



Revista Brasileira de Ciência do Solo

ISSN: 0100-0683

revista@sbcs.org.br

Sociedade Brasileira de Ciência do Solo
Brasil

PROCHNOW, L. I.; VAN RAIJ, B.; KIEHL, J. C.
EFFECT OF WATER AND CITRATE SOLUBILITY ON AGRONOMIC EFFECTIVENESS OF
ACIDULATED PHOSPHATES IN THREE CONSECUTIVE CORN CROPS
Revista Brasileira de Ciência do Solo, vol. 26, núm. 3, 2002, pp. 729-736
Sociedade Brasileira de Ciência do Solo
Viçosa, Brasil

Disponível em: <http://www.redalyc.org/articulo.oa?id=180218340018>

- Como citar este artigo
- Número completo
- Mais artigos
- Home da revista no Redalyc

redalyc.org

Sistema de Informação Científica
Rede de Revistas Científicas da América Latina, Caribe, Espanha e Portugal
Projeto acadêmico sem fins lucrativos desenvolvido no âmbito da iniciativa Acesso Aberto

SEÇÃO VIII - FERTILIZANTES E CORRETIVOS

EFFECT OF WATER AND CITRATE SOLUBILITY ON AGRONOMIC EFFECTIVENESS OF ACIDULATED PHOSPHATES IN THREE CONSECUTIVE CORN CROPS⁽¹⁾

L. I. PROCHNOW⁽²⁾, B. VAN RAIJ⁽³⁾ & J. C. KIEHL⁽²⁾

ABSTRACT

In the process of phosphate rock acidulation, several impure P compounds may be formed along with the desirable Ca and NH₄ phosphates. Such compounds normally reduce the content of water-soluble P and thus the agronomic effectiveness of commercial fertilizers. In order to study this problem, a greenhouse experiment consisting of three consecutive corn crops was conducted in samples of a Red-Yellow Latosol (Typical Hapludox) in a completely randomized design (6 x 2 x 2), with four replicates. Six commercial fertilizers were added to 2 kg of soil at a rate of 70 mg kg⁻¹ P, based on the content of soluble P in neutral ammonium citrate plus water (NAC + H₂O) of the fertilizers. Fertilizer application occurred either in the original form or leached to remove the water-soluble fraction, either by mixing the fertilizer with the whole soil in the pots or with only 1 % of its volume. The corn plants were harvested 40 days after emergence to determine the shoot dry matter and accumulated P. For the first crop and localized application, the elimination of water-soluble P from the original fertilizers resulted in less bioavailable P for the plants. For the second and third crops, the effects of P source, leaching and application methods were not as evident as for the first, suggesting that the tested P sources may have similar efficiencies when considering successive cropping. The conclusion was drawn that the water-insoluble but NAC-soluble fractions of commercial P fertilizers are not necessarily inert because they can provide P in the long run.

Index-terms: water-soluble P, water-insoluble P, acidulated P fertilizers, maize.

⁽¹⁾ Part of the Ph.D. Thesis of the first author presented to the University of São Paulo – USP. Received for publication in July of 2000 and approved in April of 2002.

⁽²⁾ Doctor Professor of the Department of Soil and Plant Nutrition, University of São Paulo – USP, Escola Superior de Agricultura “Luiz de Queiroz” – ESALQ. Caixa Postal 9, CEP 13418-900 Piracicaba (SP). E-mail: liprochn@carpa.ciagri.usp.br

⁽³⁾ Pesquisador da Embrapa Meio Ambiente. Caixa Postal 69, CEP 13820-000 Jaguariúna (SP).

RESUMO: *EFEITO DA SOLUBILIDADE EM ÁGUA E EM CITRATO DE FOSFATOS ACIDULADOS NA EFICIÊNCIA AGRONÔMICA PARA TRÊS CULTIVOS SUCESSIVOS DE MILHO*

