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Mineralization of Organic P in an Ultisol[1,2]

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ABSTRACT

One field experiment was conducted to measure residual effect of P in an Ultisol with corn as the indicator plant. Three greenhouse experiments with corn plants were also conducted to determine the relationship between plant P uptake and levels of soil organic P, soil inorganic P and available P, and to measure the effects of soil temperature, P and N applications and soil sterilization on the rates of organic P mineralization. Field data failed to reveal significant differences in respiration rates and soil pH. Soil P levels were higher in plots that received 1,120 kg/ha of P, with or with lime, than in those that received lesser amounts of P. In the greenhouse experiments, yields of corn tops were highly correlated with soil temperatures when no P was added. Plant P concentration and uptake were highly correlated with soil temperature when no fertilizer P was added. Soil sterilization with methyl bromide significantly increased N and decreased K concentrations irrespective of soil temperature. It is postulated that mineralization of organic P in Ultisols and perhaps in other highly weathered tropical soils may account for the lack of response to fertilizer P usually observed.

INTRODUCTION

Recent field experiments on several highly weathered soils of Puerto Rico have failed to elicit a consistent response to fertilizer P applications (19, 20). These results are not in accord with greenhouse trials in which estimates of plant-available P indicated that a definite response to applied P should have occurred (32). Brams (7) reported a lack of yield response to applications of fertilizer P in river terrace soils of the West African humid uplands over a continuous 3-year period with corn, rice and groundnuts. He measured a 31 to 87% increase in labile soil P (Bray No. 2 extract), in the plow layer of his check and treated plots 1 year after fertilizer P was applied. This trend persisted through the third crop year although in diminishing magnitude.

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[2] Joint contribution from the Department of Agronomy, Cornell University, Ithaca, New York, and the Agricultural Experiment Station, University of Puerto Rico, Mayagüez Campus, Rio Piedras, Puerto Rico. This study was part of the investigations supported by the U.S. AID under research contract ta-c-1104 entitled "Soil fertility in the humid tropics."

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Various equally tenable explanations have been advanced for the lack of response to fertilizer P applications. Figarella et al. (17) suggested the presence of inorganic P that may become available to the plant over the growing season but is not extracted by routine tests. Other workers propose that added fertilizer P becomes fixed or immobilized as insoluble Al, Fe or Ca phosphates (7, 18, 19, 24, 29, 32). Another possible explanation is that P present in organic form in the soil at the beginning of a season may, through mineralization, contribute substantially to the P nutrition of plants grown during that season (4, 7, 12, 21, 30).

The latter explanation is of particular relevance to soils in Puerto Rico that failed to elicit a yield response to heavy applications of fertilizer P in the summer but not in the winter months (19). Indeed, the summer climatic conditions of temperature and rainfall at a Torres clay site were more conducive to organic P mineralization than were winter conditions (4, 30). Also, organic P mineralization could be an important source of plant-available P when the high soil organic matter content of 4.25% (19) is considered.

To recommend the efficient and economic use of fertilizer P in the humid tropics, one must obtain information on the contribution of organic P mineralization to the pool of plant-available P in these soils. This paper reports data on organic P mineralization. Concomitantly, greenhouse studies were conducted to ascertain the effects of temperature and added fertilizer P on this biological process.

PEVIOUS WORK IN PUERTO RICO

Since 1910, a considerable amount of work has been conducted with fertilizer P under conditions in Puerto Rico. Samuels and Capó (27) reported sugarcane yield decreases of around 7% when P was omitted, with no differences attributable to various P placement methods. Bonnet (8) failed to obtain responses to fertilizer P on 18 consecutive sugarcane crops. No significant pineapple yield increases were obtained (26, 28) on Oxisols and Ultisols. However, yields were depressed when rates of fertilizer P exceeded 28 kg/ha. No yield differences attributable to P sources were measured. More recent work (16) indicates that maximum pineapple yields can be obtained with 25 kg/ha of fertilizer P; 148 kg/ha of fertilizer P depressed yields. No significant effects from P applications were measured in old limed coffee trees (9) nor in intensively managed sun grown coffee (2, 3). However, moderate responses were obtained with Columnaris coffee at Castañer (22) and Maricao (13).

