GAFSA ROCK PHOSPHATE AND TRIPLE SUPERPHOSPHATE FOR DRY MATTER PRODUCTION AND P UPTAKE BY CORN

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ABSTRACT: Crops in general make poor use of phosphorous fertilizer and, as a result, recommended rates and production costs are very high. Phosphorus can be made more readily available to plants by proper management of phosphate fertilization, selecting both, type of fertilizer and application method. This study was carried out to evaluate the efficiency of the natural Gafsa rock phosphate and the triple superphosphate on dry matter production and P uptake by corn plants cultivated in a greenhouse. Fertilizers were applied localized and broadcast/incorporated on to two soils with contrasting phosphorus capacity factors (PCF). Rock phosphate broadcast application was as efficient as triple superphosphate in increasing corn plant dry matter in the Tropudult, with lower PCF. This effect was not observed on the Haplustox, owing to the lower P solubility due to the higher Ca concentration in this soil. Triple superphosphate rates increased plant P uptake in both soils and for both application forms. Rock phosphate resulted in higher P-content in plants, but only for broadcast application on the Ultisol.
Key words: rock phosphate, phosphate fertilization, phosphorus fixation

FOSFATO DE GAFSA E SUPERFOSFATO TRIPLO NA PRODUÇÃO DE MATÉRIA SECA E ABSORÇÃO DE FÓSFORO PELO MILHO

RESUMO: Os fertilizantes fosfatados, de modo geral, apresentam baixa eficiência de utilização pelas culturas. Essa realidade faz com que as doses aplicadas sejam altas, elevando o custo de produção. O aumento da disponibilidade de fósforo para as plantas pode ser obtido mediante o manejo correto da adubação fosfatada, com ênfase na fonte utilizada e no modo de aplicação mais adequado para solos com diferentes capacidades de adsorção do elemento. Avaliou-se a eficiência do fosfato natural de Gafsa e do superfosfato triplo, em amostras de dois solos (Argissolo Amarelo e Latossolo Amarelo) com diferentes fatores capacidade de fósforo (FCP), em diferentes doses aplicadas de forma incorporada e localizada, sobre a produção de matéria seca e absorção de fósforo por plantas de milho cultivadas em casa de vegetação. No Argissolo Amarelo (menor FCP) o fosfato natural de Gafsa incorporado foi tão eficiente quanto o superfosfato triplo no aumento da produção de matéria seca da parte aérea das plantas de milho. Para o Latossolo Amarelo (maior FCP) esse efeito não foi obtido, provavelmente, devido à diminuição da solubilização do fosfato natural causada pelos maiores teores de Ca no solo. As doses de superfosfato triplo aumentaram a absorção de P pelas plantas de milho em ambos os solos e modos de aplicação. As doses de fosfato natural de Gafsa aumentaram o conteúdo de P nas plantas de milho apenas para a aplicação incorporada no Argissolo.
Palavras-chave: fosfato natural, adubação fosfatada, fixação de fósforo

INTRODUCTION

Highly weathered tropical soils have high phosphorus (P) fixing characteristics. In this environment, increasing P availability to plants can be achieved by proper management of phosphate fertilization, as well as by choosing the most suitable fertilizer for each soil type (Novais & Smyth, 1999).

Fertilizers of higher phosphate solubility, such as triple superphosphate, are obtained from phosphate rock that is treated and concentrated by chemical means, and have a high concentration of P readily available to plants (van Raij et al., 1982). Natural phosphates, on the other hand, can be divided in two categories: natural phosphates of low reactivity (igneous and metamorphic origin), and natural reactive phosphates (sedimentary origin).

In Brazil, natural phosphates have shown low initial efficiency in relation to superphosphates, improving after some years of application. Imported natural phosphates, such as the Gafsa, are usually more efficient than Brazilian ones. Gafsa phosphate can be as efficient as superphosphate when broadcast and incorporated into the soil, but localized application is much less efficient (van Raij et al., 1982).

Localized application of phosphorus has the advantage of temporarily decreasing soil fixation, but the disadvantage of reducing the number of roots in contact with the element. The higher the volume of soil in contact with the applied rate of P, the less P will be available to the plant, given the higher proportion of formed non-labile P. This trade-off between rate and localization is aggravated as the phosphorus capacity factor of the soil increases. Lower rates of phosphorus should be more efficient in supplying this nutrient to the plant when applied locally, but this does not mean that the supply is satisfactory, as it would be if a large rate of P is applied throughout the volume of soil available to the root system. However, a lower volume of roots in a restricted space, even if it is rich in phosphorus, may not be sufficient to supply the plant with all the required P. For satisfactory phosphorus uptake by the plant, P rates should be variable depending on the type of fertilizer and method of application (Novais & Smyth, 1999).

