Available phosphorus in soil from three sources and their effect on biomass and corn root development

Fosforo disponible de tres fuentes en el suelo y su efecto sobre la biomasa y desarrollo radical del maíz

Fósforo disponível de três fontes no solo e seu efeito na biomassa e no desenvolvimento radicular do milho

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Abstract

Phosphorus deficiency in the country is very common, to overcome the problem high soluble phosphates are applied, the use a less soluble acidulated phosphate rock with sulfuric acid (RFA) is one economical alternative. The partial substitution of sulfuric acid by ammonium thiosulfate in the acidulation process (R30T) has proven feasible. The objective of this study was to prove the effect of these P sources on the maize behavior. Two soils were used a neutral and acidic one. Four doses of P treatments were used: 0, 70, 140 and 210 $mg.kg^{-1}$, in a glasshouse experiment. 35 days after planting plants were harvest and soil and root samples were taken for phosphorus analysis and determination of dry matter, root length (LR) and root volume (VR). Partial substitution of sulfuric acid by ammonium thiosulfate does not affect the quality of the acidulated rock. A close relationship between biomass and P concentration in the corn tops with residual soil P, LR and VR increased with the first increase of soil P, successive increments of P produced a decrease in roots size. The LR and VR relationship with P uptake and biomass was not the same in the two soils, in the acidic soil there was a higher dependence on P uptake than in the neutral soil.

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Resumen

En el país es frecuente encontrar suelos deficientes en fósforo, para solucionar este problema se aplican fertilizantes fosfatados de alta solubilidad. La roca fosfórica parcialmente acidulada (RFA) con ácido sulfúrico es una alternativa económica. La sustitución parcial del ácido sulfúrico por el tiosulfato de amonio (R30T) ha demostrado ser factible. El objetivo del trabajo fue estudiar el efecto de estas tres fuentes de fósforo sobre el comportamiento del maíz. Para el trabajo se usaron un suelo neutro y otro ácido, cuatro dosis de P: 0, 70, 140 y 210 mg.kg^{-1}, en un experimento en invernadero. Las plantas se cosecharon a los 35 días y se tomaron muestras de suelo y raíces, para analizar fósforo, materia seca, longitud radical (LR) y volumen radical (VR). La sustitución parcial del ácido sulfúrico por tiosulfato de amonio no afectó la calidad de la roca acidulada. Se encontró una relación estrecha entre la biomasa y la concentración de P en el follaje con el P residual en el suelo. La LR y VR aumentaron significativamente con el primer incremento de P en el suelo, incrementos sucesivos de P residual produjeron una disminución del tamaño de las raíces. La relación LR y VR con P absorbido y biomasa no fue igual en los dos suelos, en el suelo ácido fue mayor la dependencia del P absorbido y de la biomasa que en el suelo neutro.

Palabras clave: longitud radical, tiosulfato de amonio, roca fosfórica, volumen radical.

Resumo

A deficiência de fósforo é muito comum no País. Para solucionar esse problema, são aplicados fertilizantes fosfatados de alta solubilidade. A rocha fosfática parcialmente acidificada (PRA) com ácido sulfúrico é uma alternativa econômica. A substituição parcial do ácido sulfúrico por tiossulfato de amônio (R30T) provou ser viável. O objetivo do trabalho foi estudar o efeito dessas três fontes de fósforo no comportamento do milho. Para o trabalho, utilizou-se solo neutro e ácido, quatro doses de P: 0, 70, 140 e 210 mg.kg^{-1}, em experimento em casa de vegetação. As plantas foram colhidas após 35 dias e amostras de solo e raízes foram coletadas para determinação de fósforo, matéria seca, comprimento radicular (RL) e volume radicular (VR). A substituição parcial do ácido sulfúrico por tiossulfato de amônio não afetou a qualidade da rocha acidificada. Foi encontrada uma estreita relação entre a biomassa e a concentração de P na folhagem com o P residual no solo. O LR e VR aumentaram significativamente com o primeiro aumento de P no solo, sucessivos aumentos de P residual produziram uma diminuição no tamanho da raiz. A relação LR e VR com P absorvido e biomassa não foi a mesma nos dois solos, no solo ácido a dependência do P absorvido e biomassa foi maior do que no solo neutro.

