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Title
Phosphorus utilization from 32P-triple superphosphate by corn plants, as affected by green manures and nitrogen and phosphate fertilizer rates in cerrado (savannah) soil

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Introduction

Phosphorus (P) deficiency is a major constraint to crop production in most of tropical and subtropical acid soils, and P fertilizers are required to sustain optimum crop yields (Zapata and Zaharah, 2002). In Brazil, the low rates and the incorrect managing of nitrogen (N) and P fertilizers are one of the factors responsible for low corn crop yield, allied to acidity of the soil that propitiates high P fixation (Novais and Smith, 1999; Sousa and Lobato, 2004). While the amount of N applied to corn in Brazil is, in average, 60 kg ha^{-1}, in the USA is 150 kg ha^{-1}, and in China, 130 kg ha^{-1}. The P application to corn in Brazil is also low, with average of 35 kg ha^{-1} of P_2O_5 (International Fertilizer Industry Association, 2008).

The mineralization of organic residues of green manures or of the organic matter may be a good source of P for the crops. However, as for the N, the high C/P ratio of the crop residues can also condition to P immobilization by microbial biomass (Novais and Smith, 1999).

Studies using the ^{32}P tracer methodology on the P dynamics in the soil-plant system, mainly evaluating the efficiency of soluble phosphate fertilizers, as triple and single superphosphate, have demonstrated that rarely the crops utilize more than 10% of the applied amount (Faquin et al., 1990; Salcedo et al., 1990; Franzini et al., 2009), unlike the data obtained by other methods, which could have been overestimated due to the interactions that may happen with the soil P (priming effect) (Chien et al., 1996).

The objective of this work was to evaluate the utilization, by corn plant, of P from triple superphosphate-^{32}P (TSP-^{32}P) applied at different rates, and P from soil, as affected by crop residues of green manures sunnhemp (*Crotalaria juncea* L.) or millet (*Pennisetum glaucum* L.) and different N rates.

Material and methods

The experiment was conducted in a greenhouse of the Center for Nuclear Energy in Agriculture - CENA/USP, Piracicaba, S. Paulo State, Brazil, using pots with 5 kg of soil (Rhodic Dystroferric Hapludox) Dystroferric Red Latosol, loamy, cerrado (Savanah) phase (Embrapa, 1999). Initially the green manures plants sunnhemp and millet were produced for the main experiment, in which corn plants, were grown combining green manures incorporated to the soil with different doses of urea-N and of TSP-^{32}P.

The experimental design was completely randomized, with 32 treatments and four replications, in a 4x4x2 factorial scheme. The treatments were combinations of four P rates as triple superphosphate-^{32}P: 0, 0.175, 0.350 and 0.700 g P per pot; four N rates as urea: 0, 0.75, 1.50 and 2.25 g N per pot; and sunnhemp and millet as green manures. Green manure dry matter provided 1 g N per pot.

The soil utilized was collected from layer 0.0-0.2 m and analyzed according to Raij et al. (2001): pH ($CaCl_2$): 4.8, total N: 1.0 g kg^{-1}, O.M.: 12.7 g dm^{-3}, P (resine): 11.7 mg dm^{-3}, Ca: 20.0 $mmol_c$ dm^{-3}, Mg: 10.6 $mmol_c$ dm^{-3}, K: 2.0 $mmol_c$ dm^{-3}, H+Al: 26.1 $mmol_c$ dm^{-3}, S: 7.5 mg dm^{-3}, BS: 32.6 $mmol_c$ dm^{-3}, CEC: 58.7 $mmol_c$ dm^{-3} and V: 55.5 %.

The plants were grown for 120 day after emergence, cut close to the surface of the soil, dried at 65ºC for 72 hours and, together with green manures analyzed for N and total P (Malavolta et al. (1997). The green manures plants were also analysed for total carbon using LECO CN 2000 C and N analyzer. The ^{32}P activity in the corn plants samples were determined by Cerenkov effect in the Wallac 1409 liquid scintillation counting system (Vose, 1980). Corn plants were evaluated for dry mass yield, P content, accumulated P, and P recovery from ^{32}P-triple superphosphate and from soil plus green manures. The calculations for the soil and fertilizer P recovery were done as described in Muraoka (1991). The data were analyzed statistically and when significant effects (F test. 5% of probability) were observed they were adjusted to regression equations and the relationship C/N and C/P of the green manures were compared by the Tukey test.

