the phosphorus content of the limed grass and the grass that received phosphorus or lime and phosphorus.

The fertilizer added to the soil, on November 7, 1945 contained 200 pounds of P_2O_5 to the acre equivalent to 87 pounds of P. This fertilizer was applied in the row of the corresponding plots, after the fifth grass crop was harvested. The first set of soil samples was taken 3.4 months after the fertilizer was applied and about one month previous to the harvest of the sixth grass crop. The second set of soil samples was taken 10.3 months after the fertilizer was applied or about three

weeks after the seventh grass crop was harvested. The available phosphorus present in the soil at the two sampling periods is reported in table 3.

TABLE 3.—AMOUNT OF AVAILABLE PHOSPHORUS PRESENT IN THE SOIL AT TWO SAMPLING PERIODS

Treatment	Available Phosphorus in the Soil after Superphosphate was Applied	
	3.4 months	10.3 months
	(P)	(P)
Unlimed	82	52
Limed	156	74
Phosphorus*	82	62
Lime and Phosphorus	164	110

* Received 87 lbs. P to the acre.

At the 3.4 month sampling period, the 87 pounds of available phosphorus (P) to the acre added in the fertilizer, were unaccounted for or fixed by the soil.

The yields and the mineral composition of the crops of Para-Carib grass for all the crops analyzed are reported in table 4. The minerals removed by each grass crop from the soil, in the unlimed, limed, phosphorus, and lime-phosphorus treaments, in pounds to the acre, are reported in table 5. The data were calculated from the mean values obtained in table 4.

TABLE 4.—YIELD OF CALCIUM, MAGNESIUM, MANGANESE, PHOSPHORUS, AND IRON IN FOUR CROPS OF PARA-CARIB GRASS GROWN IN FAJARDO CLAY
(dry basis)

Crop No.	Treatment	Yield Tons Acre	Ca Percent	Mg Percent	Mn Percent	P Percent	Fe Percent
2	Unlimed	2.24	.220	.151	.023	.210	.015
3	Unlimed	2.88	.201	.182	.016	.275	.020
4	Unlimed	2.68	.292	.217	.024	.245	.012
7	Unlimed	3.19	.297	.233	.022	.157	.018
MEAN		2.75	.252	.196	.021	.222	.016
2	Limed	2.41	.281	.164	.014	.242	.016
3	Limed	3.10	.335	.221	.008	.305	.016
4	Limed	2.59	.338	.209	.018	.293	.012
7	Limed	3.36	.384	.217	.013	.199	.011
MEAN		2.86	.335	.203	.013	.260	.013
7	Phosphorus	3.50	.323	.222	.025	.183	.013
7	Lime and Phosphorus	3.76	.376	.217	.013	.208	.013

The amount of calcium removed from the soil by each crop of Pará-Carib grass (table 5) varies from 14 pounds to the

TABLE 5.—POUNDS TO THE ACRE OF CALCIUM, MAGNESIUM, MANGANESE, PHOSPHORUS AND IRON REMOVED BY EACH CROP OF PARA-CARIB GRASS GROWN IN UNLIMED AND LIMED FAJARDO CLAY WITHOUT OR WITH PHOSPHORUS

Treatment	Ca	Mg	Mn	P	Fe
Unlimed	13.84	10.77	1.15	12.19	.88
Limed	19.19	11.63	.74	14.89	.74
Phosphorus	22.62	15.54	1.75	12.81	.91
Lime and Phosphorus	28.29	16.33	.98	15.65	.98

acre, in the unlimed treatment, to 28 in the lime-phosphorus treatment; the magnesium from 11 to 16; the phosphorus from 12 to 16 respectively, and the manganese and iron about one pound. The amount of available calcium in the soil, 39 months after the lime or 10.3 months after the phosphorus application (table 1) varies from 1580 pounds to the acre in the unlimed treatment, to 11,500 in the lime-phosphorus treatment; the magnesium from 346 to 292; the manganese from 80 to 12; the phosphorus from 52 to 110 and the iron from 74 to 10, respectively. This acid soil (pH 4.6) was well supplied with the above mentioned minerals for seven consecutive crops of Para-Carib grass without the addition of lime and phosphorus.

The yield and the age of each of the seven crops of Pará-Carib grass harvested are given in table 6. Bonnet and Riera

TABLE 6.—YIELD IN TONS TO THE ACRE OF SEVEN CONSECUTIVE CROPS OF GREEN PARA-CARIB GRASS HARVESTED IN FAJARDO CLAY

Treatment	Number and Age of Crops and Fertilizer Applied						
	1 5.75 mo. No Fertilizer	2 8.25 mo. No Fertilizer	3 3.50 mo. Nitrogen* Applied	4 4.25 mo. No Fertilizer	5 3.50 mo. Nitrogen* Applied	6 8.00 mo. No Fertilizer	7 5.00 mo. Nitrogen* Applied
Unlimed	8.98	7.47	9.59	8.92	9.82	1.95	10.64
Limed	11.0	8.03	10.33	8.62	9.81	1.53	11.20
Unlimed with Phosphorus**	.....	.....	.....	.....	.....	1.80	11.67
Limed with Phosphorus**	.....	.....	.....	.....	.....	1.57	12.54

* 500 lbs. ammonium sulphate to the acre.
** 200 lbs. P_2O_5 to the acre as superphosphate.