Palavras-chave: comprimento de raiz, rocha fosfática, superfície radial, tiossulfato de amônio.

Introduction

Acid soils are, in general, deficient in phosphorus, which is a limiting factor for the adequate nutrition of crops and, consequently, for productivity. To solve this problem, high solubility but expensive fertilizers are applied to the soil. The use of phosphate rock acidified with sulfuric acid has been an attempt to improve the solubility of the rock and the release of available P (Panda and Misra, 1970). Subsequently, the authors tried to improve the acidulation of phosphate rock by replacing 30 % of the sulfuric acid with ammonium thiosulfate (unpublished data), the efficiency of this way with respect to acidified phosphate rock has been successfully tested by Sequera and Ramirez (2003; 2013) and Morillo *et al*. (2007). Ammonium thiosulfate is a liquid fertilizer (12 % N and 26 % S) that acts as a reductant by oxidizing sulfur and acidifying the medium.

Under phosphorus stress conditions, modifications in certain root characteristics can occur, resulting in a greater absorption area, occupying a larger soil volume and consequently a greater increase in phosphorus uptake (Kranmitz *et al*., 1991; Sachay *et al*., 1991; Gahonia and Nilsen, 1996; 1998; Yan Ding *et al*., 2021; Li F. *et al*., 2004; Li H.B. *et al*., 2001).

Differences in P uptake capacity by plants can be explained, in part, by variations in morphological attributes of root systems (Gahoonia *et al*., 1997; Fohse *et al*., 1991). In phosphorus-poor soils, root length (RL), root volume (RV), root surface area and root radius play an important role in the processes of phosphorus uptake and accumulation in the plant (Zoysa *et al*., 1997). There is evidence that there are differences among sorghum cultivars in their efficiency to take up soil P from poorly soluble sources (Ramirez and Lopez, 2000). These differences could be attributed to changes in rhizosphere composition in phosphorus-poor soils (Hanafi and Leslee, 1996; Zoysa *et al*., 1997).

The objective of this work was to study the release of available phosphorus, in soil, by three fertilizers: Triple superphosphate (SFT), Riecito phosphate rock acidified at 50 % with sulfuric acid (RFA) and Riecito phosphate rock where 30 % of the sulfuric acid was replaced by ammonium thiosulfate (R30T) in the course of acidulation and, on the other hand, the effect of residual available P on biomass and root behavior of maize (*Zea mays* L.), in short-term experiments on two soils of different pH.

Materials and methods

Two soils were used for the study, sampled between 0 and 25 cm depth. The first one, located in Lara state, corresponded to a clayey Tropohumults of pH 4.7, with 14 mg.kg^{-1} of P, 158 mg.kg^{-1} of Ca, 1.5 cmol.kg^{-1} of Al and 4 % of organic matter. Hereafter it will be identified as acid soil. The other soil was located in Yaracuy state and classified as an Oxic Haplustalfs sandy clay loam of pH 7.4, with 7 mg.kg^{-1} of P, 1287 mg.kg^{-1} of Ca, 0.32 cmol.kg^{-1} of Al and 1.6 % of organic matter. Hereafter it will be identified as neutral soil. The soils were air-dried and sieved with a 3 mm mesh.

The phosphate fertilizers used were triple superphosphate (46 % P_2O_5 and 21 % CaO), Riecito rock phosphate (10.56 % total P) acidified at 50 % with sulfuric acid and Riecito rock phosphate acidified at 50 % replacing 30 % of the sulfuric acid with ammonium thiosulfate.

Four doses of P were applied: 0, 70, 140 and 210 mg.kg^{-1} soil, all treatments received a uniform dose in 150 mg N.kg^{-1} soil as urea and 30 mg K.kg^{-1} as KCl.