Results and discussion

The above ground straw parts of the sunnhemp and millet plans presented larger N and P content than respective root system (Table 1), representing the main drain for the accumulation of those two nutrients, as observed by Silva et al. (2008). The sunnhemp presented larger N concentration in the dry mass, but the P concentrations were similar for the two species in the straw or root parts. However, the C/N and C/P ratios of the sunnhemp were smaller than that of the millet, but to be a legume. Results fellow creatures were also observed for these species, in field conditions, by Carvalho et al. (2008).

Table 1. Total nitrogen and phosphorus contents, C/N and C/P ratio of the green manures residues (sunnhemp and millet) (straw and root) applied to soil as green manures for corn plant.

Green manures	Total nitrogen	Total phosphorus	C/N ratio	C/P ratio
	——————g kg^{-1}——————			
		Green manures (straw)		
Sunnhemp	23.9 a[(1)]	3.4 a	18/1 b	126/1 b
Millet	17.5 b	3.2 a	35/1 a	191/1 a
		Green manures (root)		
Sunnhemp	19.5 a	1.8 a	22/1 b	238/1 a
Millet	11.9 b	1.7 a	33/1 a	231/1 a

[(1)]Values followed by same letters, in the column, do not differ ($p < 0.05$) amongst themselves by the Tukey test.

The productivity of dry mass of the corn plants grown in the presence of sunnhenp or millet residues increased in a quadratic form as affected by the applied P rates (Figure 1A). Independently to the green manure used the point of maximum productivity of dry mass was reached with almost similar P rate, 0.51 and 0.50 g P per pot, respectively, for the corn crop grown in the presence of sunnhemp residues (102.7 g per plant) and millet (92.64 g per plant). Considering the maximum dry mass productivity in relation to the control with omission of P, the application of the element provided an increment of 83.76% for the corn plants grown in the presence of sunnhemp, and of 86.06% to the corn crop grown in the millet presence. The largest response in the corn dry mass productivity grown in the presence of sunnhemp residues, certainly was due to more regular supply of N, P, and of other nutrients by the legume green manure. The low C/N and C/P ratio (Table 1) probably favored the mineralization of their residues and lesser immobilization of N and P of the soil, the fertilizers, and green manures (reimobilization), as observed in other studies (Alcantara et al., 2000; Carvalho et al., 2008).