Considering that mineral fertilizers, especially phosphates, are essential for increasing or maintaining crop productivity, it is obvious that there is need to improve application methods to avoid wastage so that farmers gain maximum benefit from such treatments.

The aim of this study is to assess the efficiency of both Gafsa phosphate and triple superphosphate on samples of two soils with different phosphorus capacity factors, using different rates and application methods, in relation to the production of dry matter and uptake of phosphorus by corn plants.

MATERIAL AND METHODS

Samples of two soils from the Pernambuco Forest Zone, Brazil were collected from the 0 to 0.2 m layer: a Tropudult from the municipality of Goiana (7°33'38" S, 35°00'09" W), and an Haplustox from Sirinhaém (8°35'27" S, 35°06'58" W). The soils were selected on the basis of two criteria: low concentration of available phosphorus and different maximum phosphate adsorption capacities (MPAC). Soil samples were air-dried, broken up and passed through a 2 mm sieve. After homogenisation, sub-samples were taken for chemical and physical characterization of the soil samples (Table 1).

Soil acidity was altered by dosing with calcium carbonate and magnesium carbonate with a 4:1 molar ratio, determined beforehand by an incubation test. After acidity correction (pH in H_2O: 6.7 for the Ultisol and 6.4 for the Oxisol), phosphorus rates were applied to samples and incubated for thirty days (Gonçalves et al., 1989), with water content kept at 80% of field capacity. The applied phosphorus rates to each soil were determined according to the respective P-remaining value (Alvarez V. et al., 2000). They corresponded to 0, 75, 150, 225 and 300 mg dm^{-3} for the Ultisol and 0, 120, 240, 360 and 480 mg dm^{-3} for the Oxisol, using triple superphosphate and Gafsa phosphate. These rates were applied in two ways: incorporation throughout the soil volume to simulate broadcast application and incorporation at the centre of the pot.

The experiment was carried out in a greenhouse using pots filled with 3.5 dm^3 of soil. Ten days after sowing, the maize (São José cultivar) was thinned, leaving two plants per pot. Nutrients were supplied to the plants, except for the phosphorus, based on Alvarez V. (1974), at the following concentrations: 50 mg dm^{-3} of N (KNO3 and (NH4)2SO4), 150 mg dm^{-3} of K (KNO_3 e K_2SO_4), 40 mg dm^{-3} of S (K_2SO_4 and $(NH_4)_2SO_4$), 0.813 mg dm^{-3} of B (H_3BO_3), 3.664 mg dm^{-3} of Mn ($MnCl_2$ 4 H_2O), 4 mg dm^{-3} of Zn ($ZnSO_4$ 7 H_2O), 1.329 mg dm^{-3} of Cu ($CuSO_4$), 1.556 mg dm^{-3} of Fe ($FeSO_4$ 7 H_2O) and 0,15 mg dm^{-3} of Mo (Na_2MoO_4 2 H_2O). Pots were weighed to provide a reference for daily irrigation with distilled water to increase soil water content to 80% of field capacity. On the fortieth day after germination, the aerial plant parts were collected and oven-dried at 65ºC until a constant weight. The dry matter was assessed and the material ground up to carry out nitric-perchloric digestion and determine P levels in the extracts according to Braga & Defelipo (1974).

Table 1 - Chemical and physical characterization of soil samples used in the experiment.