Four kg of each soil were weighed and placed in plastic pots with a capacity of 5 liters, the soil of each of them was mixed with the P of the respective treatment plus N and K, then the soils were moistened and 4 seeds of maize variety Sefloarca 94 were sown in each pot. Seven days after germination, the plants were thinned, leaving two per pot. During the experiment the available water in the soil was maintained between 30 and 90 % of the field capacity, adding demineralized water when necessary.

The pots were distributed in a completely randomized design with a factorial arrangement of three P sources, four doses and four replications. Each soil constituted an independent experiment, but conducted simultaneously under the same environmental conditions of the greenhouse where the temperature varied between 19 and 35 °C.

At 35 days after germination, plants were cut one cm above the soil surface, washed with demineralized water and dried in a forced ventilation oven at 70 °C for 48 hours and then ground using a 1 mm sieve. The plant tissue was digested with sulfuric acid and hydrogen peroxide in an aluminum digestion block (Thomas *et al*., 1967). Phosphorus was determined in the extracts by colorimetry (Murphy and Riley, 1962). At the time of harvest, soil samples were taken, in each pot, from the surface to the base of the pot, with a 2.5 cm diameter tube. In each sample, the roots were separated from the soil with running water using sieves, and preserved in a 70 % alcohol solution, and then root length (Tennant, 1975) and root volume (Bhom, 1979) were measured. In a second sampling, at harvest, soil P was determined by Olsen's method (Olsen *et al*., 1954).

The analysis of variance and the Tukey test of means for $P<0.05$ were performed with the INFOSTAT program version 1.1 and the calculation of the regressions by means of Excel.

Results and discussion

The application of P to the soils, in the form of SFT, RFA and R30T, resulted in a sustained significant increase in available P, 35 days after application, when the experiment ended (Table 1). SFT was more efficient, than the other two fertilizers, in releasing available P in the two soils, because this fertilizer is more soluble than the acidified rocks.

Table 1. Residual phosphorus in two soils planted with corn and fertilized with triple superphosphate (SFT), acidified rock phosphate (RFA) and acidified rock phosphate with sulfuric acid and ammonium thiosulfate (R30T).

Phosphorus $mg\ kg^{-1}$	Neutral soil			Acid soil		
	SFT	RFA	R30T	SFT	RFA	R30T
0	6.3 d	6.3 d	6.3 d	8.3 d	8.3 d	8.3 d
70	16.7 c	13.3 c	12.3 c	16.7 c	10.0 c	11.3 c
140	45.7 b	16.3 b	23.0 b	29.3 b	15.7 b	18.3 b
210	83.3 a	26.3 a	53.3 a	53.4 a	23.3 a	27.3 a

Values within columns followed by different letters are significantly different at $P < 0.05$ according to Tukey test. Underlined values within rows, for each soil, are significantly the same.

No differences in residual P were found between RFA and R30T, which means that the partial substitution of sulfuric acid by TSA, in the rock acidification process, did not affect the quality of the final product, similar results were found by Morillo *et al*. (2007), Sequera and Ramírez (2003).

The dry matter of foliage and roots, in both soils, increased significantly with increasing doses of the fertilizers used (Tables 2 and 3). The highest levels of foliage production corresponded to the highest dose of P applied, in both soils.

Root dry matter response varied with the P sources. When SFT was used, the maximum dry matter corresponded to the application of 140 $mg.kg^{-1}$ in the two soils. With RFA the maximum response was found with the highest dose of 210 $mg.kg^{-1}$. R30T was more efficient in dry matter formation, the maximum response in the neutral soil corresponded to the lowest dose, 70 $mg.kg^{-1}$ and in the acid soil to 140 $mg.kg^{-1}$.

Table 2. Dry matter of foliage and roots of corn in neutral soil fertilized with triple superphosphate (SFT), rock phosphate acidified with sulfuric acid (RFA) and rock phosphate acidified with sulfuric acid and ammonium thiosulfate (R30T).

