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Phosphorus fertilization in sugarcane cultivation under different soil managements

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ABSTRACT
Soil preparation along with its chemical adjustment is the most important step in sugarcane plantation, especially because it provides proper conditions for plant development. The objective of the present research was to evaluate sugarcane response to the application of different phosphorus doses and their location, associated with both minimum soil tillage and conventional soil tillage. The experiment was conducted in a split-split-plot randomized block design, where the main plots were subjected to soil managements (minimum soil tillage or conventional soil tillage), the subplots to phosphorus doses in total area, and the sub-sub-plots to phosphorus doses in the crop rows. The evaluated variables were soil chemical parameters, sugarcane production and sugar production. Minimum tillage led to larger phosphorus accumulation and higher percentage of exchangeable bases in the soil, whereas the highest P dose in total area in the crop rows led to reduction of sugar production.

Palavras-chave:
manejo da adubação
fosfatagem
cultivo mínimo
incorporação de fertilizante
Saccharum officinarum

Adubação com fósforo na cultura de cana-de-açúcar em distintos manejos de solos

RESUMO
O preparo do solo realizado concomitantemente com sua fertilização química é a etapa mais importante na instalação de um canavial, visto que proporciona melhores condições para o desenvolvimento da cultura e incrementos na produtividade. Assim, objetivou-se, no presente trabalho, avaliar a resposta da cana-de-açúcar à aplicação de diferentes doses de fosfóro e sua localização, associados ao preparo convencional e ao cultivo mínimo do solo. O delineamento experimental utilizado foi em blocos inteiramente casualizados com parcelas subdivididas, sendo o tratamento principal o manejo de solo (preparo convencional e cultivo mínimo), o tratamento secundário as doses em área total, e o tratamento terciário as doses de P_2O_5 nos sulcos. Foram avaliados parâmetros químicos do solo, produtividade de colmos e açúcar. O cultivo mínimo proporcionou maior acúmulo de fósforo e maior percentual de saturação por bases na camada superficial do solo, enquanto que a maior dose de fósforo em área total gerou redução na produção de açúcar.

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Introduction

Phosphorus deficiency directly reflects in stalk yield, technological quality and longevity of the sugarcane plantation (Rodríguez et al., 1998; Franco et al., 2007). According to Resende et al. (2006), during soil tillage, the movement of soil surface can interfere with the availability of phosphorus applied in total area.

The operations carried out during soil tillage prior to sugarcane planting directly reflect in the entire crop cycle, since the operations of correction in subsequent years become unviable due to the perennial character of the sugarcane crop (Vasconcelos et al., 2007). Morelli et al. (1991), evaluating the effect of phosphorus doses applied broadcast and in the sugarcane planting furrow in a sandy soil, observed that the broadcast application resulted in higher yields. Albuquerque et al. (2016), working in medium-textured soil, obtained the highest yield with the combination in total area and bottom of the furrow. Caione et al. (2011), in soil with clayey texture, observed no difference in yield with respect to the form of phosphorus application.

In the literature, there is a divergence regarding phosphorus application. Some authors recommend application in total area, in which it is better distributed in the area, contributing to rooting and thus increasing the explored soil volume (Rossetto et al., 2008). Other authors recommend its application in the furrow, in a localized manner, since there is greater contact with the root system (Prado et al., 2001) or for being a less expensive practice, which does not lead to difference in yield compared with the application in total area (Caione et al., 2011). In this context, the objective of this study was to compare the adoption of minimum tillage and conventional tillage of the soil for sugarcane planting, associated with the form of phosphorus application at different doses, aiming at the increment of crop yield.

Material and Methods

The experiment was carried out in the municipality of Onda Verde-SP, Brazil (20º 39' S; 49º 18' W), at mean altitude of 550 m and area of medium-textured dystrophic Red Latosol (EMBRAPA, 2013), with clay content of 20% and phosphorus content of 9 to 11 mg dm^{-3} (P-resin extractor). The climate, according to Köppen's classification (Alvares et al., 2014), is described as Aw (rainy summer and defined dry season in the winter). The sugarcane variety was RB92579, which has medium/late maturation (harvest from July to October) and characteristics of high yield and vigorous sprouting of plant cane and ratoon.

The experimental design was in split-split plots with completely randomized blocks, in four replicates, totaling 18 treatments and 72 plots (75 m^2 of evaluation area). The main treatment was soil management (conventional tillage and minimum tillage), the secondary treatment was the P_2O_5 doses in total area (0, 100 and 200 kg ha^{-1}), and the tertiary treatment was the P_2O_5 doses in the furrow (0, 90 and 180 kg ha^{-1}).