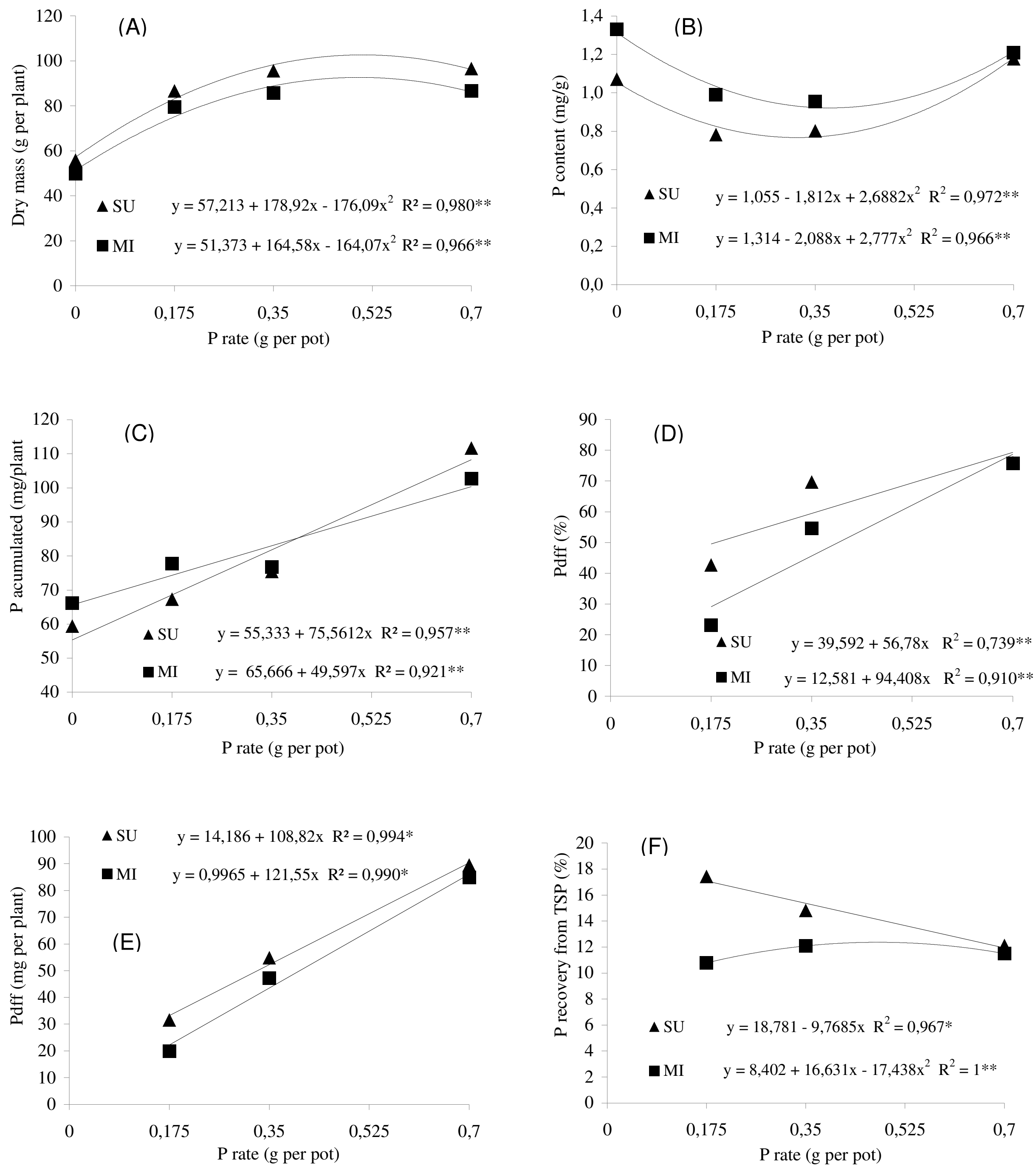

Figure 1. Dry mass productivity (A), total P content (B), P accumulation in corn shoot (C), percentage (%Pdff) (D), amount (Pdff) (E), and P recovery from the TSP (F), as affected by P rates; ** and; * significative at P< 1 and 5 % , respectively.

The amounts of accumulated P in the plant were proportional to applied TSP fertilizer rates (Figure 1C), following a quadratic model, which, partly, was due to the high productivity of dry mass, because the variation in the P contents in the corn plant was little affected (Figure 1B). The

P content in the control treatment was practically similar to that of the treatments that received highest P rate. Such a fact is due probably to the dilution effect in these treatments, which occurs when the productivity of dry mass increase with the increment of the P rate (Malavolta et al., 1997) which by turn provided increment in the amount of accumulated P, independently of the species of green manure used (Figure 1C). Independent to the residue of green manure used, the percentage (Figure 1D) and the amount of P in the corn plant derived from TSP (Figure 1E) increased lineally with the increment of the P rate. The recovery TPS-P decreased with increasing P rate (Figure 1F).

Independently to the applied N rate and of the green manure utilized, the amount of P in the corn plant (Figure 2A), the P derived from TSP (Pdff) (Figure 2C) and the utilization P from this source (Figure 2D) were smaller in the treatments without application of N. The P assimilation was stimulated by the presence of N, following the quadratic model in response to increasing rate of N (Figure 2D), as also observed by Schlegel et al. (1996).