Phosforus $mg.kg^{-1}$	Foliage ($g.pot^{-1}$)			Roots ($g.pot^{-1}$)		
	SFT	RFA	R30T	SFT	RFA	R30T
0	2.34 d	2.34 d	2.34 d	0.40 d	0.40 d	0.40 d
70	4.32 c	2.75 c	3.35 b	0.72 c	0.63 b	0.78 a
140	5.20 b	3.38 b	3.57 b	0.97 a	0.63 b	0.76 a
210	6.37 a	5.40 a	5.49 a	0.80 b	0.87 a	0.78 a

Values within columns followed by different letters are significantly different at $P < 0.05$ according to Tukey test. Underlined values within rows, for each soil, are significantly the same.

The highest dry matter production corresponded to the most soluble P source, SFT, possibly due to the most efficient release of plant-available P (Table 1). Corréa *et al*. (2005) also found higher dry matter production by corn fertilized with SFT compared to Gasfa rock phosphate.

Table 3. Dry matter ($g.pot^{-1}$) of corn foliage and roots in acid soil fertilized with triple superphosphate (SFT), acidified rock phosphate (RFA) and acidified rock phosphate with sulfuric acid and ammonium thiosulfate (R30T).

Phosforus $mg.kg^{-1}$	Foliage ($g.pot^{-1}$)			Roots ($g.pot^{-1}$)		
	SFT	RFA	R30T	SFT	RFA	R30T
0	0.73 d	0.73 d	0.73 d	0.32 d	0.32 d	0.32 d
70	1.98 c	1.61 c	2.11 c	0.97 c	0.73 c	0.87 b
140	4.09 b	3.08 b	2.83 b	2.65 a	1.05 b	1.43 a
210	4.64 a	3.59 a	4.05 a	2.05 b	2.01 a	1.69 a

Values within columns followed by different letters are significantly different at $P < 0.05$ according to Tukey test. Underlined values within rows, for each soil, are significantly equal.

Biomass formation by the plant was shown to be highly associated with the residual P released by the fertilizer sources, this relationship was linear in nature (Figure 1A and 1B). The coefficients of determination were highest for foliage, 0.90 and 0.95 and lowest for root 0.58 and 0.83 for neutral and acid soil respectively. This high dependence could be explained by the low initial P level in both soils. Sequera and Ramírez (2013) showed similar results of dependence of bean biomass on P availability in the same soils used in our experiment.

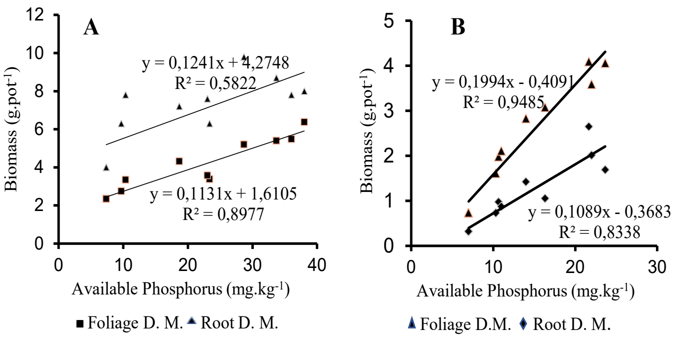

Figure 1. Available phosphorus and biomass production of maize foliage and root biomass in a neutral (1A) and an acid soil (1B).

Biomass formation by maize was shown to be highly correlated with foliar P concentration. Fitting the biomass data with absorbed and accumulated phosphorus in the foliage resulted in linear equations, except for roots in the neutral soil which were fitted to the logarithmic function (Figure 2A and 2B). The calculated coefficients of determination were 0.97 for foliage and 0.79 for roots in neutral soil and 0.95 for foliage and 0.91 for roots in acid soil.

