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Phosphorus availability from natural and soluble phosphate sources for irrigated corn production

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This research's aims were to evaluate the mixture ratios of P fertilizers in irrigated corn yield in two seasons as well as evaluate the capacity of Resin and Mehlich 1 extractors to predict the P availability under field conditions in two soils: Hapludults and Oxisol. In the first crop, the experimental design was randomized block with four replications where two P sources, Triple Superphosphate (TSP) and Daoui Natural Phosphate (DNP), were tested in four rations (100%:0%; 67%:33%; 33%:67%; 0%:100%). The second planting was carried out in a similar manner, with some modifications to verify the residual effect of the fertilizers. DNP provided lower productivity and leaf P levels when compared to TSP in the first year but the DNP contributed with a higher residual effect through the test conditions. DNP fertilization provided higher residual effect in Hapludults than in Oxisol. Only Resin extractor, in Oxisol without TSP application in the second cultivation, was efficient in estimating the availability of P to the corn plants in the experiment conditions. In the experiment conditions, DNP provided productivity and leaf P levels similar to Triple Superphosphate in the first year and its residual effect is highly dependent on the soil type.

Key words: *Zea mays,* fertilizing, phosphorus, extractors.

INTRODUCTION

Northern Minas Gerais is part of Brazilian semi-arid region and presents areas recognized as having agricultural potential due to their topographical conditions and favorable soils for diverse several agricultural activities. However, poor rain distribution and droughts severely limit agricultural activities in a more intensive and competitive way, making it highly dependent on irrigation.

There is a great lack of information on corn (*Zea mays* L.) plants and P fertilizers in irrigated areas in the North of Minas Gerais, especially about natural phosphates which can be an interesting alternative to soluble phosphates (Moreira et al., 2002). Another concern is that Brazil has only 2% to 3% of the world reserves of P (Lopes, 1999), that is, raw materials used in phosphate fertilizer production are scarce, non-renewable and without substitution.

Natural phosphate rocks (PRs) (that is, natural phosphates of low reactivity or natural reactive phosphates) (Corrêa et al., 2005) for direct use on soil has gained attention worldwide as a natural raw material. However, more importance must be given regarding the

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Table 1. Chemical and physical properties of the 0 to 20 cm layer of the two soils studied.

Soil	pH[1]	P[2]	K[2]	Ca[3]	Mg[3]	Al[3]	H+Al[4]	Sand	Silt	Clay
		mg dm^{-3}	mmolc dm^{-3}					g kg^{-1}		
Hapludults	5.6	1	2.05	31.0	1.4	0.0	60.8	340	210	450
Oxisol	6.1	1	1.76	28.0	1.1	0.0	52.4	550	130	320

[1] pH H_2O; [2] Mehlich I extraction; [3] KCl extraction; [4] Calcium acetate extraction.

roles of phosphorus fertilizers on the accumulation of trace elements (As, Cd, and Pb) in production fields, which seems common and consequently may reach crops (Jiao et al., 2012). PRs are considered as a nutrient-rich P source for organic farming and, thus, interest in PRs as a “natural fertilizer” could open future markets (Smalberger et al., 2006). On the other hand, P fertilization in Brazilian Cerrado soils is mostly based on soluble sources (Ramos et al., 2009).

Soluble phosphate provides a higher response in the first year when compared to natural phosphates of small initial efficiency (Horowitz and Meurer, 2004). Associated to low efficiency, excessive or inappropriate use of fertilizers can affects the environment resulting in leaching by irrigation or precipitation, besides it causes pollute ground or underground water (Chen et al., 2009). However, P fixation occurs more intensely in high solubility sources than in natural phosphates, which release P more slowly and minimize the fixation process (Novais and Smyth, 1999). Consequently, the efficiency differences between the sources tend to decrease with time.

Many of the soil analysis laboratories in Brazil have adopted Mehlich 1 extraction and the anionic exchange resin to quantify phosphorous availability to plants. The objectives were to evaluate varying mixes of triple superphosphate and Daoui natural phosphate on the productivity of irrigated corn in northern of Minas Gerais, and to evaluate the potential of Mehlich 1 and anionic exchange resin to predict P availability under these conditions.

MATERIALS AND METHODS

Site characteristics

The experiment was carried out under field conditions in Montes Claros, State of Minas Gerais, Southeast Brazil located at 16°40’12,5” South and 43°50’40,1” West, 630 m above sea level, during the corn (2004/2005) season. The climate, according to the Koppen classification, is Aw, considered as tropical of savannah, with dry winter and rainy summer. Two low P level soils, a Hapludults and an Oxisol, were treated with dolomitic limestone (Table 1) and the cultivated corn hybrid was BR-201.