Sweet potatoes (10, 14, 22, 23) and sweet corn (25) do not respond to fertilizer P. Significant increases in yield of cantaloupes, cucumbers, watermelons, snapbeans,[4,5] and pumpkins (15) were reported. Yield re-

[4] Spain, G., Unpublished data, Univ. P.R. Agri. Exp. Stn., 1971

[5] Spain, G., Unpublished data, Univ. P.R. Agri. Exp. Stn., 1973

sponses attributable to fertilizer P were obtained from tropical kudzu and Napier grass on Oxisols and Inceptisols (1, 17). However, no responses were obtained over a 5-year period on an Alfisol from Napier, Guinea and Pangola grasses in soils which had been previously under well-fertilized sugarcane (17).

Large responses to fertilizer P were obtained from corn grown in sunken drums experiments (20). However, under field conditions, no responses were measured (20). Bunch and fruit weight of plantains increased when fertilizer P was increased from 0 to 56 kg/ha at planting time and with 179 kg/ha from residual P. Lack of fertilizer P reduced weight and pulp content in the fruits of the third hand (11).

MATERIALS AND METHODS

FIELD EXPERIMENT

Field studies were conducted at Cidra at the same site on which the P studies commenced November 23 and 26, 1971[6]. The soil is classified as Torres clay (Orthoxic Palehumults). Corn was the indicator plant. Attention was focused on plots that received 0, 90, 179, 358, and 1,120 kg/ha of broadcast P. Studies began at the same time when the 1973-74 winter crop was sown.

Beginning on the date of planting and at 28-day intervals thereafter through physiological maturity, soil samples were taken at depths of 0-15, 15-30, and 30-45 cm. Samples were analyzed for organic matter content, organic P, inorganic P, available P by the Olsen and Bray No. 2 methods,[7] total soil N, and pH.

Additionally, plant tissues were sampled at 28-day intervals beginning 30 days after planting and continuing through physiological maturity. Samples were analyzed for P and N.

Plant heights were measured at fixed intervals throughout the growing period and total P and N uptake of grain and stover were determined following harvest. Respiratory activity was measured according to the method outlined in Black et al. (5, 6).

Data on soil and air temperatures, rainfall, evaporation from a class A pan, relative humidity and total radiation were recorded.

GREENHOUSE EXPERIMENTS

First experiment

Torres clay, with a low available P content, (0-2 p/m by Olsen and Bray extracts), was brought to the laboratory and prepared[8]. The soil

[6] Del Valle, R., Personal communication, November, 1972.

[7] In recent studies on 155 West Indian soils Olsen's method gave the best estimates of available P (31).

[8] Preliminary studies on plant available P content of seven samples taken from areas peripheral to the experimental site, and using three methods of determination gave an average value of 2.0 p/m labile P.

received a blanket application of fertilizer as follows: 300 p/m N as ammonium nitrate, 200 p/m K as muriate, 50 p/m Mg as sulfate, 5 p/m Zn as sulfate, 5 p/m Fe as iron chelate, 0.5 p/m Cu as sulfate, and 2.4 p/m B as borax. Enough $Ca(OH)_2$ was added to neutralize the soil exchangeable Al. Two levels of P were studied: 0 P (the check treatment) and 500 p/m of fertilizer P as double superphosphate. These treatments will be hereafter referred to as 0 P and + P, respectively.

The soils were moistened to near field capacity and allowed to incubate at room temperature for 14 days. They were kept at field capacity throughout the experiment.

After incubation, the soils were potted in 20 × 20 cm plastic pots and the pots were taken to a greenhouse and immersed in water baths adjusted to 17°, 25° and 35° C. After the soils were in equilibrium with the water bath temperatures, Funk's G-795W corn was planted in one set of pots having 0 P and + P. Another set of pots having 0 P and + P were maintained at field capacity but in fallow. Pots were sampled at time of planting and, thereafter, at 15-day intervals through 30 days. Samples were analyzed for the same set of components as previously outlined for the field experiments.

Plant height was measured at weekly intervals beginning 14 days after planting and continuing through 30 days. At this time, plants were harvested and the dry matter data recorded. Plant tissues were analyzed following harvest for total N, K and P uptake.

Second experiment

Corn was planted in the same potted soils as in Experiment 1. Three new sets of pots were added with a 0 N treatment. There were all possible combinations of P and N treatments as 18, 25 and 35° C. New blanket fertilizer was applied as follows: 300 p/m N, 250 p/m P in pots where this nutrient was excluded in experiment 1, and 50 p/m Mg. The 0 N pots received the same blanket application as in Experiment 1.