No processo de acidulação de fosfato de rocha, vários compostos classificados como impuros podem ser obtidos paralelamente aos fosfatos de cálcio e de amônio. Tais compostos normalmente reduzem o teor de P solúvel em água e a eficiência agronômica dos fertilizantes. Com o objetivo de estudar este problema, desenvolveu-se um experimento em casa de vegetação; três cultivos sucessivos de milho foram feitos em amostras de um Latossolo Vermelho-Amarelo em esquema fatorial completo (6 x 2 x 2), com quatro repetições. Seis fertilizantes fosfatados acidulados comerciais foram adicionados a 2 kg de solo na dose de 70 mg kg⁻¹ de P, a qual foi determinada de acordo com o teor de P solúvel em citrato neutro de amônio + água (CNA + H₂O) dos fertilizantes. Os fertilizantes foram aplicados na forma original ou lavados para remover a fração de fósforo solúvel em água e incorporados em volume total de terra ou com 1 % do volume. As plantas de milho foram colhidas após 40 dias da emergência e a matéria seca e P acumulado foram determinados. No primeiro cultivo, e aplicação localizada, a eliminação do P solúvel em água dos fertilizantes originais resultou em menor quantidade de P biodisponível às plantas. Nos demais cultivos, os efeitos de fonte de fósforo, lavagem e método de aplicação não foram tão evidentes como no primeiro cultivo, sugerindo que as fontes de P testadas podem ter eficiência semelhante quando se consideram vários cultivos. Concluiu-se que a fração insolúvel em água, porém solúvel em CNA, dos fertilizantes testados não deve ser vista como totalmente inerte, uma vez que pode disponibilizar fósforo a longo prazo.

Termos de indexação: P solúvel em água, P insolúvel em água, fertilizantes fosfatados acidulados, milho.

INTRODUCTION

When phosphate rock (PR) is acidulated to form more soluble P fertilizers, iron and aluminum P compounds can also form other than the desired calcium and ammonium phosphates (Lehr et al., 1966; Frazier & Lehr, 1967; Gilkes & Lim-Nunez, 1980; Dillard & Frazier, 1983). These compounds decrease the content of water-soluble P (Bartos et al., 1992; Hamond et al., 1989; Mullins, 1988; Prochnow et al., 1997; 1998) and may decrease the agronomic effectiveness of fertilizers (Lehr, 1980; Cathcart, 1980; Lehr, 1984).

It has been shown that the efficiency of the P fraction only soluble in neutral ammonium citrate (NAC) is generally lower when compared to the water-soluble fraction or the monocalcium phosphate monohydrate p.a. - MCP - (Sikora et al., 1989; Mullins et al., 1995). Gilkes & Mangano (1983) showed that the water-insoluble Fe-Al-P compounds in monoammonium and diammonium phosphates (MAP and DAP) presented 35 to 60 % of the efficiency of the MCP in providing P for wheat plants.

Available information suggests that there are abundant supplies of PR reserves for the immediate future (Cathcart, 1980; Lehr, 1984), however, the quality of the PR available for the phosphate fertilizer industry has been declining (McClellan &

Gremillion, 1980; Lehr, 1980, 1984). With rising amounts of cationic impurities in PR utilized by the companies, in the near future P fertilizers in the market will be of great variability in composition and quality, a problem that should be studied worldwide.

In Brazil, where PR normally contains high amounts of cationic impurities (especially Fe and Al), little effort has been made to evaluate the P-supplying efficiency of the phosphates obtained from these materials and specifically from the fraction only soluble in NAC. Prochnow et al. (1997) compared four experimental phosphates produced from raw materials with different amounts of cationic impurities and found that, for the first crop, the NAC-P fraction was less efficient in supplying this nutrient to the corn plants than the NAC + H₂O-soluble fraction. However, for the second crop, the efficiency of the NAC-P fraction increased and became superior to the NAC + H₂O fraction.

The efficiency of the NAC-soluble fraction of Brazilian commercial acidulated P fertilizers is unknown. This information would be important for a quality evaluation of the P fertilizers farmers have been using in the field.

The objective of this study was to compare the P availability of some of the main Brazilian commercial P fertilizers, both in the original and

water leached form, in order to evaluate the efficiency of the NAC-soluble fraction for three consecutive corn crops.