Experimental design and treatments

The P sources were the triple superphosphate - TSP (0 - 48 - 0; as standard or reference) and the Daoui natural phosphate – DNP (highly reactive phosphate rock of sedimentary origin from Morocco, with total P_2O_5 - 32%, soluble P_2O_5 in citric acid 2% (1:100) - 9%, Ca - 36%, physical nature: bran), used in different proportions. The irrigation control was done through tensiometer and the water supply was established when the matric potential reached -60 kPa.

The first cultivation was conducted in summer season. The experimental design was a completely randomized block with four P ratios from two forms of phosphate as aforementioned (100%:0%; 67%:33%; 33%:67%; 0%:100%, TSP and DNP, respectively) and four replications. Each experimental unit covered a total area of 75 m^2 (5 m x 15 m), with five rows, 15 m in length, spaced one meter. For yield evaluation, a central useful area of 9 m^2 was considered (three rows of three meters in length).

The second cultivation was carried out off-season, as described for the first one, with some modifications to verify the residual effect of the natural phosphate. The experimental design was a completely randomized block in 2 × 4 factorial scheme as follows: with and without application of triple superphosphate in the 2nd cultivation and 4 levels of DNP:TSP in the 1st cultivation, with four replications. Each plot was divided in two parts, where half received triple superphosphate fertilizer and the rest did not.

Field practices and management

P application rate was 100 kg P_2O_5 ha^{-1}, according to the recommendations for corn culture cultivated under low P-level soils in the Minas Gerais State (Alves et al., 1999). At soil tillage, in the first season, 2 Mg ha^{-1} of dolomitic limestone was applied to raise the pH in water of the soil close to 5.5, that is, an amount previously determined through a neutralization curve in laboratory. Inter row fertilizers were applied for amounts of N and K_2O, in potassium chloride and ammonium sulfate forms being 20 kg ha^{-1} of N and 70 kg ha^{-1} of K_2O for Hapludults and 20 kg ha^{-1} of N and 100 kg ha^{-1} of K_2O for the Oxisol. In both planting times and soils (Hapludults and Oxisol), a total of 120 kg ha^{-1} of N in urea form was applied on surface, split in two applications.

Measurements

In the beginning silking, leaf samples located below the corn ear were collected to determine the foliar P levels according to the methodology described by Malavolta et al. (1997). In the end of the growing season, grain yield was determined and grain moisture was adjusted to 12%. Before the second planting, soil samples were collected to determine “available” P. Two extractors were used: anionic exchange resins (Raij et al., 1986) and Mehlich 1 (Mehlich, 1978). The estimated P from these extractors was averaged and supported the recommendation of 80 kg P_2O_5 ha^{-1} in the form of triple superphosphate.

Statistical analysis

All variables were subjected to variance analysis. The addition or no addition of triple superphosphate in the 2nd season was compared by the F test and the DNP:TSP proportions in the 1st cultivation were compared by regression analysis.

Table 2. Yield and leaf P levels of Oxisol and Hapludults soils (first cultivation).

Treatment*	Yield kg ha^{-1}	Leaf P Levels mg kg^{-1}
	Oxisol	
100% DNP:0% TSP	4,580	2.14
67% DNP:33% TSP	4,767	2.19
33% DNP:67% TSP	4,776	2.22
0% DNP:100% TSP	4,785	2.20
Average	4,727	2.19
	Hapludults	
100% DNP:0% TSP	4,608	2.08
67% DNP:33% TSP	4,712	2.10
33% DNP:67% TSP	4,978	2.25
0% DNP:100% TSP	5.008	2.31
Average	4.826	2.18

* DNP=Daoui Natural Phosphate and TSP=Triple Superphosphate. Treatments represent the percent of P_2O_5 applied from each source. Each data is mean of four replications.

RESULTS AND DISCUSSION

In the first experiment, there was no difference among the treatments for corn yield or foliar P concentrations for either soil (Table 2). However, in the first crop it must be considered that, although not statistically significant, the average yields of corn fertilized only with TSP were 5% and 8% higher, respectively, for the Oxisol and Hapludults compared to fertilization only with DNP. These results are in agreement with Richart et al. (2006) who did not verify superphosphate superior than natural reactive phosphate in an evaluation of the P and sulfur availability to soybean.

Some studies have demonstrated a low agronomic effectiveness of natural phosphates when applied alone (Prochnow et al., 2004; Franzini et al., 2009). However, the natural phosphates can be quite effective than higher solubility sources to supply P to plants, because they are sources of controlled P release and this minimizes the nutrient fixation processes (Rajan et al., 1996; Horowitz and Meurer, 2004; Resende et al., 2006). Therefore, natural phosphate could be used for the immediate supply of P to plants (Table 2), still providing a probable residual effect (Table 3). Thus, the residual effect becomes a very important component in agronomic and economic evaluation of phosphate fertilization practices (Resende et al., 2006).