Third experiment

New soil was brought from the field and potted. Three additional sets of pots were included. Then, half of all potted soils were sterilized for 48 hours with methyl bromide. The same blanket fertilizer was applied as in experiment 1, except that no lime was added.

RESULTS AND DISCUSSIONS

Data from the field experiment failed to reveal significant differences in respiration rates and soil pH, attributable to previous soil treatments. Soil P levels were higher in plots that had previously received 1120 kg/ha of P, with and without lime, than in plots receiving fertilizer P at rates of 0, 90, 179 and 358 kg/ha, with or without lime.

Tables 1, 2 and 3 summarize data from the greenhouse experiments. In all three experiments, yields of corn tops were highly correlated with soil temperatures when no fertilizer P was added. Values for r^2 ranged from 0.544 to 0.959. In none of the experiments, was the yield of corn tops correlated with soil temperature when P was added (r^2 = 0.114 to 0.289). Plant P concentration was highly correlated with soil temperature in all three experiments when no fertilizer P was added (r^2 = 0.582 to 0.855). Plant P concentration was correlated with soil temperature in two of the three experiments when P was added (r^2 = 0.171 to 0.588). Plant P uptake was also correlated with soil temperature when no P was added (r^2 = 0.666 to 0.950). Plant P uptake was correlated with soil temperature in two of the three experiments when P was added (r^2 = 0.157 to 0.603). All of the above correlations are linear.

With soil sterilization these correlations with soil temperature were not apparent. Sterilizing the soil significantly increased N concentration and decreased K concentration at all three temperatures. There was biological activity (CO_2 evolution) in both sterilized and non-sterilized soils by the end of the growing period. With no added P, increases in P uptake of corn tops with increases in soil temperature from 18 to 35° C, were of the order of over 300%.

It appears as though the failure to obtain responses to fertilizer P applications on Ultisols can be explained on the basis of the mineralization of organic P that occurs at the prevailing higher soil temperatures. Mean soil temperature at 15 cm under field conditions, as measured during the course of these experiments, was 24.2° C from January 1 to March 15. An average maximum soil temperature of 28.3° C was measured. In the summer months, mean soil temperature in the field at 15 cm was 28.0° C. This situation might explain, to some extent, the lack of response to fertilizer P usually observed in Ultisols and other highly weathered soils of the humid tropics.

Weaver[9] observed that wetting and drying of soil samples at 35° C appeared to be the most effective treatment causing mineralization of organic P under laboratory conditions. His work with the Catalina, Humatas and Torres soils confirms results in the literature that added lime and increased temperature cause an increase in mineralization of organic P. The greatest amount of mineralized P was obtained from Torres clay. Most of the organic P mineralized appeared to be that extracted by either 0.3 *N* NaOH or HCl + NaOH.

[9] Weaver, R. M., Personal communication, February 19, 1974.

TABLE 1.—*Yield, plant nutrient concentration and nutrient uptake of corn grown in pots under greenhouse conditions at two P levels and three soil temperatures*

Treatment No.	P added	Soil temperature	Yield		Plant nutrient concentration			Nutrient uptake of tops		
			Top	Root	N	P	K	N	P	K
	P/m	°*C*	*Gm/pot*			%			*Mg/pot*	
1	0	35	7.75b[1]	4.51a	4.25c	.22b	6.73b	329c	17.2c	522c
2	500	35	17.47d	6.87b	4.20bc	.31cd	5.78a	734e	54.8e	1010d
3	0	25	5.29a	3.58a	3.96b	.18a	7.05b	209b	9.5b	374b
4	500	25	16.26cd	3.91a	4.61d	.33d	6.68b	749e	53.6e	1083d
5	0	17	3.29a	3.69a	3.69a	.14a	7.20b	122a	4.6a	236a
6	500	17	14.90c	6.48b	4.04bc	.27c	6.73b	600d	39.6d	994d

[1] Means followed by one or more letters in common do not differ significantly at the 5% probability level.