Limestone and gypsum were used according to the usual practices prior to sugarcane planting and their doses were determined based on a composite soil sample of the experimental area, with a single dose for all treatments (2.2 t ha^{-1} of dolomitic limestone and 1.2 t ha^{-1} of agricultural gypsum), incorporated by harrowing at depth of 0.1 m. Then, the secondary treatment was applied (phosphate doses in total area), with a broadcast granule distributor. The phosphorus source was monoammonium phosphate, in the commercial formulation 9-50-00 (N-P_2O_5-K_2O). The main treatment was applied in August 2012, approximately 30 days after the application of the second treatment and correctives in an agricultural year with high rainfall volume (204 mm in May and 1036 mm accumulated during January until treatment application), promoting ideal conditions for subsoiling and plowing.

A four-disc plow was used in the conventional soil tillage, working at a mean depth of 0.45 m and, subsequently, the soil was leveled with a light harrow at depth of 0.06 m. Minimum tillage was performed using a subsoiler with four shanks at a mean depth of 0.45 m.

With the beginning of the spring rains, on October 31, planting was performed with application of the tertiary treatment (phosphorus in the furrow), approximately 70 days after applying the primary treatment (soil tillage). Firstly, the furrows were opened and fertilization with potassium chloride (0-0-60) at the dose of 300 kg ha^{-1} was applied at the depth of 0.40 m. After opening the furrows, phosphorus doses (tertiary treatments) were manually distributed in the subplots. The phosphorus source was monoammonium phosphate and, since this commercial product contains nitrogen, all treatments received 60 kg ha^{-1} of nitrogen (quantity complemented with ammonium nitrate), along with the application of the tertiary treatment to homogenize the treatments, so that the observed differences would exclusively be a response of the applied treatments. After the tertiary treatment was applied, a semi-mechanized planting team distributed the seedlings, using 18 buds m^{-1}. Two sprays were applied, the first one to control weeds in pre-emergence and the second one to control sugarcane borer (*Diatraea saccharalis*).

The harvest of the plots was manually performed 12 months after planting. The plots were totally harvested and weighed using a dynamometer. Subsequently, 10 canes were randomly collected in each plot for the technological analysis, following the methodology proposed by CONSECANA (2006).

The soil samples were collected (Dutch auger) after crop harvest, in two layers (0-0.20 and 0.21-0.40 m). Each composite sample consisted of three samples from the beginning, middle and end of each plot, collected in two ways in each plot: three samples in the cane row (to evaluate the effect of doses in the planting furrow) and three samples in the interrow (to evaluate the effects of phosphate application in total area). Sugar yield was measured by the ton of sugar per hectare (TSH), resulting from the product between ton of cane per hectare (TCH) and total recoverable sugars (TRS).

The results were subjected to analysis of variance by F test, in a 2 x 3 x 3 factorial scheme, and the means were compared by Tukey test (at 0.1 probability level) when the interactions showed significant differences (Barbosa & Maldonado Junior, 2015).

Results and Discussion

The results of the analysis of variance for the treatments are presented in Table 1. The interaction between soil management

Table 1. Analysis of variance for phosphorus content (mg kg^{-1}) in the soil sampled in the row (PR) and interrow (PIR), in the layers of 0-0.20 and 0.21-0.40 m, total recoverable sugars (TRS), ton of recoverable sugar per hectare (TSH), pH in the interrow in the layer of 0-0.20 m (pH) and base saturation in the layer of 0-0.20 m (V)

Treatments	PR	PR	PIR	PIR	TRS	TSH	pH	V (%)
	(m)							
	0-0.20	0.21-0.40	0-0.20	0.21-0.40				
	F test							
Soil management (P)	0.24 ns	118.92 **	37.38 **	0.00 ns	0.47 ns	0.00 ns	14.60 **	8.65***
Dose in total area (S)	1.19 ns	2.21 ns	6.75 *	8.38 **	8.58 **	3.46***	2.22 ns	1.12 ns
Dose in the furrow (T)	9.72 **	14.68 **	2.35 ns	1.21 ns	2.11 ns	0.55 ns	4.40 *	0.02 ns
P X S	0.85 ns	1.23 ns	1.05 ns	1.29 ns	0.04 ns	0.88 ns	0.23 ns	0.34 ns
P X T	0.14 ns	0.61 ns	7.41 **	1.40 ns	0.26 ns	0.60 ns	0.28 ns	0.06 ns
S X T	0.21 ns	0.96 ns	1.46 ns	1.11 ns	0.33 ns	0.84 ns	4.08 **	2.08 ns
P X S X T	0.70 ns	0.34 ns	0.81 ns	0.51 ns	0.23 ns	2.18 ns	2.61 ns	0.03 ns
Overall mean	17.27	14.57	13.03	8.14	124.09	16.89	4.58	52.73
CV (%) (P)	71.85	13.30	32.06	62.22	7.03	18.84	9.09	38.78
CV (%) (S)	34.33	63.99	46.64	45.58	7.42	12.03	4.73	19.61
CV (%) (T)	42.50	56.21	33.83	28.44	6.44	10.54	4.25	17.13

