CORN GROWTH AND CHANGES OF SOIL AND ROOT PARAMETERS AS AFFECTED BY PHOSPHATE FERTILIZERS AND LIMING[1]

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ABSTRACT - Soil and root parameters that influence nutrient uptake were evaluated in this study of comparing the effectiveness of phosphate fertilizers in an acid soil. North Carolina rock phosphate (RP), partially acidulated Togo rock phosphate (PA), monocalcium phosphate (MCP), and diammonium phosphate (DAP) were applied to limed (pH 5.6) or unlimed (pH 4.6) soil samples. Eighteen days later, transplanted corn (*Zea mays* L) seedlings were grown in pots for 12 days. Soluble phosphates, DAP and MCP, were the most efficient fertilizers for increasing corn dry matter on limed pots; in absence of limestone, the best yield was obained with DAP because it decreased soil solution Al. Phosphorus in the soil solution (P_{li}) was lower on limed than on unlimed samples, but resin-exchangeable P was not affected by liming. MCP gave the highest increase of P_{li} on unlimed samples whereas DAP did it in presence of liming. Root dry matter and root length were greater on limed than on unlimed pots for all sources of P, except for DAP, where the soil acidity had no detrimental effect on these parameters.

Index terms: phosphorus, pH, soil solution, nutrient uptake.

RENDIMENTO DE MATÉRIA SECA DE MILHO E MODIFICAÇÃO EM PARÂMETROS DE SOLO E DE RAIZ AFETADOS POR FERTILIZANTES FOSFATADOS E PELA CALAGEM

RESUMO - Parâmetros de solo e de planta que afetam a absorção de nutrientes foram determinados neste estudo para comparar a eficiência de fertilizantes fosfatados num solo ácido. Monocálcio fosfato (MCP), diamonofosfato (DAP), fosfato natural de Norte Carolina, e fosfato natural de Togo parcialmente acidulado foram aplicados em amostras, calcariadas (pH 5,6) ou não (pH 4,6), de um alfissolo. Dezoito dias após, plântulas de milho (*Zea mays* L.) foram transplantadas para vasos e cultivadas por doze dias. Os fosfatos solúveis, MCP e DAP, promoveram os maiores aumentos de matéria seca de milho no solo calcariado; sem calcário, DAP foi o mais eficiente porque diminuiu o Al da solução do solo. Fósforo na solução do solo (P_{li}) foi mais baixo com calcário do que na ausência de calagem, mas P-resina não foi afetado pela calagem. O maior aumento no P_{li} foi obtido com MCP na ausência de calcário, e com DAP no solo calcariado. O comprimento e a matéria seca de raízes foram maiores na presença do que na ausência de calagem, exceto para o DAP, onde o pH baixo não afetou negativamente esses parâmetros.

Termos para indexação: pH, fósforo, solução do solo, absorção de nutrientes.

INTRODUCTION

Phosphorus availability to crops depends on the soil supply to the roots, on root morphology and growth, and on plant uptake kinetics (Barber 1984). The concentration of P in the soil solution (P_{li}) is the most important soil parameter governing soil P supply to the roots (Ernani & Barber 1991, Chen 1989, Barber 1984). Solution P may increase by different magnitudes depending on the kind of phosphate fertilizer added to the soil because dissolution, adsorption, and precipitation reactions that control P_{li} may differ with solubility and the chemical composition of each P compound.

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Root parameters can also be affected differently by each phosphate fertilizer because the phosphates may affect to a different degree the soil pH and the concentration of Al in the soil solution around the fertilized zones. In addition, supplying Ca or NH_4 as the accompanying cation may also affect crop growth in some situations.

The effectiveness of each form of P has varied with crops (Oliveira et al. 1984, Goedert & Lobato 1984) and soils (Ernani & Barber 1990), especially with soil pH (Oliveira 1981). Rock phosphates (Goedert & Lobato 1984) and partially acidulated rock phosphates normally have lower capability to supply P than water soluble P fertilizers; in soils with high P fixation capacity, however, this may not always be true (McLean & Logan 1970), in low pH soils. The reasons for the differences among phosphates normally are not known because root parameters and some of the most important soil parameters that determine P availability (P_{li} and D_e) have not been measured.

The objective of this research was to evaluate the effect of four phosphate fertilizers to increase corn dry matter on a soil at two pH levels, and to determine the reasons for the differences in their effects by evaluating the effect on the soil and root parameters that affect phosphorus uptake.

