No-till corn performance in response to P and fertilization modes

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ABSTRACT

No-tillage systems provide soil changes that affect nutrient dynamics, hence, changing rates and forms of fertilizer application. This study aimed to evaluate the effect of phosphorus (P) and modes of nitrogen (N) and P application in corn under long-term no-tillage in a clayey Oxisol. Two experiments were carried out in the same experimental area and in the same year, in a randomized blocks design with four replications. In experiment I, the treatments consisted of five doses of phosphorus (0, 40, 80, 120 and 160 kg ha^{-1} of P_2O_5) applied in the sowing furrow. In experiment II, the treatments consisted of the N and P application modes (topdressing, in the sowing furrow and control - without N and P). Experiment I evaluated the root length, P uptake and grain yield and, the Experiment II, the firing height and yield. The P rates provided linear increases in root length in the 0-10 cm layer, P uptake and grain production. The different modes of application provided differences in the firing height and corn yield. The control treatment (0 kg ha^{-1} of N and P) provided the highest firing height, superior than those of topdressing and application in the furrow, which were not significantly different. The topdress application of N and P provided an increase in corn yield that exceeded 16 and 42% of the application in the furrow and the control, respectively. Thus, the results confirmed that increasing rates of P_2O_5, in soil with high initial P content, influence positively corn production factors, but with little significant responses, and the topdress application of N and P on soil with high P content, without water restriction, provided increased grain yield in relation to the application in the furrow.

Key words: *Zea mays*, phosphorus, location, topdressing, furrow.

RESUMO

Desempenho da cultura do milho no plantio direto em resposta ao P e ao modo de fertilização

O sistema plantio direto proporciona, ao solo, alterações que atuam profundamente na dinâmica de nutrientes, alterando as doses necessárias e as formas de aplicação de fertilizantes. Esse estudo teve por objetivo avaliar o efeito de doses de fósforo (P) e de modos de aplicação de nitrogênio (N) e P, na cultura do milho sob plantio direto de longa duração, em um Latossolo Vermelho argiloso. Dois experimentos foram desenvolvidos, na mesma área experimental e no mesmo ano, sendo utilizado o delineamento de blocos ao acaso, com quatro repetições. Em um experimento, os tratamentos foram constituídos por cinco doses do fósforo (0, 40, 80, 120 e 160 kg ha^{-1} de P_2O_5) aplicadas no sulco de semeadura. Em outro experimento, os tratamentos foram constituídos pelos modos de aplicação de N e P (a lanço, localizado no sulco e controle – sem aplicação de N e P). No primeiro experimento, foram avaliados o comprimento radicular, a absorção de P e a produtividade de grãos. No segundo, avaliaram-se a altura de requeima e a produtividade. As doses de P promoveram aumentos lineares no comprimento radicular, na camada de 0-10 cm, na absorção de P e na

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produção de grãos da cultura. Os modos de aplicação proporcionaram diferenças na altura de requeima e na produtividade do milho. O tratamento testemunha (0 kg ha^{-1} de N e P) proporcionou a maior altura de requeima, sendo superior à dos tratamentos aplicação a lanço e no sulco, que não diferiram entre si. A aplicação a lanço de N e P proporcionou incremento na produtividade de milho, superior a 16 e 42%, com relação ao da aplicação no sulco e da testemunha, respectivamente. Com isso, corrobora-se que doses crescentes de P_2O_5, em solo com teor inicial alto de P, afetam de forma positiva fatores de produção do milho, porém com respostas pouco expressivas, e a aplicação de N e P a lanço, em solo com alto teor de P e sem restrição hídrica, proporciona maior produtividade do milho, em relação à do tratamento aplicação dos nutrientes, localizada no sulco.

Palavras-chave: *Zea mays*, adubação fosfatada, localização, lanço, sulco.

INTRODUCTION

Adoption of no-till management practices has increased during the last decade. No-till is effective in reducing soil loss and water erosion (Amaral et al., 2008), increasing soil aggregation (Barreto et al. 2009) and increasing concentration of nutrients and soil organic matter (SOM) in the superficial layers (Muzilli, 1983; Sá & Lal, 2009), mainly because of the maintenance of a permanent vegetable cover.