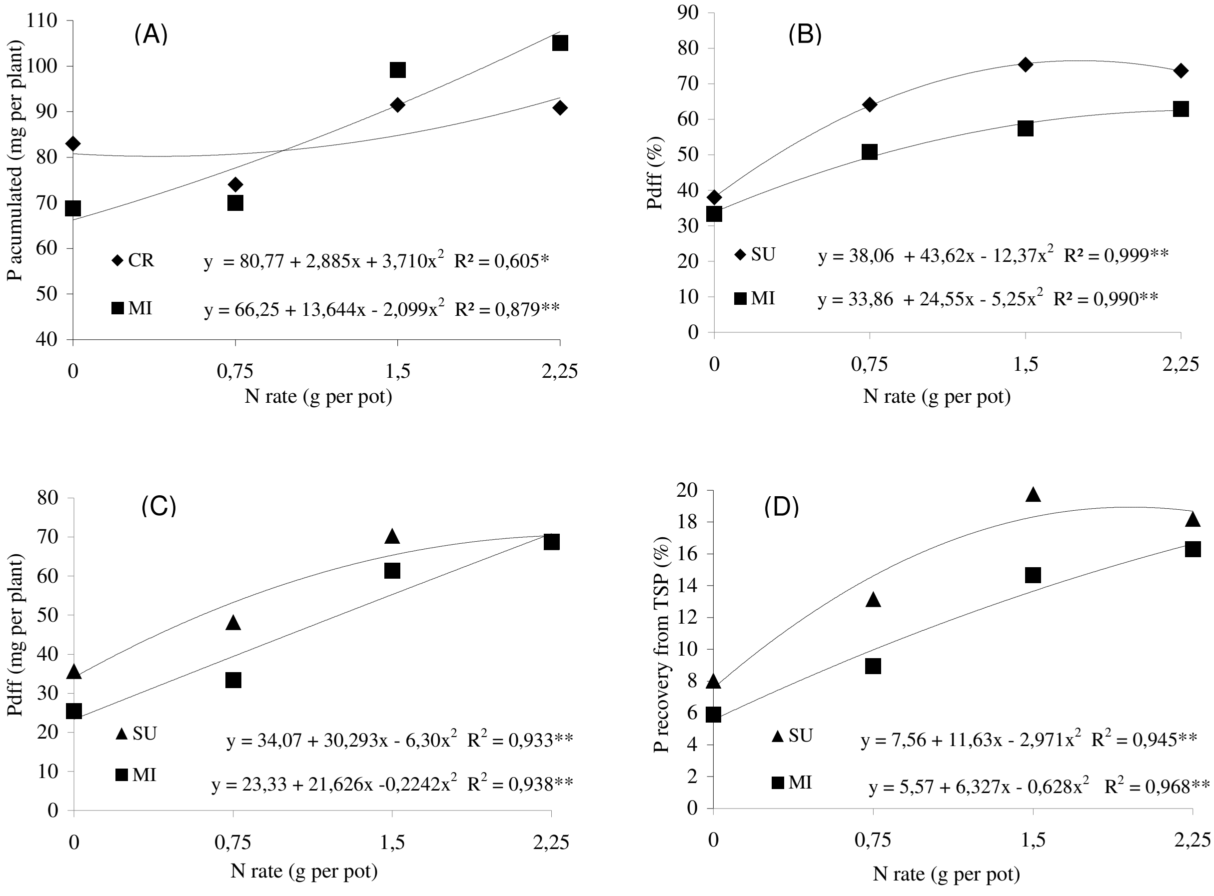

Figure 2. Phosphorus accumulation in the corn shoot (A), percentage (%Pdff) (B), amount (Pdff) (C) and TSP-P recovery (D), as affected by N rates; ** and; * significative at $P < 1$ and 5%, receptively.

Considering the N rates, its utilization by the corn plants were, on average, 6.98, 11.06, 17.21 and 17.25%, respectively, for the N rate of: 0, 0.75, 1.5, and 2.25 g N per pot. The P utilization was: 14.11, 13.45 and 11.81%, respectively, for the P rates of 0.175, 0.350, and 0.700 g P per pot. The average value (13.12%) was slightly superior to those obtained by Franzini et al. (2009), 10.52%, also in pot experiment, using a dystroferric Yelow-Red Latosol. Studies carried out using the ^{32}P methodology on the P dynamics in the soil-plant system, evaluating the P recovery from soluble phosphate fertilizers as TSP and SSP have demonstrated that rarely the P use efficiency by the crop surplus 10% (Faquin et al., 1990; Salcedo et al., 1990; Chien et al., 1996; Franzini et al., 1999), contradicting the efficiency obtained by other methods, which could be because of the interactions of green manure and soil P (priming effect) (Chien et al., 1996). The variation in the P recovery from mineral fertilizers by the plants may have been caused by several factors, mainly related to the conditions of soil, which exert great influence on P fixation capacity (Novais and Smith, 1999). Also the fertilizer used, which varies in solubility (Prochnow et al., 2003; Prochnow et al., 2004; Franzini et al., 2009).