(1, 2) reported before: "The increase in the grass yield, due to liming, was significant for the first and third crop but was not significant for the second, fourth, and fifth crops, or for the total of the five consecutive crops." No significant difference was found between the grass yields of the four treatments given to the sixth or to the seventh crop. The addition of phos-

phorus, with or without lime, was not effective toward increasing the crop yield. The mean yield of all treatments of the seventh crop was 11.51 tons to the acre of green Para-Carib grass and that of the sixth crop was only 1.71 tons. The seventh crop yielded about seven times as much forage as the sixth crop. This increase in yield was due to the application of 500 pounds to the acre of ammonium sulphate.

SUMMARY

Results are given here of the effect of adding phosphorus to an acid soil, limed or unlimed, on the pH and mineral composition of the red soil Fajardo clay. Data are also given for similar effect on the yield and mineral composition of a mixture of Pará grass *Panicum purpurascens* and Carib grass *Eriochloa polystachya*. The minerals studied were calcium, magnesium, manganese, phosphorus, and iron.

The main results are as follows:

1. Lime was still effective in keeping the soil slightly acid (pH 6.0 and 6.3) 32 and 39 months after it was applied. That of the unlimed soil was strongly acid, from pH 4.3 to 4.6.
2. There was a highly significant increase in the available calcium and a highly significant decrease of the available manganese and iron of the soil and no significant difference for the magnesium, 32 and 39 months after the lime application, when phosphorus was not added.
3. There was a highly significant increase in the soil available phosphorus, 32 months after the lime application but no significant difference at 39 months. At the latter period the lime was not effective in raising the soil available phosphorus.
4. The lime was as effective, 32 months after its application, as the phosphorus, 3.4 months after its application, in raising the soil available phosphorus. But seven months later, the phosphorus-lime treatment was significantly better than the lime treatment.
5. When lime or lime with phosphorus, was applied, there was a highly significant increase of calcium and of phosphorus and a highly significant decrease of manganese in the grass, but the iron and magnesium contents were not changed.
6. When phosphorus was applied without lime, there was a significant increase of phosphorus in the grass, but no significant change in the other minerals.

There was also a significant difference in the phosphorus content of the grass which received calcium and phosphorus. The latter had the higher content. There was no significant difference between the phosphorus content of the limed grass and the grass which received phosphorus or lime and phosphorus.

7. At the sampling period, 3.4 months after the superphosphate application, the 87 pounds of available phosphorus (P) to the acre applied, were unaccounted for or fixed by the soil.
8. No significant difference was found between the yields of each of two consecutive crops of Para-Carib grass mixture due to the addition of phosphorus to an acid soil, with or without lime.

RESUMEN

Se informa aquí el efecto que ha tenido una aplicación de fósforo, en la ausencia o presencia de cal, sobre el pH y la composición mineral del suelo rojo y ácido, Fajardo arcilloso. También se informa el efecto que ha tenido dicha aplicación de fósforo sobre el rendimiento y la composición mineral de una mezcla de yerbas Malojillo *Panicum purpurascens* y Malojilla *Eriochloa polystachya*. Los minerales estudiados fueron calcio, magnesio, manganeso, fósforo y hierro.

Los resultados obtenidos se resumen como sigue:

1. La cal sostuvo la reacción del suelo, ligeramente ácida (pH 6.0 y 6.3), a los 32 y 39 meses después de su aplicación. El suelo ácido tuvo en dichos períodos, una reacción fuertemente ácida (pH 4.3 y 4.6).
2. A los 32 y 39 meses después de aplicar la cal sola, se produjo un aumento en el calcio asimilable del suelo y un descenso en el manganeso y en el hierro asimilable, lo cual fué altamente significativo en ambos casos. No hubo diferencia significativa en el magnesio.
3. A los 32 meses después que se aplicó la cal sola se produjo un aumento altamente significativo del fósforo asimilable en el suelo; pero a los 39 meses no hubo diferencia significativa. El efecto de la cal en aumentar el fósforo asimilable en el suelo fué nulo a los 39 meses.
4. La cal fué tan eficiente a los 32 meses después de su aplicación como lo fué el fósforo a los 3.4 meses después de aplicado, para subir el contenido de fósforo asimilable del suelo. Siete meses después, el tratamiento de cal y fósforo fué significativamente mejor que la cal sola.

5. La aplicación de cal al suelo, con o sin fósforo, produjo aumentos de calcio y fósforo en la yerba y descenso en el manganeso, lo cual fué altamente significativo en ambos casos. Los contenidos de hierro y magnesio no fueron afectados.
6. Cuando se aplicó el fósforo, sin la cal, hubo un aumento significativo de fósforo en la yerba pero no hubo cambio en los otros minerales. También hubo una diferencia significativa, entre el contenido de fósforo de la yerba en el tratamiento con fósforo y el tratamiento con cal y fósforo siendo mayor la diferencia en este último. No hubo diferencia significativa entre el fósforo de la yerba en el tratamiento con cal y en el tratamiento con cal y fósforo.
7. Las 87 libras de fósforo (P) asimilable del superfosfato no aparecieron en el suelo, a los 3.4 meses después de aplicada; lo que indica que el fósforo fué fijado en el suelo.
8. No hubo diferencia significativa, entre los rendimientos de dos cosechas consecutivas de yerbas Malojillo-Malojilla cuando se añadió fósforo a un suelo ácido, en la ausencia o presencia de cal.

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