In this system, crop residues retained on the field favor the cycling of P in the soil surface layer, reducing losses and promoting its accumulation in this layer (Muzilli, 1983; Sá & Lal, 2009). In addition, the increased aggregation in an untilled soil reduces contact between colloids and the phosphate ion, reducing the adsorption reactions (Sá, 1993). Likewise, the increase of the soil organic matter (SOM) in no-till systems (NT) contributes to the saturation of the adsorption sites (Andrade et al., 2003), lowering the binding energy of the phosphate with the colloids in the soil and increasing P in more labile forms.

The increase in P availability in NT can reduce the application rates of P fertilizers. In eleven-year trials conducted by Howard et al. (2002), the increase in production of corn in conventional tillage system (CT) was up to the rate of 39 kg P ha^{-1} (8.6 Mg ha^{-1}), while in NTS, the increase was only up to the rate of 20 kg P ha^{-1} (8.1 Mg ha^{-1}), demonstrating the reduced need for phosphorus fertilization in this system.

In long-term NT, besides the P rates, the mode of application of fertilizers is still a matter of controversy among researchers. In an Alfisol in Rio Grande do Sul, with 42 g kg^{-1} of SOM and low P availability (4.3 mg dm^{-3} of P extracted by Mehlich^{-1}), Pöttker (1999) found that the shoot dry matter production of corn and wheat grains were significantly higher when the nutrient was applied sidedress. In contrast, Pauletti et al. (2010), in an Oxisol in Paraná, under NT for over 10 years, with 51 g dm^{-3} of SOM and high levels of P (51 mg dm^{-3} of P extracted by ion exchange resin) found no difference in the yield of soybean, corn and beans, when fertilization was done in the furrow or topdress.

Considering the importance of a deeper understanding on fertilizer management in a long-term no-till system, the aim of this study was to evaluate the corn yield in response to increasing rates of phosphorus and different application modes of N and P in long-term NTS, with high initial soil P level.

MATERIAL AND METHODS

The study was conducted in Pirai do Sul - PR (49°57'W and 24°32'S, 974 m altitude). The region has a Cfb humid subtropical, mesothermal climate (Koeppen), with average temperature of the warmest month of 24 ºC and the coldest month of 15 ºC. The soil of the experimental area was classified as Typic Oxisol, characterized as eutrophic in the A horizon (epi-eutrophic), due to the management, clayey texture, depth, good structure and good drainage. The chemical and textural analyzes of the 0-10 cm layer provided the following results: pH ($CaCl_2$) 5.1; 0.0 $cmol_c$ dm^{-3} Al^{+3}; 6.5 $cmol_c$ dm^{-3} Ca^{+2}; 3 $cmol_c$ dm^{-3} Mg^{+2}; 0.57 $cmol_c$ dm^{-3} K^+; potential acidity (H+Al) of 6.69 $cmol_c$ dm^{-3} and 32 mg dm^{-3} of P (Mehlich-1); 38 g dm^{-3} of total organic-C and 620, 251 and 129 g kg^{-1} of clay, silt and sand, respectively.

Before being used for cropping, the land was under natural native grasslands, known in Brazil as “Campos Nativos”. The conversion of these fields in areas of cultivation began in the 80s. The experimental area has been 18 years under NT, with crop rotation: black oat (*Avena strigosa* Schreb.) and soybean (*Glycine max* Merr.) in the winter and summer of the first year; wheat (*Triticum aestivum* L.) and soybean in the second year; and black oat and corn (*Zea mays* L.) in the third year. The previous crop before corn was black oat, to form a vegetable cover.

Two experiments were carried out in the same year and in the same experimental area, with a randomized block design with four replications. In Experiment I, the treatments consisted of sidedress applications of five rates of phosphorus: 0, 40, 80, 120 and 160 kg ha^{-1} of P_2O_5. In Experiment II, the treatments consisted of the following modes of application of nitrogen and phosphate fertilizers: (a) in the furrow - at 5 cm beside and below the seed; (b) topdress application - manually spread fertilizer on the soil surface after planting; (c) control - with no fertilization. The amount of N applied at sowing was 45 kg ha^{-1} and the total amount of P was 75 kg ha^{-1} of P_2O_5. The fertilization of the two experiments also included the application of 150 kg ha^{-1} of potassium chloride at planting, topdressed on the entire experimental area.