The effect of N on P utilization from TSP was more intense in the treatments with higher N rates (1.5 or 2.25g N per pot), almost three times, compared to the treatment that received 0.750 g N per pot (Figure 2D). However, in general, the application of N resulted in more than the double of P recovery by corn plant, in relation to omission of N. Such an increase in the use of P can be expressive in economical and environmental terms. Similar results were also reported by Schlegel et al. (1996).

The percentage of P in corn plant derived from soil (Pdfs) decreased with the increasing rate of P (Figure 3A) and of N (Figure 3B), evidencing that the high availability of these nutrients reduces the assimilation of soil P, which decreased in detriment to the one of the fertilizer, although the %Pdff (Figures 1D and 2B) increased with the increasing rate of N and P. The Pdfs values were higher in the control treatment and in the presence of both green manures and decreased in a linearly with increasing rates of P and quadratically with the increment of N rates.

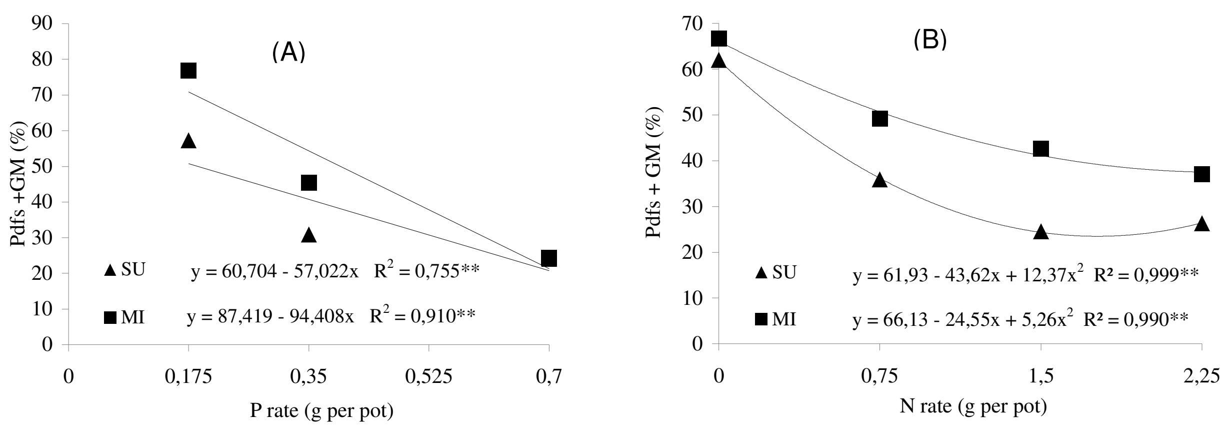

Figure 3. Percentage of phosphorus derived from soil + green manure (GM) in the corn shoot (%Pdfs), as affected by P rates (A) and N rates (B). ** Significative at P< 1 %.

The TSP-P was the main source of corn plants accumulated P, in relation to the soil and green manures. However on average, more than 85% of the fertilizer P was not absorbed by the corn plant and it remained in the soil. In a general way, both the mineral fertilizer N and green manure P promoted synergic effects on the assimilation of P of the TSP. The N favored the root system growth, which, by turn, favored the absorption of water and other nutrients, mainly all of those that have low diffusive flow in the soil, like P (Novais and Smith, 1999). With regard to the effect of the P addition, probably accursed due to the increase on the availability of the element in the sorptive soil complex.

The corn of recovery of TSP-P as well as soil plus green manure P, is worth considering, since the values obtained in this work was not considered the P contained in the corn root system, therefore, the total P recovered value is underestimated.

Conclusions

1. The triple superphosphate P recovery increased with increasing nitrogen supply and decreased with increasing rate of TSP.
2. The mineral fertilizer supplied most of the corn plants accumulated phosphorus. The recovery P fertilizer by corn plant was in average 13.12%.
3. The different residues of green manures influenced the TSP-P utilization by corn plant.

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