MATERIAL AND METHODS

Six of the main Brazilian commercial acidulated P fertilizers were used: MgO-enriched Superphosphate (Mg-SSP); Ammoniated Single Superphosphate (ASSP); Single Superphosphate (SSP); Partially Acidulated Phosphate Rock with H₂SO₄, 50 % acidulation (PAPR); Triple Superphosphate (TSP); Imported Triple Superphosphate (ITSP) produced with Florida PR. All sources were analyzed for total P, P in NAC + H₂O-soluble and water-soluble P (Table 1), as described by AOAC (1984). The NAC + H₂O-soluble P refers to the amount of P extracted by first leaching fertilizer samples with water and then shaking the residue with a NAC solution according to the mentioned procedure. Fe and Al contents were determined in hydrochloric acid digests and quantified by atomic absorption spectrophotometry (Table 1). The ratio of water-soluble P to NAC + H₂O-soluble P (named "fi ratio") was calculated for all sources of P (Table 1).

A greenhouse experiment was conducted in a completely randomized design, with four replicates, and treatments in a 6 x 2 x 2 factorial arrangement consisting of the six P sources, two ways of preparing the phosphates (leaching, in order to remove the water-soluble P, or not leaching), and two application methods (mixed with the whole soil content in the pots or with only 1 % of its volume).

The leaching procedure used to remove water-soluble P from the phosphorus sources was adapted from Bartos et al. (1991). Twenty-five grams of

fertilizer were agitated with 250 mL of de-ionized water for 1 h and the solution filtered through Whatman paper number 42 utilizing a Buchner-type funnel and suction flask. The water-insoluble residue remaining on the filter paper was washed with two 65 mL portions of de-ionized water, and then rinsed with acetone to promote rapid drying. Water-insoluble residues were scraped off the filter paper and stored in plastic bottles. The residues were analyzed for remaining water-soluble and NAC + H₂O-soluble P and the "fi" ratio was calculated (Table 2).

The P sources were thoroughly mixed with 2 kg of soil in pots (mixed application) or with a portion of 20 g of soil, which was applied at the center of the pots, approximately 2.5 cm below the surface (localized application). The application rate was 70 mg kg⁻¹ P of soil, calculated according to the NAC + H₂O-soluble P content in the phosphates. Phosphate sources were applied based on AOAC (1984) available P, instead of total fertilizer P for three reasons: (1) citrate-insoluble P is considered to be unavailable to plants by AOAC standards; (2) phosphate fertilizers in Brazil, and in many other countries, are sold and applied on the basis of their AOAC available P content; (3) studies that have evaluated the effect of water-soluble P have expressed this water-soluble P as a percentage of the available P (Mullins & Sikora, 1995).

The study was conducted with a medium-textured Red-Yellow Latosol (Typical Hapludox) with a pH in water of 4.9. Resin-extractable P (Raij & Quaggio, 1983) was 3 mg dm⁻³, which represents a low content. Cation exchange capacity was 8.87 cmol_c dm⁻³. The base saturation was adjusted to 70 % (approximately pH 6.2) by adding dolomitic limestone (CaO = 32.5 %, MgO = 18.1 %). Nitrogen and potassium were added as base application at

Table 1. Total P, P soluble in NAC + H₂O, water-soluble P, Fe and Al and percentage of water-soluble in relation to NAC + H₂O-soluble P ("fi") of commercial acidulated P fertilizers

P source ⁽¹⁾	P			Fe	Al	fi
	Total	Soluble in NAC+H ₂ O	Water-soluble			
	%					
Mg-SSP	8.4	8.0	2.7	2.3	0.2	33.8
ASSP	9.3	8.5	5.6	2.9	0.2	66.9
SSP	9.1	8.5	5.6	3.1	0.2	65.9
PAPR	8.6	5.0	2.1	1.4	1.1	42.0
TSP	20.7	20.0	16.9	1.8	1.1	84.5
ITSP	20.9	20.3	16.5	1.8	1.1	81.3

⁽¹⁾ Mg-SSP = MgO-enriched Superphosphate; ASSP = Ammoniated Single Superphosphate; SSP = Single Superphosphate; PAPR = Partially Acidulated Phosphate Rock; TSP = Triple Superphosphate; ITSP = Imported Triple Superphosphate.