Characteristic	Tropudult	Haplustox
pH (H_2O) [1]	5.3	4.4
Ca^{++} (mmol$_c$ dm^{-3}) [1]	5.0	1.2
Mg^{++} (mmol$_c$ dm^{-3}) [1]	5.5	6.3
K^+ (mmol$_c$ dm^{-3}) [1]	0.2	0.2
H^+ + Al^{+++} (mmol$_c$ dm^{-3}) [1]	37.2	145.2
Al^{+++} (mmol$_c$ dm^{-3}) [1]	3.9	19.8
Potential CTC (mmol$_c$ dm^{-3})	47.9	152.9
Available P (Mehlich-1) (mg dm^{-3}) [1]	2.12	4.08
Remaining-P (mg L^{-1}) [2]	47.01	12.82
MPAC (mg dm^{-3}) [3]	103	964
Adsorption energy (mg L^{-1})$^{-1}$ [3]	0.7252	0.5168
k-Freundlich [4]	0.0559	0.3592
Sand (g kg^{-1}) [1]	880	480
Silt (g kg^{-1}) [1]	30	40
Clay (g kg^{-1}) [1]	90	480
Bulk density (g cm^{-3}) [1]	1.47	1.15
Particle density (g cm^{-3}) [1]	2.71	2.66
Field capacity (g g^{-1}) [1]	0.0511	0.2534
Permanent wilting point (g g^{-1}) [1]	0.0390	0.1875
Porosity (%)[1]	45.76	56.77

[1]EMBRAPA (1997), [2]Alvarez V. et al., (2000), [3]Alvarez V. (1987), [4]Equilibrium constants of Freundlich isotherm (Novais & Smyth, 1999). MPAC: Maximum phosphate adsorption capacity.

The experiment was set up as a randomized block design in a factorial scheme, with two types of soil, two phosphorus sources, two application methods for the sources and five rates, with three replicates, totalling 120 plots. The data were submitted to variance and regression analysis. The degrees of freedom for the treatments were broken down to assess the main effects of the factors and interaction among them.

RESULTS AND DISCUSSION

A significant difference was observed by the F-test ($P < 0.01$) for production of dry matter in the aerial plant parts as a function of sources, for both soils (Table 2). In treatments with triple superphosphate, which on average produced a higher proportion of dry matter as compared to natural phosphate, the greater amount of P available probably offset the smaller volume of root in contact with the fertilizer, since no interaction ($P < 0.05$) was observed between application methods and rates of fertilizer. In line with this observation, other authors (Castilhos & Anghinoni, 1988; Alves et al., 1999) have also observed that the application of soluble P to only part of corn root systems does not influence the production of dry matter the plants.

On the other hand, Barreto & Fernandes (2002) confirmed that broadcast application with incorporation into the soil of triple superphosphate increased corn production in the Ultisol, by comparison with the localized application of this fertilizer. This apparently conflicting result is related to the low P absorption capacity of the soil studied by these authors, allowing a higher P uptake owing to the increased root contact with the fertilizer, with no significant increase in P-fixation. In our study, the lower rate of triple superphosphate used in the Ultisol (75 mg dm^{-3}) supplied the P required for plant growth since there was an increased P-content in the plants receiving higher rates (Table 3) without a proportional increase in the production of dry matter (Table 2), as observed by the square-root behaviour of production as a function of P rates (Table 4).

In the case of the loamy soil, despite the fact that the averages for different localizations of triple superphosphate did not differ by the F-test, the rate x distribution interaction was significant ($P < 0.05$), indicating a higher increase in the production of dry matter when rates of up to 240 mg dm^{-3} triple superphosphate were applied locally (Table 2). Silva et al. (1993) and Prado et al. (2001) observed that sources of soluble P applied on a localized basis increased the production of corn dry

Table 2 - Production of dry matter by corn shoot as a function of rates, sources and distribution of P in the samples of two soils with different phosphorus capacity factors.

Rate	Source of phosphorus			
	Triple Superphosphate		Gafsa phosphate	
	Incorporated	Localized	Incorporated	Localized
mg dm^{-3}	---------- g per pot ----------			
	Ultisol			
0	0.24	0.24	0.24	0.24
75	24.21	27.93	17.40	1.33
150	25.09	27.00	23.68	1.11
225	26.12	27.02	26.87	1.49
300	28.50	30.24	27.01	1.16
Ave (Local)	20.83 a	22.49 a	19.04 a	1.07 b
Ave (Source)	21.66 A		10.05 B	
	Oxisol			
0	0.90	0.90	0.90	0.90
120	20.40	32.36	2.08	1.09
240	25.41	33.96	2.71	1.40
360	37.66	34.65	4.01	1.39
480	42.10	40.20	4.63	1.20
Ave (Local)	25.29 a	28.41 a	2.86 a	1.20 b
Ave (Source)	26.85 A		2.03 B	

Averages followed by the same letter, lower case between distributions and upper case between sources, did not differ in the F-test ($P < 0.05$).

Table 3 - Phosphorus content of corn shoot dry matter as a function of rates, sources and distribution of P in samples of two soils with different phosphorus capacity factors.