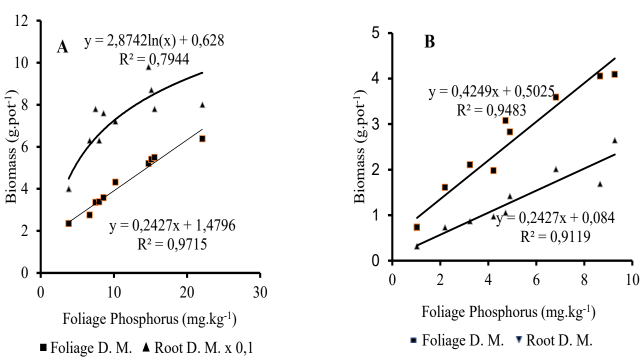

Figure 2. Accumulated phosphorus in corn foliage and its relationship with biomass production in a neutral (2A) and an acid soil (2B).

Foliar P concentration increased significantly with soil P availability (Table 4). P levels in the treatment without fertilizer were low, demonstrating nutrient deficiency in the soils. P uptake by the plant was more efficient when SFT, a more soluble form, was applied than when acidulated rocks were used, this behavior could be explained because SFT releases an amount of available P in the soil in shorter periods of time than acidified rocks.

Table 4. Percentage of phosphorus in corn foliage in two soils fertilized with triple superphosphate (SFT), acidulated rock phosphate (RFA) and rock phosphate acidified with sulfuric acid and ammonium thiosulfate (R30T).

Phosforus mg.kg^{-1}	Neutral soil			Acid soil		
	SFT	RFA	R30T	RFT	RFA	R30T
0	0.16 d	0.16 d	0.16 d	0.14 c	0.14 b	0.14 c
70	0.24 c	0.24 c	0.22 c	0.21 b	0.14 b	0.15 c
140	0.28 b	0.24 c	0.24 c	0.23 b	0.15 b	0.17 b
210	0.35 a	0.28 b	0.28 b	0.27 a	0.19 a	0.21 a

Values within columns followed by different letters are significantly different at P<0.05 according to Tukey test. Underlined values within rows, for each soil, are significantly the same.

The coefficients of determination indicate that the formation of dry matter, foliage and root, could be attributed in 97 and 79 % of the cases to the effect of P absorbed in the neutral soil and in 94 and 91 % in the acid soil, respectively. The high dependence of maize biomass on available phosphorus in the soil and its absorption could be attributed to the low initial phosphorus contents in the soils, 7 mg kg^{-1} in the neutral soil and 14 mg kg^{-1} in the acid soil.

Relationship between available P and root growth

The LR and VR, showed similar behavior with the application of the different forms of P, in both soils. Root growth was significantly stimulated with the first dose of P applied to the soil, with any of the sources used; successive increases in P did not produce increases in LR and VR but, on the contrary, significant reductions. Sequera and Ramírez (2013) working with the same soils, but with beans (*Vigna unguiculata* L. Walp), found similar LR behavior in neutral and acid soil. Fernandez and Ramirez (2000) reported an increase in LR and VR, in several maize lines, which resulted in increased soil volume exploration and phosphorus uptake.

These results coincide with those reported by other authors who point out that the increase of P in the nutrient solution or in the soil results in a decrease in the length of root absorbing hairs (Anghinoni and Barber, 1980; Fohse and Jungk, 1983; MacKay and Barber, 1984).

Root growth in relation to soil P seems to be influenced by different factors, Moller and Pellegrini (1999) pointed out that the response of RL to phosphorus availability was influenced by the duration of the experiments. Sequera and Ramírez (2003) found differences in maize RL growth in a limed and unlimed acid soil, possibly due to the effect of aluminum and calcium in the soils.

Relationship of root growth with P uptake and biomass production

Root growth pattern showed different behavior on biomass and phosphorus uptake by maize. The biomass and P absorbed (Pab) data were fitted to different models to choose those with the highest coefficients of determination.