Table 2. Soluble phosphorus in NAC + H₂O, water-soluble P and percentage of water-soluble in relation to NAC + H₂O-soluble P ("fi") of commercial acidulated P fertilizers, after water leaching

P source ⁽¹⁾	P		fi
	Soluble in NAC + H ₂ O	Water-soluble	
	%		
Mg-SSP	16.3	1.3	8.0
ASSP	10.0	0.6	6.0
SSP	10.2	0.6	5.9
PAPR	7.9	0.3	3.8
TSP	24.4	0.9	3.7
ITSP	25.5	1.2	4.7

⁽¹⁾ Mg-SSP = MgO-enriched Superphosphate; ASSP = Ammoniated Single Superphosphate; SSP = Single Superphosphate; PAPR = Partially Acidulated Phosphate Rock; TSP = Triple Superphosphate; ITSP = Imported Triple Superphosphate.

rates of 100 mg kg⁻¹ N, as urea, and 250 mg kg⁻¹ K, as KCl. A mixture containing all micronutrients was added in order to supply 5, 10, 10, 10, 5 and 1 mg kg⁻¹ of B, Fe, Mn, Zn, Cu and Mo, respectively.

Eight seeds of corn (*Zea mays*, hybrid ICI-8568) per pot were sown at a depth of \approx 1 cm. After germination, plants were thinned to four per pot. De-ionized water was added at a rate of 170 mL kg⁻¹ of air-dried soil. During the entire experiment, de-ionized water was added daily to maintain the initial soil moisture, preserving the original pot weight. Top dressing N and S were applied at rates of 250 mg kg⁻¹ N and 50 mg kg⁻¹ S, split in two applications. The amounts of nutrients applied by liming + basal application + top dressing were adequate to rule out any potential side-effect when comparing P sources which include different amounts of some of the nutrients.

Harvesting was performed 40 days after planting. Shoots were removed by cutting the stalk 1 cm above the soil surface. The plant material was dried at 50 °C, weighed, and subsamples subjected to digestion and P determination according to procedures described by Malavolta et al. (1989).

After harvesting, the soil in each pot was mixed. Subsamples were collected from the center of the pots at a depth of 0-15 cm for analysis of P-resin following the procedure described by Raij & Quaggio (1983). In order to evaluate the residual effect of the applied P, two consecutive corn crops were grown for 40 days using the same procedure described for the first growing period. The same amount of N, K and micronutrients utilized for the first crop were reapplied to the soil before the second and the third crop to prevent any nutrition side-effect.

Variance analysis for dry matter yield and P uptake was performed considering each cropping separately and for the three croppings together. Means were compared using the Tukey test at a 0.05 significance level.

RESULTS AND DISCUSSION

Phosphorus source characteristics and leaching effects

The "fi" ratio ranged from 33.8 % for the Mg-SSP to 84.5 % for the TSP (Table 1). Prochnow et al. (1997) found a high negative relation between the "fi" ratio and the amounts of Fe + Al of the tested experimental single superphosphates. In the present study some of the commercial P fertilizers used are not in the same class as single superphosphates. For the Mg-SSP the NAC fraction is composed primarily by Mg forms of P, while PAPR is not acidulated as much as a single superphosphate and so the composition of the NAC fraction could greatly differ from that found in SSPs. Therefore, no relation was established between the "fi" ratio and the amounts of Fe + Al in this study.

The leached residues still contained some water-soluble P, but in amounts so small that the maximum "fi" ratio (in the Mg-SSP) was only 8 % (Table 2). The presence of small amounts of water-soluble P in residues has also been found by other authors (Bartos et al., 1991; Sikora et al., 1992; Prochnow et al., 1997; 1998). The concentration of P soluble in NAC + H₂O in the leached residues was higher than the concentration of total P in the original fertilizers (Tables 1 and 2) in spite of the removal of most of the water-soluble P. This is due to the leaching of a smaller P proportion than the proportion of total weight lost by the solubilization of other elements and substances.

Dry-matter yield and phosphorus uptake by the first crop

All commercial fertilizers in the original form resulted in higher dry matter yield and P uptake than in the leached form, when applied in a localized way, although the differences for two of the fertilizers were not statistically significant (Table 3). The data suggest that, in general, the NAC-soluble fraction (leached phosphates) of the commercial P fertilizers were less efficient in providing P to the corn plants, compared to the NAC + H₂O-soluble fraction. Bartos et al. (1992) and Mullins et al. (1995) have observed similar results. Thus, in general, NAC-soluble P fractions, when localized, are no substitute for water-soluble P in a first cropping.