In off-season cultivation, all the treatments that received triple superphosphate fertilization provided superior grain productivity than those without fertilizer application for both Oxisol and Hapludults soils (Table 3). For the two soils, the increment of soluble phosphate levels at the first cultivation did not influence yield and leaf phosphorus levels in the second cultivation with or without triple superphosphate application. These results corroborate with Fageria et al. (1991), which report that the residual effect of the triple superphosphate is usually low.

While the triple superphosphate application in the second cultivation strongly influenced corn yield, in the oxisol, there was no difference to grain production and P leaf concentrations in Hapludults in these conditions (Table 3). The highest production in Hapludults was 5.084 kg ha^{-1} under 59% of DNP and 41% of TSP applied in the first cultivation (Figure 1). Possibly this result is due to the differences in the soils' mineral constitutions. The natural phosphate dissolution is dependent to pH and Solution Ca and the existence of soil components, or plants, acting as P and mainly, Ca drains is considered as a major factor for the dissolution and effectiveness of the natural phosphates (Rajan et al., 1996; Novais and Smyth, 1999). If a soil has previously limed and contains only permanent charge, just a few quantity of the natural phosphate would be dissolved by the end of the second year after their application. However, whether a soil at these conditions contains variable-charge components, all natural phosphate applied would have dissolved in this soil by the end of the second year. These results corroborate the findings of Robinson et al. (1994), who also noted the dissolution of a reactive phosphate rock (Gafsa phosphate rock) in soils ever in the second year.

In the Table 4 presents phosphorus for the two soils. Overall, the extractors were not efficient in predicting phosphorus availability for corn plants in both soils and different proportions of phosphates studied. However, the resin extractor was numerically more efficient in predicting the availability of P regardless of the type of soil.

In general, there was no correlation between the P extraction by Mehlich 1 and anionic exchange resin and the corn yield under the experiment conditions (Table 5). These results differ from those obtained by Moreira

Table 3. Yield and leaf P levels of Oxisol and Hapludults soils (second cultivation).

Primary treatment (first year)	Secondary treatment (second year)	Yield kg ha^{-1}	Leaf P Levels mg kg^{-1}
		Oxisol	
100% DNP:0% TSP	+ TSP	5,114*	2.12^{ns}
	- TSP	3,128*	2.09^{ns}
67% DNP:33% TSP	+ TSP	5,041*	2.15^{ns}
	- TSP	3,201*	2.16^{ns}
33% DNP:67% TSP	+ TSP	5,104*	2.20^{ns}
	- TSP	2,458*	2.22^{ns}
0% DNP:100% TSP	+ TSP	4,987*	2.19^{ns}
	- TSP	2,452*	2.22^{ns}
		Hapludults	
100% DNP:0% TSP	+ TSP	5,847*	2.22^{ns}
	- TSP	4,589*	2.45^{ns}
67% DNP:33% TSP	+ TSP	5,752*	2.14^{ns}
	- TSP	5,024*	2.35^{ns}
33% DNP:67% TSP	+ TSP	5,814*	2.45^{ns}
	- TSP	4,915*	2.31^{ns}
0% DNP:100% TSP	+ TSP	5,428*	2.14^{ns}
	- TSP	3,987*	2.31^{ns}

* - significant at 5% level; ^{ns} - not significant. DNP = Daoui natural phosphate and TSP = Triple Superphosphate. For the same proportion DNP:SP. Each data is mean of four replications.

Table 4. Available P by Mehlich 1 extraction and Resin capsule equilibrium from Oxisol and Hapludults.

Treatments	Mehlich 1 (mg dm^{-3})	Resin (mg dm^{-3})
	Oxisol	
100% DNP:0% TSP	10	22
67% DNP:33% TSP	7	21
33% DNP:67% TSP	7	20
0% DNP:100% TSP	7	20
	Hapludults	
100% DNP:0% TSP	15	52
67% DNP:33% TSP	13	45
33% DNP:67% TSP	12	38
0% DNP:100% TSP	12	38

DNP=Daoui Natural Phosphate and TSP=Triple Superphosphate. Treatments represent the percent of P_2O_5 applied from each source. Each data is mean of four replications.

(1997) and Faria et al. (2006), who found a high correlation between the two extractors for P available (r=0.96*) and P plant and P soil concentration (r values higher than 0.90), respectively.