Corn sowing of both experiments was performed in October 2004, using a triple early maturing hybrid. The plots consisted of seven rows of 8 m length, spaced at 0.80 m, with a total area of 44.8 m^2. The nitrogen fertilization was performed on the V6 stage of the crop, at the rate of 99 kg ha^{-1} N, applied as urea broadcasted between rows.

In the experiment with P levels, at the full flowering stage, the root system was evaluated and leaves were collected - ten leaves per plot - removing the leaf immediately below and opposite the spike (flag leaf) for chemical analysis of P level, as described by Malavolta et al. (1997). Quantification of root length in the soil profile by means of digital images was performed with the software SIARCS 3.0, developed by Embrapa Agricultural Instrumentation and reported by Crestana et al. (1994). Digital images were obtained according to Sa et al. (2010). For this purpose, trenches were dug perpendicular to the centerline of each experimental unit. The face of the trench used to evaluate the roots was manually scarified (± 1 to 2 cm) to expose the root system. A wooden frame (0.80 m wide and 0.5 m deep) divided into 10 x 10 cm squares by a nylon thread, was fixed to the scarified face of the trench and each square was photographed with a digital camera, at the 0-10, 10-20, 20-30, 30-40 and 40-50 cm depths. In the experiment with N and P application modes at the full flowering stage, the height of fired leaves - N deficiency symptoms – was evaluated using five sampled plants per plot. Grain production was obtained by harvesting, in March 2005, from both experiments, 5 m of the two central rows of each plot, making a plot useful area of 8 m^2.

The results for the P levels were subjected to regression analysis and the significance level was found using the software JMP IN version 3.2.1. The results for application modes were submitted to analysis of variance and means were compared by the Tukey test at 5% probability level ($p < 0.05$) using the software SISVAR - version 5.1.

RESULTS AND DISCUSSION

The analysis of the root length showed differences between the P rates only in the 0-10 cm layer, with the greatest concentration of roots, nearly 50% of the whole soil profile. In this layer, the P rates affected significantly the corn root length with linear positive response to increasing nutrient rates (Figure 1). However, the rates 80 and 120 kg ha^{-1} P accounted respectively for 84 and 92% of the production of the maximum rate, showing that even in the topsoil, there is little response of corn to rates above those.

The results showed that root growth is directly related to the availability of P in the soil, but with little response when the soil levels are already high, as in our experiment (32 mg dm^{-3}). Accordingly, Klepker & Anghinoni (1995) carried out a greenhouse study with P application in one fraction of the soil, with different initial levels of soil P, and demonstrated that the root growth of corn was increased with increasing dose of P in the central portion of the pot. However, this more intense growth decreased with increasing level of P in the side portions of the pot, confirming that the increase in density of roots in soil supplied with P occurs when the initial availability in the soil is low.

No influence of P application on root length of corn was found in the layers 10-20, 20-30, 30-40 and 40-50 cm (Figure 1). The lack of response to P levels in the deeper layers demonstrates the low mobility of phosphate ions in the soil profile, because of its strong adsorption to clay particles (Guimarães et al., 2008).

The analysis of the flag leaf indicated a linear increase in the absorption of P with increasing rates of the P fertilizer (Figure 2a), with accumulation of 1.6 mg P in the leaves per kg of P_2O_5 added to the soil. Despite the increasing absorption with higher P rates, the P content in the leaves at the rate 0 kg ha^{-1} of P_2O_5 was 88% of the content achieved with the highest rate (160 kg ha^{-1} the P_2O_5).

The little difference between the lowest and the highest P rates indicates that in soils with high levels of P, as in this experiment, the response in the absorption of the nutrient may not be as significant. On the other hand, in soils with low initial P content, the absorption efficiency is greater. Barreto & Fernandez (2002), in a study with conventional tillage in soil with low initial P (1 mg dm^{-3}), reported an absorption efficiency of 8 mg per kg of P_2O_5 added to the soil, well above the values obtained in this study.