nsNot significant; *Significant at 0.01 probability level; **Significant at 0.05 probability level; ***Significant at 0.1 probability level

and dose in total area was significant at 0.05 probability level, for the P content in the soil sampled in the interrow in the layer of 0-0.20 m, as well as for the difference in pH, favored by soil management. The other interactions were not significant.

The P doses applied in total area increased the content of this element in the soil, and both P doses increased its content in the upper soil layer (0-0.20 m). The doses of 100 and 200 kg ha^{-1} of P_2O_5 were equal and differed from the control (0 kg P_2O_5). Therefore, the dose of 100 kg ha^{-1} applied in total area is already sufficient for the increment of this element in the surface soil layer. On the other hand, in the layer of 0.21-0.4 m, there was no difference between the doses 0 and 100 kg ha^{-1} of P_2O, where the difference was only in relation to 200 kg ha^{-1} of P_2O_5 (Table 2), i.e., for an increase of P content in subsurface, the highest dose evaluated in the present study should be used.

The results found by Corrêa et al. (2004) corroborate those of the present study. These authors found similar results and reported increments in the levels of available P in the soil as a function of phosphate doses, which was justified by the fact that adsorption of P decreases with the increment in concentration and capacity of adsorption of this element in the soil.

For P contents relative to the dose in the furrow, it is noted that the doses of 90 and 180 kg ha^{-1} P_2O_5 did not differ, which suggests that the dose of 90 kg ha^{-1} of P_2O_5 was sufficient to

Table 2. Phosphorus contents in the layers of 0-0.20 and 0.21-0.40 m for doses applied in total area and in the furrow

Dose in total area (kg ha^{-1})	P resin (mg dm^{-3}) 0-0.20 m	0.21-0.40 m
0	9.33 b	6.04 b
100	14.52 a	7.96 b
200	15.25 a	10.42 a
LSD	3.97	2.43
CV (%)	20.89*	18.37*
Dose in the furrow (kg ha^{-1})	**0-0.20 m**	**0.21-0.40 m**
0	12.47 b	7.26 b
90	17.56 a	17.27 a
180	21.80 a	19.19 a
LSD	4.49	5.01
CV (%)	15.13*	22.12*

*Transformation: Log (x+0)

increase the content in the soil, both in surface and subsurface (Table 1). In this case, only the dose of 90 kg ha^{-1} of P_2O_5 in the furrow would be sufficient to obtain the potential yield of 90 to 100%, according to the classification suggested by Raij et al. (1996), considering the absence of limitations of other nutrients.

Caione et al. (2011), working with forms of application and doses of P, concluded that high doses in total area and high doses in the furrow did not lead to expressive increments of yield in the plant cane, and that it is possible to opt for doses from 143 to 170 kg ha^{-1} of P_2O_5 in one single form of application. Both forms of application led to similar yields.

Simões Neto et al. (2012) concluded that sugarcane production increases as a function of the applied P doses, but the highest increments of TCH occurred with the lowest doses, indicating that the limitation of P was supplied at the lowest doses.

This suggests that, under the conditions of the present study, there was no deficiency, even in the absence of phosphate, and there was a negative effect at very high doses. The TCH exhibited an overall mean of 136.08, which is much higher than the yield of 12-month-old plantations in Brazil. Oliveira et al. (2010), working with 11 varieties, noted that the variety RB92579, used in the present study, showed highest TCH and highest P use efficiency, which guarantees good representativeness of the results regarding the response of the crop to the treatments.

The dose of 200 kg ha^{-1} caused decrement in TRS, compared with the dose of 100 kg ha^{-1}, as shown in Table 3.