Table 3. Effect of method of application, water leaching and acidulated P fertilizers on the yield of dry matter and P uptake by corn plants grown for 40 days in samples of a Red-Yellow Latosol (first crop)

P source ⁽¹⁾	Phosphate condition ⁽²⁾	Method of application ⁽³⁾	
		Mixed	Localized
Dry matter, g pot ⁻¹			
Mg-SSP	Original	20.1 AaC	22.6 AaCD
	Leached	24.3 Aac	19.8 Aac
ASSP	Original	21.2 AaC	24.2 AaCD
	Leached	19.4 Aac	11.3 Bbd
SSP	Original	21.6 AaC	25.0 AaCD
	Leached	21.9 Aac	11.9 Bbd
PAPR	Original	19.8 AaC	18.7 AaD
	Leached	18.5 Aac	10.0 Bbd
TSP	Original	24.1 AaC	28.2 AaC
	Leached	23.9 Aac	6.8 Bbd
ITSP	Original	23.1 AaC	24.8 AaCD
	Leached	23.6 Aac	8.3 Bbd
P uptake, mg pot ⁻¹			
Mg-SSP	Original	27.2 AaC	19.5 BaCD
	Leached	27.2 Aac	17.6 Bac
ASSP	Original	24.1 AaC	20.9 AaCD
	Leached	25.9 Aac	9.4 Bbd
SSP	Original	29.6 AaC	19.9 BaCD
	Leached	26.0 Aac	10.2 Bbcd
PAPR	Original	23.8 AaC	14.3 BaD
	Leached	24.9 Aac	9.6 Bacd
TSP	Original	24.7 AbC	24.4 AaC
	Leached	32.7 Aac	8.9 Bbd
ITSP	Original	22.8 AaC	26.3 AaC
	Leached	27.5 Aac	8.5 Bbd

Values followed by the same letter (normal capital in the line comparing methods of application, normal lower case in the column comparing phosphate condition (original form vs. leached for each P source), italic capital in the column comparing original P source and italic lower case comparing leached P source) are not statistically different ($p < 5\%$).

⁽¹⁾ Mg-SSP = MgO-enriched Superphosphate; ASSP = Ammoniated Single Superphosphate; SSP = Single Superphosphate; PAPR = Partially Acidulated Phosphate Rock; TSP = Triple Superphosphate; ITSP = Imported Triple Superphosphate. ⁽²⁾ Phosphate condition: original= not submitted to a procedure used to remove water-soluble P, leached = submitted to leaching. ⁽³⁾ Methods of application: mixed = P sources thoroughly mixed with the whole soil, localized = mixed with 1 % of the soil.

For the mixed application, excepting the TSP, for which the leached fraction gave better results when considering the P uptake, no differences were found between the two studied phosphate conditions. This leads to the idea that once these P fertilizers are incorporated into the soil in relatively high P amounts, the NAC-soluble fraction will be as efficient as the NAC + H₂O fraction.

For the leached phosphates, except for the dry-matter yield of the Mg-SSP treatment, mixed application led to a higher dry matter yield and P uptake than when the fertilizers were localized, suggesting that the fraction only soluble in NAC behaved as low solubility phosphates. When applied in the original form and mixed with the whole soil in the pots, the Mg-SSP, SSP and PAPR were also more efficient in providing higher P uptake to the corn plants. It is notable that two of these three fertilizers presented the lowest "fi" ratio among the P fertilizers tested. This indicates that these phosphates with low amounts of water-soluble P in relation to the NAC + H₂O soluble P, have a similar behavior as low solubility phosphates such as phosphate rocks, concerning on the application method.

No differences were found between the commercial acidulated P sources, in both phosphate conditions (original form and leached form), when phosphates were mixed with the whole volume of soil (Table 3). Instead, some differences were observed for the localized application, as the PAPR presented low efficiency when the sources were applied in the original form and the Mg-SSP showed the highest efficiency among the leached phosphates. Mullins & Sikora (1995) also verified that the efficiency of the water-insoluble fraction in supplying P to plants was source dependent. In the case of the studied Brazilian fertilizers, P fertilizers were source dependent when localized, even in their original form.

The results show that the Mg forms of P included in the Mg-SSP, which are water-insoluble, present higher efficiency than the forms of P contained in the conventional acidulated P fertilizer, such as SSP and TSP. This result is in agreement with Sinden (1990), who discussed this fertilizer in detail and concluded that even with lower water-solubility the Mg-SSP can be as efficient as the SSP for corn and soybean in acid soils with a high P adsorption capacity.