The corn yield was also affected by the treatments, responding linearly with increasing rates of applied P (Figure 2b). Despite these results, the treatment with the rate 0 kg ha^{-1} of P_2O_5 showed 91% of the production achieved with the highest rate 160 kg ha^{-1} P_2O_5 (9398 kg ha^{-1}).

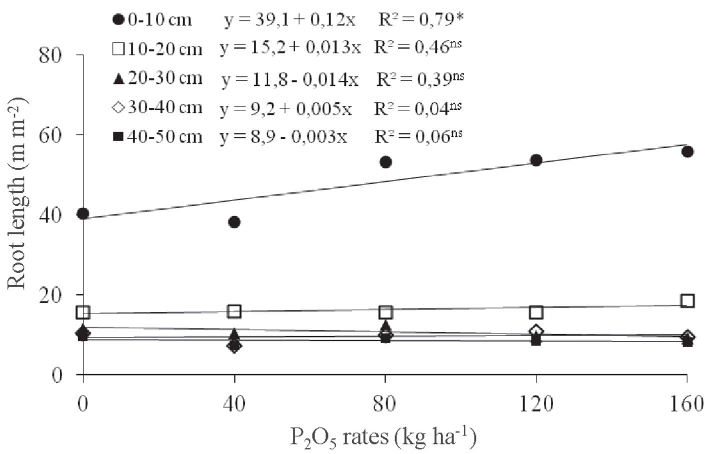

Figure 1. Root length of corn plants in different soil layers in response to phosphorus application to an Oxisol under long-term no-till system. NsNon significant; * Significant at 5% probability.

This result demonstrates that in soils whose initial P content is high, especially in long-term NT, wherein the phosphorus adsorption is lower (Sa, 1993) and maintenance of the humidity is higher (Martorano et al., 2009), increasing the efficiency of nutrient absorption, the application of P cannot be justified, both from a technical and economic standpoint. In such cases, only the replenishment of nutrient exported by grains should be performed, or even, in a few years, waived, depending on the ratio of marginal product to input price.

The application modes, topdressing and in the furrow, were not significantly different for firing height, both with less than 2.0 cm of N deficiency symptom (Table 1). However, the two treatments differed from the control, which showed a firing height of 38.0 cm. The severe symptoms observed on the control plants showed the deficiency of the nutrient for the normal development of the crop. In corn, the evaluation of the firing height is a simple way to determine N deficiency, since its evolution indicates the transfer of N from the older leaves to grains and newer leaves, because of the high mobility of the nutrient in the plant. According to Ferreira et al. (2009), the magnitude of this variable is closely and inversely related to the N content in the leaf and also with the corn yield.

The influence of the N and P application modes was confirmed on the corn yield (Table 1). The topdress application was the most responsive, providing a yield of 10,717 kg ha^{-1} in comparison with 9240 kg ha^{-1} obtained by the application in the furrow. The control treatment gave the lowest yield (7542 kg ha^{-1}). Thus, the topdress application of P and N provided an increase of 42% (3,175 kg ha^{-1}) in relation to the control yield, and a yield increase of 16% (1,478 kg ha-1) in relation to the application in the furrow.

The higher corn yield under topdress application of P in comparison with the application in the furrow is possibly related to the localized supply of P in the soil: in application in the furrow, only a fraction of the corn roots came into contact with the fertilizer, which may have resulted in the compartmentalization of P in the aerial parts of the plant (Stryker et al., 1974). This compartmentalization is attributed to the vascular organization of roots and shoots of corn and can lead to nutritional imbalances in certain