MATERIALS AND METHODS

We applied North Carolina rock phosphate (RP), partially acidulate Togo rock phosphate (PA), and reagent grades monocalcium phosphate (MCP), and diammonium phosphate (DAP), at a rate of 232 mg P/kg^{-1} to unlimed (pH 4.6) and limed (pH 5.6) Rarden soil samples (clayed, mixed, mesic Aquic Hapludalfs). North Carolina rock phosphate is a clastic phosphorite with 30.1% of total P_2O_5 and 7.6% of P_2O_5 soluble in citrate. Partially acidulated rock phosphate was obtained from an African rock (Togo), and it was used after being treated with 50% of the H_2SO_4 necessary to get complete acidulation. The percentage of P_2O_5 total, soluble in citrate, and soluble in water in this material was respectively 41.3, 17.4, and 8.1. Rock phosphate and PA were applied as dry powder. All P fertilizers were mixed with the soil samples, and the soil water was raised to -25 kPa of water tension. After light days of incubation, KCl, and $MgSO_4$ were applied to all treatments, and NH_4NO_3 to the treatments where DAP was not applied. Then the soil samples were incubated for ten more days. We applied 100, 60, and 80 mg of K, Mg, and S respectively per kg of soil. Nitrogen was applied at a rate of 209 mg N kg^{-1} in order to add the same amount of N as in samples treated with DAP.

Eighteen days after application of P treatments, four 7-day-old pregerminated corn plants, hybrid B73 x Mo17, were transplanted to 2,5 L-pots, each pot with 2.35 kg of soil (oven-dry basis). Each plant had four roots, 4 cm long, and they were grown for twelve days at 25°C in a growth chamber ajusted to 16 hours of light per day. The soil volumetric water in the pots was raised to 0.20 after transplanting and the moisture was adjusted daily to this value by weighting the pots. We used a completely randomized design with two replicates per treatment.

Phosphorus, pH, and Al were determined in the soil solution and on the solid phase of samples collected at the time that corn plants were transplanted. Soil solution was obtained by the displacement procedure, as described by Ernani & Barber (1991). Resin-exchangeable P (P_{si}) was extracted with Dowex 2 x 8 anion exchange resin, into which 1.0 g of soil, 2.5 cm^3 of resin, and 100 mL of deionized water were shaken for 24 hours. Then, the resin was separated from the soil, and shaked with 50 mL of warm (60°C) 1N NaCl, during one hour, in order to extract P. Phosphorus in the soil solution (P_{li}) and P_{si} were determined as described by Murphy & Riley (1962). Exchangeable Al was extracted with 1N KCl solution, and determined by titration with NaOH; solution Al was determined by the cathecol violet method (Mosquera & Mombiella 1986), with modifications described by Ernani (1989). The pH was determined by potentiometry in a soil/water ratio of 1:1.

Root length (L_o) and root radius (r_o) were determined for each pot after harvesting. Root length was determined by the intersect method as described by Tennant (1975); r_o was calculated from the formula $r_o = (F_W / L_o)^{1/2}$, where F_W is fresh weight of roots. Roots and shoots were dried at 60°C until constant weight, ground, passed through a 20 mesh sieve, and digested. In the digestion procedure we used 0.200 g of sample, 1.5 mL of H_2SO_4, 2 mL of

H_2O_2, and 0.7 g of digestion mixture (K_2SO_4 + + $CuSO_4$ + metallic selenium at ratio of 100:10:1). This procedure took three hours and it was done on a hot plate kept at 300°C.

We divided the total P content present in the whole plants (shoots + roots) in two forms: (i) the amount taken up from the soil plus that translocated from the seeds, and (ii) that taken up only from the soil, by subtracting from the former form the amount of P present in four seeds (130 micromoles of P).

RESULTS

Water soluble phosphates (DAP and MCP) were the most efficient fertilizers for increasing dry matter of shoots on limed pots. In absence of liming DAP was the best source of P for corn because the shoot dry matter was more than twice those obtained with the other P fertilizers (Table 1). Addition of limestone increased the dry matter of shoots for all P treatments (Table 1).

Uptake of P was greater on limed than on unlimed pots for all sources of P, and on both pH levels DAP gave the greatest uptake. On unlimed pots the total P in the corn plants (shoots + roots) for RP, PA, or MCP was less than the amount of P present in four seeds (130 micromoles); the amount of P taken up by DAP, however, was about 3-fold greater than that in the seeds (Table 2).