Taking into consideration that the amount of NAC + H₂O-soluble P applied to the pots was the same for all P sources, they should all have brought forth similar results for dry matter yield and P uptake if this extractor could really predict P availability. The fact that results were not similar when the original P sources were localized (Table 3) indicates, as already verified by other authors (Bartos et al., 1991; Prochnow et al., 1997), that the content of P soluble in NAC + H₂O (AOAC method) is not an adequate index for evaluating the phosphorus availability of all acidulated P fertilizers. It seems that those with a low fi ratio, in the case of our study the PAPR, could not be well characterized in terms of P availability by this method.

Therefore, when fertilizers are localized, P recommendations only based on the NAC + H₂O-

soluble fraction could lead to unsatisfactory results. The rates of water-soluble P and the "fi" ratio could also be considered, especially for fast growing crops.

Dry-matter yield and phosphorus uptake by the second crop

The data variance analysis obtained in the second crop shows that a significant effect was only for the application method of the P sources, with higher dry matter yield (17.8 vs. 16.3 g pot⁻¹) and P uptake (38.5 vs. 30.1 mg pot⁻¹) for the localized application than when the fertilizers were thoroughly mixed with the soil. There were no effects of P source and leaching. The idea is that the P contained in the water-insoluble fraction was absorbed in low amounts by the first crop, becoming more available by revolving the soil before the second crop. A possible explanation would be that the water-insoluble fraction of the fertilizers could then interact with the soil particles enhancing the P dissolution and providing more available forms of P.

The results obtained for dry matter yield and P uptake in the second crop are in accordance with the results obtained for the P-resin of soil samples collected after harvesting the first crop. These results pointed out no difference in the soil status of P between the various P sources and leaching and, concerning on the method of application, higher amounts of P for the localized application (25.2 vs. 17.9 mg dm⁻³ P of soil).

Dry-matter yield and phosphorus uptake by the third crop

For the third crop, the variance analysis showed a difference between the original and leached P sources, with higher results of dry matter yield (10.1 g pot⁻¹ vs. 9.2 g pot⁻¹) and P uptake (25.8 mg pot⁻¹ vs. 22.9 mg pot⁻¹) for the leached sources. This confirms the hypothesis that the NAC fraction, in general, did not perform well in the first crop but its P availability would increase with further cultivation of the soil. So, it seems that water-insoluble but NAC-soluble forms of P can be plant available for subsequent or perennial crops.

For P uptake, the analysis of variance showed an effect of the application method, with the ones localized, before the first crop, performing better than the mixed (26.7 vs. 22.0 mg pot⁻¹). This can be attributed to the effect of still remaining residues, especially of the water-insoluble fraction of the P fertilizers, which were mixed with the whole volume of soil between the first and second cropping.

Phosphorus uptake by the three crops

When the results were considered for the three crops together, the only difference observed was in relation to the method of application, when the phosphates were applied in the original form, with

better results for the localized before the first crop (Table 4). The lack of significance observed for P source and leaching shows that, although differences exist for the first cropping, P sources can present similar efficiencies when considering successive cropping. Consequently, as already stated by Prochnow et al. (1997), the conclusions drawn based on a first cropping – related to the lower efficiency of the NAC fraction and to the inadequacy of the NAC + H₂O method (AOAC) for evaluating the P availability of fertilizers – may not be the same as those based on successive cropping, or longer cropping systems than the one used in this study, i.e., 40 days. The adequacy of the NAC + H₂O as a mean to evaluate the available P from the acidulated P fertilizers varied depending on the application method and number of croppings. Data obtained confirms the importance of experiments that include the evaluation of the residual effect from P applications.