TABLE 2.—*Yield, plant nutrient concentration and nutrient uptake of corn tops grown in pots under greenhouse conditions at two P levels, two N levels and three soil temperatures*

Treatment No.	P added	N added	Soil temperature	Yield of corn tops	Plant top nutrient concentration			Nutrient uptake of tops		
					N	P	K	N	P	K
	P/m	*P/m*	*°C*	*G/pot*		%			*Mg/pot*	
1	250	0	35	13.35b[1]	2.86b	.44f	6.93d	377e	58.1de	921d
2	250	0	25	13.43b	2.18a	.37e	6.86cd	291de	49.3cd	923d
3	250	0	18	11.85b	2.30a	.31cd	6.30bc	273cd	36.4b	747bc
4	0	300	35	4.65a	4.00c	.16b	5.85b	185bc	7.4a	273a
5	250	300	35	20.83c	3.79c	.31d	4.55a	788g	67.6e	956d
6	0	300	25	2.94a	3.95c	.12a	6.30bc	116ab	3.4a	186a
7	250	300	25	20.06c	3.91c	.31cd	4.59a	780g	62.2e	908cd
8	0	300	18	1.95a	4.42d	.12a	6.00b	86a	2.3a	117a
9	250	300	18	16.60c	3.95c	.28c	4.08a	656f	46.3bc	676b

[1] Means followed by one or more letters in common do not differ significantly at the 5% probability level.

TABLE 3.—*Yield, plant top nutrient concentration and top nutrient uptake of corn tops growing in pots under greenhouse conditions at two P levels in sterilized and non-sterilized soils*

Treatment No.	P added	Soil sterilization	Soil temperature	Yield of corn tops	Plant top nutrient concentration			Nutrient uptake of tops		
					N	P	K	N	P	K
	P/m		°*C*	*G/pot*		%			*Mg/pot*	
1	0	Sterilized	35	2.03a	6.45ef	.14a	4.34a	132a	2.85a	87a
2	0	Non-sterilized	35	3.78a	4.22ab	.24b	8.21d	161a	9.38a	312c
3	500	Sterilized	35	13.65d	5.16d	.36d	6.62bc	705bc	49.68c	907d
4	500	Non-sterilized	35	10.60b	4.13ab	.38d	8.13d	436b	40.90b	861d
5	0	Sterilized	27	2.07a	6.88f	.12a	4.03a	143a	2.55a	84a
6	0	Non-sterilized	27	3.22a	4.02ab	.22b	8.16d	130a	7.20a	265bc
7	500	Sterilized	27	17.10e	5.11d	.39d	6.91bc	870d	67.07d	1177e
8	500	Non-sterilized	27	11.25bc	4.48bc	.38d	8.02d	503b	42.22bc	901d
9	0	Sterilized	18	2.10a	6.00e	.13a	4.57a	126a	2.70a	96a
10	0	Non-sterilized	18	2.28a	3.83a	.13a	6.47bc	88a	2.97a	147ab
11	500	Sterilized	18	13.08cd	4.80cd	.31c	6.34b	626c	40.55b	816d
12	500	Non-sterilized	18	11.75bcd	4.14ab	.30c	7.21c	486b	34.63b	848d

[1] Means followed by one or more letters in common do not differ significantly at the 5% probability level.

RESUMEN

Se realizaron experimentos de campo para medir el posible efecto residual de aplicaciones previas de P y otros tres en invernadero, para determinar la relación entre la absorción de P y los niveles de P orgánico en el suelo, P inorgánico y P disponible a las plantas. También se estudió el efecto de la temperatura del suelo, las aplicaciones de P y N y la esterilización del suelo sobre la mineralización del P orgánico. Los datos obtenidos bajo condiciones de campo no revelaron diferencias significativas en la respiración de la planta ni en el pH del suelo. Los niveles de P fueron más altos en parcelas que habían recibido 1120 kg/ha de P, con o sin cal, que los obtènidos en las que recibieron cantidades menores. En los experimentos en invernadero se encontró: 1) una alta correlación entre los rendimientos de la parte aérea de las plantas de maíz y la temperatura del suelo, cuando no se abonó con P; 2) una alta correlación entre la concentración y la absorción de P en la planta con la temperatura del suelo, cuando no se aplicó P como abono; 3) la esterilización del suelo con bromuro de metilo aumentó significativamente el nivel de N y redujo el de K en la planta, independientemente de la temperatura del suelo. Se postula que la mineralización del P orgánico en los Ultisols, y quizás en otros suelos tropicales altamente intemperizados, puede explicar, por lo menos en parte, la falta de respuesta a las aplicaciones de abonos fosfatados que generalmente se observa.

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