In the neutral soil the best fitting equation for LR with biomass and Pab was of polynomial form (Figure 3) with negative trend and high R^2 values 0.73 for Pab and 0.72 for biomass. Dry matter production and P accumulation in the plant were not stimulated with increasing LR. Sequera and Ramírez (2003) found a similar behavior between LR and Pab, when they worked in a limed acid soil.

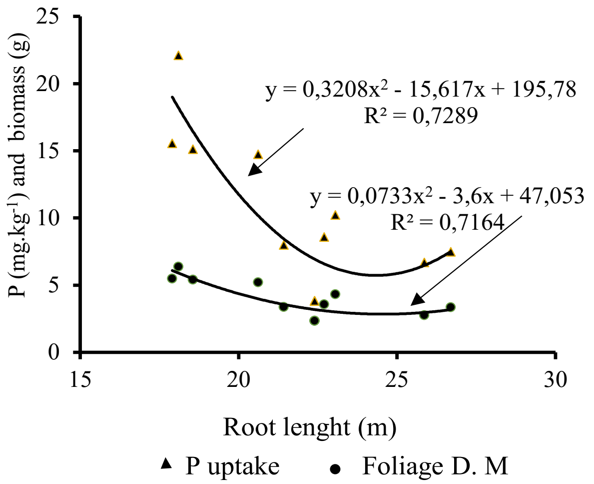

Figure 3. Relationship of root length (m) with P absorbed and corn biomass in neutral soil.

The behavior of LR and VR with respect to Pab and biomass formation by maize in acid soil was very different from that found in neutral soil. The calculation of the regression equations showed that there is a significant influence of the behavior of LR and VR on the Pab and biomass of corn in the acid soil, while in the neutral soil no relationship was found between the variables considered.

The best fit equations in the acid soil were of a positive polynomial character (Figure 4A and 4B). The R^2 coefficient calculated for LR and Pab was 0.56 and for biomass 0.62. When the variable VR was considered, the R^2 coefficients were higher, 0.90 for Pab and 0.93 for biomass. These results indicate that the variable VR is more efficient than LR in predicting the behavior of Pab and biomass formation by maize.

The shape of the curves shows that there is a high increase in Pb and biomass with initial root growth, rapidly reaching a maximum and then decreasing; this behavior indicates that plant P accumulation and matter formation do not increase continuously with root growth.

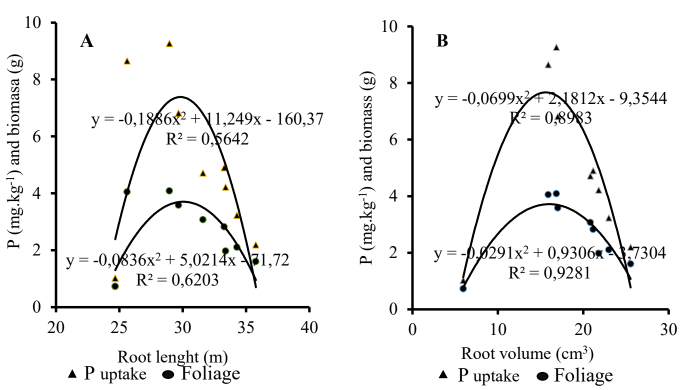

Figure 4. Relationship of root length (A) and root volume (B) with absorbed phosphorus and biomass of maize in an acid soil.

The LR relationship with Pab biomass in acid soil differs from that obtained with beans in the same soil by Sequera and Ramírez (2013). The fitting equations found by these authors were linear in nature, the difference could be attributed, in part, to the different behavior between the grass, maize, and the legume.

Conclusions

The three sources of phosphorus evaluated showed differences in their ability to release available P. SFT was more efficient as a source of available P in the soil and in dry matter production, compared to acidified rocks. R30T proved to be as efficient as RFA in its ability to release available phosphorus and produce dry matter by corn.

Root development in terms of LR and VR increased in response to a small increase in soil available P, but with successive increases in available phosphorus a decrease was found. The behavior of the measured root parameters varied with soils.

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