Based on the poor performance of the PAPR for the first crop, when localized, and its increasing efficiency through time, it is suggested that the availability of residual P could be taken into account when determining P rates that are to be localized in the soil for different crops. The results of previous studies (Prochnow et al., 1997; Prochnow et al., 1998), in which experimental sources of P were prepared under laboratory conditions and tested in

Table 4. Effect of acidulated P fertilizers, application methods and water leaching on the P uptake by three corn crops grown in samples of a Red-Yellow Latosol

P source ⁽¹⁾	Original ⁽²⁾		Leached ⁽²⁾	
	Mixed ⁽³⁾	Localized ⁽³⁾	Mixed	Localized
	mg pot ⁻¹			
Mg-SSP	80.5	81.4	79.6	79.9
ASSP	74.3	87.6	73.9	80.7
SSP	74.4	88.3	75.7	78.2
PAPR	76.4	71.4	80.4	70.7
TSP	72.9	87.4	89.8	76.8
ITSP	77.2	85.3	86.5	84.2
Mean	76.0 B	83.6 A	81.0 A	78.4 A

Values followed by the same letter in the line comparing methods of application inside each phosphate condition are not statistically different ($p < 5\%$).

⁽¹⁾ Mg-SSP = MgO-enriched Superphosphate; ASSP = Ammoniated Single Superphosphate; SSP = Single Superphosphate; PAPR = Partially Acidulated Phosphate Rock; TSP = Triple Superphosphate; ITSP = Imported Triple Superphosphate. ⁽²⁾ Phosphate condition: original = not submitted to a procedure used to remove water-soluble P, leached = submitted to leaching. ⁽³⁾ Methods of application: mixed = P sources thoroughly mixed with the whole soil, localized = mixed with 1 % of the soil before the first crop.

greenhouse experiments, and of the present study, in which commercial sources of P were evaluated, suggest that for fast growing crops, with a high P demand, rates of localized P could be elevated when phosphates have low "fi" values, since the solely NAC-soluble fraction presents low agronomic effectiveness. One possibility to attain this objective would be to calculate the P rate that is to be applied based on the water-soluble and not on the NAC + H₂O-soluble fraction. In contrast, for slow growing crops as pastures and perennial plants, the residual effect of the NAC-soluble fraction could be considered and the NAC + H₂O used to determine the rate of P fertilization. This, however, still awaits validation under field conditions.

It has been shown that the water-insoluble but NAC-soluble fraction present in P fertilizers should not be considered as totally inert. This is in accordance with Sikora et al. (1992) who, using solubility products, showed that some compounds which are not water-soluble but soluble in NAC may not be immediately available but tend to solubilize in the soil in course of time, thus providing P to the plants.

CONCLUSIONS

1. For the first crop and localized application, except for the Mg-SSP and PAPR, the P in the NAC fraction of the tested Brazilian commercial P fertilizers was not as available to corn plants as the P in the NAC + H₂O fraction.

2. For the first crop and mixed application there were no differences between P availability of the NAC fraction and of the NAC + H₂O fraction.

3. In the second and third crop, the effects of P source and of leaching out the water-soluble P were not as evident as in the first crop, leading to the idea that the studied P sources can present the same efficiency when considering successive cropping.

4. The NAC fraction of commercial P fertilizers is not necessarily unavailable, since P from this less readily available fraction can be provided in the long run for successive slow growing crops, like perennial plants or pastures.

ACKNOWLEDGMENTS

The authors wish to express their gratitude to Dr. Norman Chien, from the International Fertilizer Development Center, for the relevant opinions and review, which certainly improved the quality of this paper. The first author wishes also to express his gratitude to CNPq for his scholarship in research.