The concentration of P was greater in the shoots than in the roots. DAP gave the greatest concentration of P in the shoots on unlimed pots; on limed pots there was no difference between DAP and MCP (Table 2). Liming increased the concentration of P in the shoots only on pots treated with MCP (Table 2). The concentration of P in the shoots as well as in the roots in pots treated with PA and RP was not affected by the soil pH because the small growth of corn in absence of liming (Table 2).

TABLE 2. Percentage of P in the shoots and in the roots, and total P of 18-day old corn plants as affected by liming and phosphate fertilizers.

	Shoot		Root		Total P	
	Unlimed	Limed	Unlimed	Limed	Unlimed	Limed
	%				umol/pot	
RP	0.27	0.27	0.21	0.18	93	216
PA	0.29	0.22	0.25	0.16	62	158
MCP	0.24	0.42	0.22	0.24	80	367
DAP	0.43	0.44	0.27	0.28	348	520
LSD (0.05)	0.094		0.045		127	

Least significant difference by the Tukey test at 5% significance level.

TABLE 1. Dry matter of shoots and roots of 18-day old corn plants as affected by liming and phosphate fertilizers.

	Shoot				Root			
	Unlimed	(RE)*	Limed	(RE)	Unlimed	(RE)	Limed	(RE)
	g/pot							
RP	0.75	(40)	1.80	(61)	0.44	(44)	1.06	(90)
PA	0.42	(22)	1.45	(49)	0.26	(26)	1.03	(87)
MCP	0.68	(36)	2.15	(73)	0.40	(40)	0.96	(81)
DAP	1.88	(100)	2.93	(100)	1.00	(100)	1.18	(100)
LSD (0.05)	0.79				0.51			

Least significant difference by the Tukey test at 5% significance level.

* RE: relative efficiency based on DAP yield.

The concentration of P in the soil solution (P_{li}) was greater on unlimed than on limed samples for all sources of P, except for DAP. Resin-exchangeable P (P_{si}), however, was not affected by application of limestone, except for RP where P_{si} increased with liming (Table 3). The greatest increase of P_{li} was obtained with MCP on unlimed samples, and with DAP in presence of limestone. Partially acidulated Togo rock phosphate was the P source with the least ability to increase P_{si} and P_{li} on both pH levels (Table 3). The pH of the soil decreased after addition of P fertilizers and salts by about 0.3 to 0.6 units. The soil pH befere application of fertilizers was 4.6 and 5.6 respectively for unlimed and limed samples. The least decrease of pH occurred with DAP and the greatest with MCP (Table 3). Aluminum in the soil solution increased from 0.1 to more than 2.0 mM L^{-1} after application of P and salts (Table 3). Diammonium phosphate, however, decreased Al in the soil solution (Table 3). Addition of limestone eliminated Al in the soil solution in all treatments.

Dry matter of roots (Table 1) and root length (Table 4) were much greater on limed than on unlimed samples, except for DAP where they were the same for both pH levels. These two root parameters did not differ among sources of P on limed pots but in absence of liming they were many times greater with DAP than with the other sources of P (Tables 1 and 4).

The mean root radius was about 0.18 mm on limed pots, and in this pH level it did not differ among sources of P; in absence of liming DAP had the thinnest roots (0.16 mm) and PA the thickest (0.26 mm) (Table 4). The root radius decreased in some P sources after addition of limestone, but statistic significance was not attained for any treatment (Table 4).

TABLE 4. Values of root length (L_0) and root diameter (R_0) of 18-day old corn plants as affected by liming and phosphate fertilizers.

	Root length		Root diameter	
	Unlimed	Limed	Unlimed	Limed
	------- m/pot -------		------- mm --------	
RP	39.6	133.0	0.21	0.19
PA	12.7	131.5	0.26	0.18
MCP	24.6	113.0	0.24	0.19
DAP	157.5	160.5	0.16	0.17
LSD (0.05)	-------- 72.3 --------		------ 0.0090 -------	

Least significant difference by the Tukey test at 5% significance level.

TABLE 3. Values of resin-exchangeable P (P_{si}), P in the soil solution (P_{li}), solution aluminum, and soil pH of Rarden soil samples collected at transplanting time as affected by liming and phosphate fertilizers.