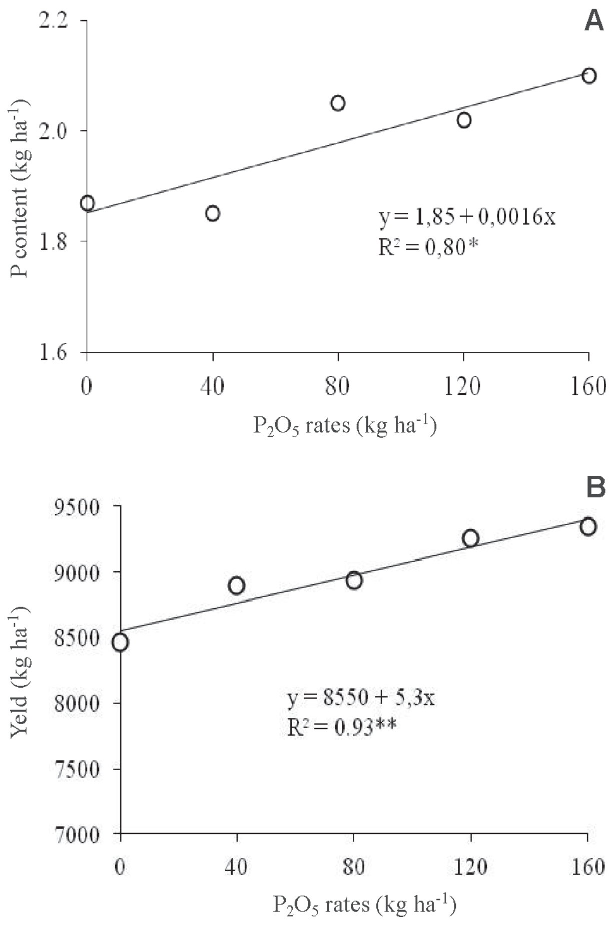

Figure 2. P content in leaves (a) and yield (b) of corn in response to P rates applied to an Oxisol under long-term no-till system. * and ** Significant at 5 and 1% probability, respectively.

plant parts, whether by excess or deficiency of P, in relation to other nutrients such as N, K, Ca and Mg. Along the same line, in a study with corn, in which one portion of roots was supplied with P, and the other one was not, Alves et al. (1999) showed that the portion supplied with P was unable to provide adequately the portion that was not in contact with the nutrient, leading to a lower P accumulation in the shoots. This demonstrates that for corn, P must be in contact with the largest possible volume of roots, so that the crop is not undermined by limitations in internal cycling of P in the plant.

Besides, it is likely that the greatest corn yield achieved with the topdress application of P is related to the fact that the study area has been under-long term NT. In no-till systems, the untilled soil and high soil aggregation reduce the contact between the phosphate ion and the soil colloids, unfavoring adsorption (Sá, 1993). In addition, the high amount of organic carbon (OC) in long-term NT (38 g dm-3) blocks the action of adsorption sites (Andrade et al., 2003), hindering the access of P and decreasing its adsorption. Similarly, decomposition of plant residues in the system leads to the release of organic anions, which bind cations such as Fe and Al (Franchini et al., 1999), reducing P fixation. Therefore, the increase in soil aggregation, levels of SOM and crop residues are crucial to provide a better utilization of P by plants in no-till systems.

It is noteworthy, however, that in areas where the P levels are below the critical level, or in initial no-till adoption, it is recommended to apply the phosphate fertilizer in the planting furrow, especially in years with drought conditions, or otherwise incur in loss of yield with topdress applications (Rheinheimer et al., 2008).

There were no episodes of water deficit at the time of N topdressing, on the contrary, soon after its application there were occurrences of rainfall. According to Cantarella et al. (1988), when urea is applied to the soil surface with occurrence of rainfall shortly after the application, no difference in corn yield is observed when compared with the results of the application in the furrow, because the rain plays an important role in the incorporation of the fertilizer, avoiding losses by volatilization of NH_3.

Table 1. Firing height and grain yield in corn as a function of N and P application modes in long-term no-till system

Application mode	Corn characteristic	
	Firing height cm	Yield kg ha^{-1}
Control	38 a	7,542 c
Furrow	0.8 b	9,240 b
Topdressing	1.0 b	10,717 a

Means followed by the same letters in the columns are not significantly different by the Tukey test at 5% probability.

Additionally, the no-till system used in the experiment may also have provided smaller losses through volatilization of NH_3, since the soil moisture remains high because of the C accumulation and the maintenance of soil cover (Da Ros et al . 2005).

CONCLUSIONS

Increasing rates of P affected positively and linearly the root length in the 0-10 cm layer, the P uptake and the yield of corn, but with little expressive responses, demonstrating that the effect of P on the corn crop is reduced in soil with high initial P content.

The N and P topdress application provided higher corn yield in relation to the application in the furrow, in soil under long-term no-till, high levels of P and without water restriction.

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