LITERATURE CITED

- ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS - AOAC. Official methods of analysis. 14.ed. Arlington, 1984.
- BARTOS, J.M.; MULLINS, G.L.; SIKORA, F.G. & COPELAND, J.P. Availability of phosphorus in the water-insoluble fraction of monoammonium phosphate fertilizers. *Soil Sci. Soc. Am. J.*, 55:539-543, 1991.
- BARTOS, J.M.; MULLINS, G.L.; WILLIAMS, J.C.; SIKORA, F.J. & COPELAND, J.P. Water-insoluble impurity effects on phosphorus availability in monoammonium phosphate fertilizers. *Soil Sci. Soc. Am. J.*, 56:972-976, 1992.
- CATHCART, J.B. World phosphate reserves and resources. In: KHASAWNEH, F.E.; SAMPLE, E.C. & KAMPRATH, E.J., eds. *The role of phosphorus in agriculture*. Madison, American Society of Agronomy, 1980. p.1-18.
- DILLARD, E.F. & FRAZIER, A.E. Precipitated impurities in monoammonium phosphate and their effect on chemical and physical properties of suspension fertilizers. Muscle Shoals, Alabama, National Fertilizer Development Center, 1983. 57p.
- FRAZIER, A.W. & LEHR, J.R. Iron and aluminum compounds in commercial superphosphates. *J. Agr. Food Chem.*, 15:348-349, 1967.
- GILKES, R.J. & LIM-NUNEZ, R. Poorly soluble phosphates in Australian superphosphate: their nature and availability to plants. *Aust. J. Soil Res.*, 18:85-95, 1980.
- GILKES, R.J. & MANGANO, P. Poorly soluble, iron-aluminum phosphates in ammonium phosphate fertilizers: their nature and availability to plants. *Aust J. Soil Res.* 21:183-194, 1983.
- HAMMOND, L.L.; CHIEN, S.H.; ROY, A.H. & MOKWUNYE, A.U. Solubility and agronomic effectiveness of partially acidulated phosphate rocks as influenced by their iron and aluminum oxide contents. *Fert. Res.*, 19:93-98, 1989.
- LEHR, J.R. Impact of phosphate rock quality on fertilizer market uses. *Ind. Miner.*, 200:127-153, 1984.
- LEHR, J.R. Phosphate raw materials and fertilizers, Part I - a look ahead. In: KHASAWNEH, F.E.; SAMPLE, E.C. & KAMPRATH, E.J., eds. *The role of phosphorus in agriculture*. Madison, American Society of Agronomy, 1980. p.81-120.
- LEHR, J.R.; FRAZIER, A.W. & SMITH, J.P. Precipitated impurities in wet-process phosphoric acid. *J. Agr. Food Chem.*, 14:27-33, 1966.
- MALAVOLTA, E.; VITTI, G.C. & OLIVEIRA, S.A. Avaliação do estado nutricional das plantas, princípios e aplicações. Piracicaba, Associação Brasileira da Pesquisa Potassa e Fósforo, 1989. 201p.
- MCCLELLAN, G.H. & GREMILLION, L.R. Evaluation of phosphatic raw materials. In: KHASAWNEH, F.E.; SAMPLE, E.C. & KAMPRATH, E.J., eds. *The role of phosphorus in agriculture*. Madison, American Society of Agronomy, 1980. p.43-80.
- MULLINS, G.L. Plant availability of P in commercial superphosphate fertilizers. *Comm. Soil Sci. Plant Anal.*, 19:1509-1525, 1988.

- MULLINS, G.L. & SIKORA, F.J. Effect of soil pH on the requirement for water-soluble phosphorus in triple superphosphate fertilizers. *Fert. Res.*, 40:207-214, 1995.
- MULLINS, G.L.; SIKORA, F.J. & WILLIAMS, J.C. Effect of water-soluble phosphorus on the effectiveness of triple superphosphate fertilizers. *Soil Sci. Soc. Am. J.*, 59:256-260, 1995.
- PROCHNOW, L.I.; KIEHL, J.C. & RAIJ, B. van. Influence of cationic impurities in acidulated phosphates on the availability of phosphorus to two corn crops. *Comm. Soil Sci. Plant Anal.*, 28:1375-1391, 1997.
- PROCHNOW, L.I.; KIEHL, J.C. & RAIJ, B. van. Plant availability of phosphorus in the neutral ammonium citrate fraction of Brazilian acidulated phosphates. *Nutr. Cyc. Agric.*, 52:61-65, 1998.
- RAIJ, B. van & QUAGGIO, J.A. Métodos de análise de solo para fins de fertilidade. Campinas, Instituto Agronômico de Campinas, 1983. 31p.
- SINDEN, J. MFM-magnesium multiphosphate. *Phosph. Potassium*, 167:20-25, 1990.
- SIKORA, F.J.; DILLARD, E.J.; COPELAND, J.P. & MULLINS, G.L. Chemical characterization and bioavailability of phosphorus in water-insoluble fractions of three monoammonium phosphate fertilizers. *J. Association Off. Anal. Chem.*, 72:852-856, 1989.
- SIKORA, F.J.; COPELAND, J.P. & MULLINS, G.L. Apparent solubility products of phosphorus impurity compounds in commercial monoammonium phosphate fertilizers. *Soil Sci. Soc. Am. J.*, 56:402-407, 1992.