This is an important result of the study, which can be explained by various factors and discussed by different authors, who found

Table 3. Production of total recoverable sugars (TRS) and tons of total recoverable sugars per hectare (TSH) for P_2O_5 dose in total area

P_2O_5 in total area (kg ha^{-1})	TRS kg t^{-1} stalk	TSH t of sugar ha^{-1}
0	127.36 a	17.21 ab
100	127.18 a	17.45 a
200	117.36 b	16.01 b
LSD	6.02	1.33
CV (%)	7.42	12.04

Table 4. Effect of soil management on pH, phosphorus (P) content and base saturation (V%) in the layers of 0-0.20 and 0.21-0.40 m, collected in the interrow (0.75 m from the row)

Type of soil management	pH		P (mg dm^{-3})		V%	
	Depth (m)					
	0-0.20	0.21-0.40	0-0.20	0.21-0.40	0-0.20	0.21-0.40
Minimum	5.14 a	4.40 b	16.04 a	8.15 a	59.82 a	37.06 a
Conventional	4.85 a	4.77 a	10.02 b	8.13 a	45.64 b	42.59 a
LSD	0.38	0.23	2.32	2.81	11.35	10.42
CV (%)	13.86	9.09	13.77*	25.38*	25.75**	28.66**

*Transformation: Log(x+0); **Arcsine(root(V%/100)); means followed by the same lowercase letter in the column do not differ at 0.1 probability level

different results, as shown hereinafter. Elamin et al. (2007) reported that P deficiency leads to significant reduction in sucrose accumulation. Glaz et al. (2000), in experiments conducted in Florida (USA), with similar location and in soils with the same characteristics, found different results; in two localities, the response was positive to phosphate fertilization with respect to sugar yield, while for the other there was no response. For Lima et al. (2006), Korndörfer & Melo (2009) and Simões Neto et al. (2012), phosphate fertilization had no effect on sugar content.

In the present study, there was a reduction in sugar accumulation, which is not related only to the element P available to plants, but also to other biotic and abiotic factors. Pereira et al. (1995) reported that factors such as climate, varieties and soil management exert influence on the sugar content accumulated in the stalks. The study of Teixeira et al. (2016) demonstrates different responses in relation to P doses and sugar accumulation in different varieties harvested in 3 periods. Some varieties showed highest TRS at the lowest P dose, others exhibited no response and others showed highest TRS at the highest dose, i.e., there are large variations in the results of these variables, which are affected by various factors; therefore, it cannot be claimed that only P acts in the results.

Phosphorus caused significant effects on sugar production per hectare among the treatments. The dose of 200 kg ha^{-1} of P_2O_5 in total area led to reduction in TRS and, consequently, resulted in loss of TSH (Table 3).

Albuquerque et al. (2016) obtained maximum TSH production with the combination of 200 kg ha^{-1} of P_2O_5 in total area and 100 kg ha^{-1} of P_2O_5 in the planting furrow. However, the highest P doses combined in total area and furrow also resulted in TSH loss, corroborating with the results obtained here. Similarly, Calheiros et al. (2012) obtained the highest gains of cane and sugar yield at the intermediate doses of 192.60 and 175.64 kg ha^{-1} of P_2O_5, respectively, for the sugarcane varieties RB867515 and RB92579.

According to the effect of soil management on P content, pH and base saturation, the latter two selected due to a possible interference in P availability and for being indicators of soil correction, it was observed that the minimum tillage led to higher base saturation and P content in surface, compared with the conventional tillage, probably due to higher contents of limestone and phosphate in the surface layer, while the conventional tillage dilutes the amount of limestone and phosphate in larger soil volume (Table 4).

According to Carneiro et al. (2011), the fact of not incorporating P or incorporating it with lower intensity with minimum tillage may interfere with its dynamics and availability in the soil and with the response of the crops to phosphate fertilization, reducing the contact between soil colloids and the phosphate ion, and decreasing the adsorption, which is favorable. Hence, fertilization management must favor the absorption, reduce the processes of fixation by the soil and, consequently, increase P use by plants (Novais & Smyth, 1999). This fact is observed in the present study, because minimum tillage led to increase in base saturation and P content in the surface layer, which creates favorable conditions for greater absorption of the element by the roots, since most roots are concentrated in this layer, and also favorable condition for the lower adsorption by soil colloids, i.e., the element becomes more available for plants to absorb it.

Based on the effects caused by soil management on pH, the conventional tillage showed superiority in comparison to minimum tillage for the correction in subsurface (Table 4), since the conventional tillage is a preparation in subsurface and distributes limestone and phosphate in a larger soil volume, while minimum tillage mobilizes a more limited soil volume.

Conclusions

1. The doses of phosphorus in total area increased its content in the soil layer of 0-0.20 m; however, in the layer of 0.21-0.40 m, the dose of 200 kg ha^{-1} of P_2O_5 is indispensable for the increment of phosphorus content in subsurface.
2. The dose of 200 kg ha^{-1} of P_2O_5 in total area, not associated with the application in the furrow, resulted in the reduction of sugar content and, consequently, sugar yield (TSH).
3. The minimum tillage system increases phosphorus content and base saturation in the surface soil layer, in comparison to the conventional tillage.

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