Rate	Triple superphosphate		Gafsa phosphate	
	Incorporated	Localized	Incorporated	Localized
mg dm^{-3}	g per pot			
	Ultisol			
0	0.15	0.15	0.15	0.15
75	34.59	21.47	19.58	0.67
150	84.29	69.52	24.27	0.48
225	105.10	69.27	29.90	0.83
300	159.96	75.99	43.43	0.54
Ave (Local)	76.82 a	47.28 b	23.47 a	0.53 b
Ave (Source)	62.05 A		12.00 B	
	Oxisol			
0	0.39	0.39	0.39	0.39
120	19.89	33.63	1.86	0.59
240	26.60	50.09	2.04	0.48
360	67.94	79.11	3.91	1.02
480	113.31	109.28	2.37	0.66
Ave (Local)	45.63 a	54.50 a	2.11 a	0.60 b
Ave (Source)	50.06 A		1.37 B	

Averages followed by the same letter, lower case between distributions and upper case between sources, did not differ in the F-test.

Table 4 - Regression equations and determination coefficients between P rates (mg dm^{-3}) and production of dry matter (g per pot) for corn plants submitted to triple superphosphate (TSP) and natural phosphate (NP) in two soils and using two application methods.

Distribution	Equation	R^2
	Ultisol	
TSP incorporated	$\hat{Y} = 0.548 + 3.510^{**}X^{0.5} - 0.114^{*}X$	0.98
TSP localized	$\hat{Y} = 0.719 + 4.062^{*}X^{0.5} - 0.143^{*}X$	0.96
NP incorporated	$\hat{Y} = 0.096 + 2.589^{**}X^{0.5} - 0.057^{*}X$	0.99
NP localized	$\hat{Y} = 0.258 + 0.171^{*}X^{0.5} - 0.006^{*}X$	0.90
	Oxisol	
TSP incorporated	$\hat{Y} = 1.037 + 1.395^{*}X^{0.5} - 0.023^{*}X$	0.99
TSP localized	$\hat{Y} = 1.382 + 3.503^{*}X^{0.5} - 0.083^{*}X$	0.97
NP incorporated	$\hat{Y} = 0.988 + 0.0078^{**}X$	0.99
NP localized	$\hat{Y} = 0.861 + 0.0033^{*}X - 0.00005^{*}X^2$	0.92

**, * significant to 1 and 5%.

matter in two Oxisols. Above the rate of 360 mg dm^{-3}, however, the production of dry matter was the same for both methods of applying the fertilizer, indicating that the favourable effect of localized application of P regarding dry matter depends on the rate. Despite the high maximum phosphate adsorption capacity (MPAC) of this soil (Table 1), high rates distributed throughout the volume of the soil were capable of supplying the P-contents required for plant growth, probably because higher quantities of the element were available in relation to the higher quantities adsorbed as a result of this type of application.

The production of dry matter of Gafsa phosphate treated corn was influenced by the method of application for the two soils, although this effect was much more pronounced for Ultisol (Table 2), for which the effect of the dose depended on the way in which the fertilizer (P < 0.01) was applied. For this soil, the broadcast application of natural phosphate with incorporation resulted in shoot dry matter production equal to that obtained with a soluble source, as suggested by van Raij et al. (1982) and Korndörfer et al. (1999).

The recommended broadcast distribution with incorporation of natural phosphates, suggested by van Raij et al. (1982), did not have a satisfactory effect in relation to localized application, although significant in the production of dry matter for the Oxisol (higher P capacity factor, Table 2). Shoot dry matter production obtained with Gafsa phosphate in both distributions on Oxisol was very low and lower than that obtained with triple superphosphate. Similar results were obtained by Coutinho et al. (1991), Oliveira et al. (1996), Sambatti et al. (1998) and Gatiboni et al. (2000), who compared the effect of Gafsa phosphate with soluble phosphorus fertilizers on the production of green matter.