	P_{si}		P_{li}		Al		pH	
	Unlimed	Limed	Unlimed	Limed	Unlimed	Limed	Unlimed	Limed
	---------------------------- mM/L ----------------------------							
RP	4.00	6.32	0.0044	0.0013	2.30	0.0	4.2	5.2
PA	1.13	1.28	0.0030	0.00070	3.15	0.0	4.1	5.0
MCP	3.57	4.36	0.016	0.0028	2.39	0.0	4.0	5.0
DAP	3.90	4.32	0.0066	0.0074	0.38	0.0	4.3	5.3
LSD (0.05)	-------1.49 --------		------ 0.00151 --------------		0.11 --------			

Least significant difference by the Tukey test at 5% significance level.

DISCUSSION

The greater effectiveness of DAP for increasing corn dry matter of shoots and roots on unlimed pots was due to the decrease of Al in the soil solution rather than supplying P. Phosphorus in the soil solution, P_{li}, that is the soil P parameter most highly associated with P uptake (Barber 1984, Soltanpour et al. 1974), was higher with MCP than with DAP on unlimed pots, but in this pH level corn growth was severely limited by solution Al on pots treated with MCP, RP, and PA. The amount of P taken up by corn on unlimed pots treated with DAP was greater than on pots treated with the other phosphates regardless of the P_{li} values because solution Al was lower, root length was greater, and root radius was finer with DAP than with the other sources of P. Root length followed by root radius are the two most important root parameters describing uptake of P from the soil (Barber 1984).

The decrease of Al in the soil solution on DAP-treated samples was probably caused by precipitation of Al by P from DAP. The higher pH in soils treated with DAP than with the other phosphates may also have contributed to the decrease in solution Al. Precipitation of P by DAP may explain the lower values of P_{li} in absence of liming with DAP than with MCP. On limed samples P_{li} was 3-fold greater with DAP than with MCP. According to Ernani & Barber (1990) the effect of DAP is much greater on solution Al than exchangeable Al. The increase of Al in the soil solution after addition of PA, RP, and MCP on unlimed soil samples was caused by application of KCl, $MgSO_4$ and especially N salts. Ernani (1989) observed that addition of 460 mg of ammoniun kg^{-1} as NH_4Cl to this soil increased solution Al from 0.1 to 5.18 mM L^{-1}. Soluble salts, in addition to displace Al from the exchange sites (Ernani & Barber 1991) decrease the soil pH (Ernani 1989, Al-Showk et al. 1987). Aluminum in the soil solution of unlimed samples was 0.1 mM L^{-1} before application of treatments in the present study. Dissolution of Al and decrease of soil pH were also obtained by Gebhardt & Coleman (1974) after addition of phosphates.

The dry matter of shoots and roots did not differ between MCP and DAP on limed pots, but the amount of P taken up by corn was greater with DAP than with MCP due to the higher values of P_{li} on pots treated with DAP than with MCP.

The greater efficiency of RP relatively to PA was due to a greater release of P from RP than from PA (Table 3). Normally PA is more efficient than RP when both fertilizers are obtained from the same rock. We are not able to compare the effect of rock acidulation on P availability to corn in this study because we used two different rocks: North Carolina for RP, that is one of the most soluble U.S. rock phosphates, and Togo, and African rock phosphate, for PA.

The lower values of P_{li} on limed than on unlimed samples was probably due to the creation of new sites for adsorption of P after precipitation of Al as insoluble polymeric hydroxy-Al species (Haynes 1982). Decrease of P_{li} after liming has been obtained by other authors (Helyar & Anderson 1974, Harrison & Adams 1987, Chen 1989). Plants do not take advantage of the higher P availability that occurs at low pH values in some soils because Al normally restricts root growth in these situations. In the present study only corn treated with DAP overcame Al toxicity, and thus, DAP would be the most highly recommended source of P for acid soils containing Al.

CONCLUSIONS

1. Diammonium phosphate (DAP) was the best source of P for corn on unlimed pots; in presence of liming DAP and MCP gave better yield than RP and PA.

2. Dry matter of corn was higher on limed than on unlimed pots for all phosphate fertilizers.

3. The concentration of P in the soil solution was lower on limed than on unlimed soil samples; resin-exchangeable P, however, was not affected by liming.

4. The highest increase of P in the soil solution was obtained with MCP in absence of liming, and with DAP on limed samples.

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