Only Resin extractor, in Oxisol without TSP application in the second cultivation, was efficient in estimating the availability of P to the corn plants in the experiment conditions (Table 5). In assessing the liming-phosphated

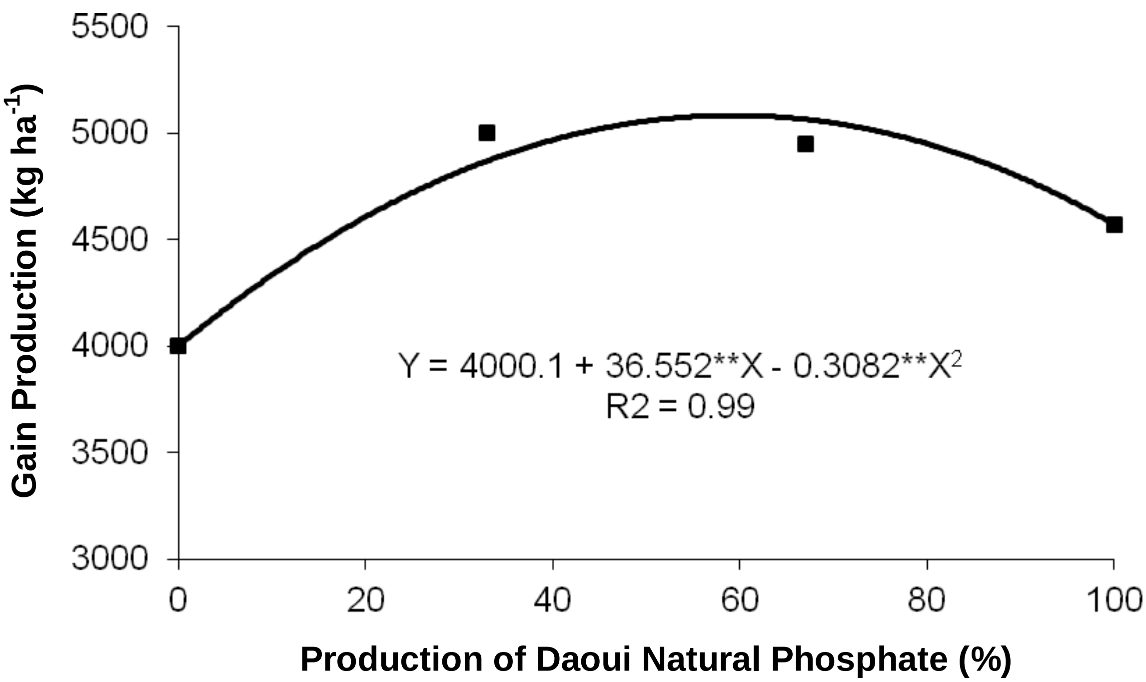

Figure 1. Residual P response of corn to proportions of Daoui Natural Phosphate levels grown on Hapludults without application of triple superphosphate, in the second year of cultivation.

Table 5. Correlation coefficients for the Mehlich 1 and Resin extraction in Oxisol and Hapludults, with grain production in the second cultivation.

Extrator	Oxisol		Hapludults	
	With TSP	Without TSP	With TSP	Without TSP
Mehlich 1	0.60^{ns}	0.52^{ns}	0.46^{ns}	0.05^{ns}
Resin	0.50^{ns}	0.87*	0.52^{ns}	0.24^{ns}

* - significant at 5% level; ^{ns} - not significant. DNP = Daoui Natural Phosphate; TSP = Triple Superphosphate.

fertilizing influence interaction on the critical P levels and on the growth of eucalyptus in a typical Dystroferric Red Latosol, the resin extractor was the most efficient in predicting the availability of P in the soil to the eucalyptus seedlings (Silva et al., 2007). The acid extractors are not suitable for soils that have recently received applications of natural phosphates because they tend to overestimate the P readiness of the plants, i.e., they are capable of extracting insoluble P from the natural phosphates (Novais and Smyth, 1999). In general, Mehlich 1 extracts preferably the fractions of phosphorus bound to calcium (Lacerda et al., 2013).

Conclusions

The productivity and leaf P levels in both soils were slightly higher when there was application of Triple Superphosphate compared to the application of Daoui Natural Phosphate in the first year of application, although was observed residual effect in the test conditions for Daoui Natural Phosphate.

Daoui Natural Phosphate fertilization supplied higher residual effect in Hapludults than in Oxisol in the test conditions being the residual effect highly dependent on the soil type.

In general, there is no correlation between corn yield and P extraction by Mehlich 1 and anionic exchange resin when natural phosphates are applied.

Conflict of Interest

The authors have not declared any conflict of interest.

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