Calcium treatment can reduce the solubilization of natural phosphates due to the elevation of the pH and Ca content (Kaminski & Peruzzo, 1997; Novais & Smyth, 1999). However, elevation of the pH was not the main reason for the lower efficiency of the natural phosphate in the Oxisol, since the pH of the two soils after calcium treatment was similar, whereas the P-contents of the plants for broadcast application on the Ultisol were very much higher than those observed under the same conditions for Oxisol (Table 3). Exchangeable Ca contents in the soil after application of calcium, however, were much higher in the Oxisol (66.7 $mmol_c$ dm^{-3}) than in the Ultisol (19.8 $mmol_c$ dm^{-3}). Korndörfer et al. (1999) observed that the efficiency of Gafsa phosphate was practically equal to that of triple superphosphate in supplying P to corn plants in an Oxisol (pH in water: 5.8), with Ca contents (19 $mmol_c$ dm^{-3}) very similar to those observed in the Ultisol. Therefore, the high content of exchangeable Ca was probably the main cause of lower solubilization of Gafsa phosphate in the Oxisol and, consequently, the lower efficiency of this source in relation to triple superphosphate.

In addition, the inverse relationship between the P capacity factor and uptake (Gonçalves et al., 1989; Carvalho et al., 1993; Novais & Smyth, 1999) may have contributed to this result. In this case, the lower quantity of P released by solubilization of the natural phosphate may have been adsorbed in the Oxisol at a rate higher than the plant capacity to take up the element. For the Ultisol, thanks to its lower P capacity factor, competition between fixation by the soil and uptake by the plant was not significant, resulting in higher contents available to the plants.

As a result of the natural scarcity of P in the soils, there was a strong increase in the production of plant dry matter after the addition of the first dose of the element, with a lower increase in production for subsequent doses, as characterized by the square-root adjustment obtained for the majority of regressions (Table 4).

Comparing the two triple superphosphate application methods, there is a higher P-content in shoot dry matter using broadcast application with incorporation for the Ultisol, which is not the case for the Oxisol (Table 3). However, the interaction (P < 0.05) between distribution and rate that occurred in the Oxisol reinforced that the localized application of the fertilizer promoted a higher accumulation of P for rates of 120, 240 and 360 mg dm^{-3}, confirming the results for dry matter production (Table 2). This soil with higher MPAC (Table 1) acted as a phosphorus drain and competed with the plant for phosphorus (Novais & Smyth, 1999) owing to the higher area of contact resulting from application with incorporation; at the highest rate (480 mg dm^{-3}) this effect was not observed, probably owing to the higher availability of P to the plants at this high concentration, which could have hastened the fixation and increased the P-content in soil solution.

Localized application of triple superphosphate to soils with high maximum phosphate adsorption capacity provides a way of reducing contact between the phosphate fertilizer and the soil, thus reducing P adsorption, allowing the fertilizer to have a more prolonged residual effect, as observed by Fernández et al. (2000) in experiments with *Eucalyptus camaldulensis* assessed nine years after installation.

Table 5 - Regression equations and determination coefficients between P rates (mg dm^{-3}) and P-contents (mg per pot) in corn plants receiving triple superphosphate (TSP) in two soils and using two different distribution methods, and rates of Gafsa phosphate (GP) broadcast on Ultisol.

Soil	Distribution	Equation	R^2
Ultisol (TSP)	Incorporated	$\hat{Y} = -1.208 + 0.520^{**}x$	0.99
	Localized	$\hat{Y} = -3.687 + 0.561^{**}x - 0.001^{*}x^2$	0.94
Oxisol (TSP)	Incorporated	$\hat{Y} = -9.152 + 0.228^{**}x$	0.92
	Localized	$\hat{Y} = 1.848 + 0.219^{**}x$	0.99
Ultisol (GP)	Incorporated	$\hat{Y} = -4.090 + 0.129^{*}x$	0.92

**, * significant to 1% and 5%.

On the basis of the P-content in plant shoot, regression equations were adjusted as a function of the rates of triple superphosphate and natural phosphate. The responses were linear, with exception to localized triple superphosphate application to the Ultisol, which had a highly significant square adjustment (Table 5). Significant models for P-content as a function of Gafsa phosphate were not obtained, with exception to broadcast application with incorporation in Ultisol, corroborating to a lower P solubilization of this source and its lower efficiency when applied locally.

CONCLUSION

For the Ultisol, the incorporated Gafsa phosphate was as efficient as the triple superphosphate in increasing the production of shoot dry matter of corn plants. For the Oxisol, this did not happen owing to the reduced solubilization of the natural phosphate, probably due to the higher Ca-content of the soil.

Triple superphosphate rates increased corn plant phosphorus uptake in both soils and application methods. Gafsa phosphate increased the amount of phosphorus extracted by corn plants only when incorporated into the Ultisol.

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