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Effect of sources and rates of phosphorus associated with filter cake on sugarcane nutrition and yield

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Abstract

The application of filter cake associated with phosphorous can prevent the adsorption of this nutrient by soil colloids. The objective of this work was to evaluate the effect of sources and rates of phosphorous on the soil P content and in the nutritional status and yield of sugarcane cultivated in Kandiudalf and Haplustox soils in the presence and absence of filter cake. Experiments were carried out in the 2012/2013 cropping season in the state of São Paulo, Brazil. The experimental design was a randomized block in a 3x4x2 factorial arrangement with three sources of phosphorus (Phosphate of Araxá, Gafsa phosphate and triple superphosphate) and four rates of P [zero (control); 90; 180 and 360 kg ha^{-1} of P_2O_5] in the presence and absence of 7.5 t ha^{-1} of filter cake (dry basis), with three replicates. Treatments were applied in the planting furrows. Parameters evaluated were availability of P in the soil, nutritional status of P in the leaves, yield of straw and stalks and phosphorous buildup by the plants. The application of phosphorous in the soil promoted increases in the levels of P-resin in the top layer (0 – 20 cm) of 53 and 807% and in the sub surface layer (20 – 40 cm) of 839 and 432%, regardless of the phosphorous source in Kandiudalf and Haplustox without the use of filter cake, respectively. The increase of phosphorous availability in the soil increased the absorption of this nutrient with the application of P-fertilizer with filter cake. The use of Gafsa phosphorous source in Kandiudalf increased stalk production compared to the other sources tested, reaching 214 t ha^{-1} with the rate of 209 kg ha^{-1} of P_2O_5, while triple superphosphate yielded 190 t ha^{-1} with the highest rate (360 kg ha^{-1} of P_2O_5), regardless of the presence or absence of filter cake. In the Haplustox, stalk yield increased with P-fertilization (360 kg ha^{-1} of P_2O_5) with filter cake yielding 188.2 t ha^{-1}; 19.6% higher than without filter cake.

Keywords: Gafsa phosphate; Haplustox; Phosphate of Araxá; *Saccharum spp;* triple superphosphate; Kandiudalf.
Abbreviations: P_phosphorous; DAP_days after planting; P-resin_determination of available P by the resin method; O.M._organic matter; CEC_cation exchange capacity; TNP_total neutralizing power; NP_neutralization power; TSP_triple superphosphate; Gafsa_Gafsa phosphate; Araxá_Araxá phosphate; Int_ interaction.

Introduction

Nowadays, the consumption of energy and the intensity of global carbon emissions have increased worldwide, reviving concerns about the polluting potential of fossil fuel. This increase, accompanied by political instability in oil producing regions has prompted many countries to seek alternative energy sources (Martinelli and Filoso, 2008), among them the production of ethanol from sugarcane in Brazil reaching 23.64 billion liters in 2012/13 (Porto et al., 2013) taking sugarcane enormous socioeconomic importance in the country. However, specifically in Brazil, phosphate nutrition for sugarcane is extremely limiting. Concentrations of available P are naturally low and highly weathered soils have low cation exchange capacity (CEC) and high anion adsorption, increasing the need for nutrient supply to plants to optimize production (Santos et al. 2010). In this sense, Loganathan and Fernando (1980) stated that when they applied a soluble source of phosphorus in a particular soil over 90% of the total applied was adsorbed by colloids in the first hour of contact with the soil. Novais (1980) also reported that the higher the soil phosphate contact time, the greater its solubility, resulting in reduced availability of phosphorus for plants due to its adsorption by colloids. Thus, an alternative to increase soil P availability in soils cultivated with sugarcane is the addition of phosphate fertilizers associated with an organic waste. To increase the effectiveness of phosphorus use in sugarcane crops supplied with phosphate fertilizer and subsequent reduction in P rates, Bittencourt et al. (2006) recommend the use of an organic carrier such as filter cake to prevent phosphorus from fixing. However, there are several sources of P available in the market classified into soluble, sparingly soluble and insoluble; the former are readily available and the most commonly used to increase the amount of P available to plants. This fast release may also favor the adsorption and precipitation of soluble forms by soil components, making it unavailable to plants (Horowitz and Meurer, 2003), being this more expressive as more clayey is the soil. Several studies have highlighted the importance of applying P enriched with filter cake in sugar cane (Santos et al., 2010, 2014) under laboratory conditions in Brazil (González et al., 2014) and in other countries such as Bangladesh (Bokhtiar et al., 2008) and Sudan (Elsayed et a., 2008). Therefore, the objective of this work was to evaluate the effects of rates and sources of P in the soil P content and in the nutritional status and yield of fully developed sugarcane plants cultivated in Kandiudalf and Haplustox soils in the absence and presence of filter cake.

Results and Discussion

General effect of P in the soil

In Kandiudalf the levels of P-resin in the surface layer (0-20 cm) were affected by P rates. In the subsurface layer (20-40 cm), there was interaction between P rates and filter cake. On the other hand, in Haplustox P rates altered the P-resin content in the two layers (0-20 and 20-40 cm). The application of filter cake increased P-resin levels in the superficial layer in Haplustox and in the subsurface layer in Kandiudalf (Table 1).

Soil P content in Kandiudalf

In Kandiudalf, there was no interaction between P levels and filter cake on the P-resin content at 0-20 cm depth (Table 1). However, in the absence of filter cake a linear increase in the soil P content was observed, reaching 46.9 mg dm^{-3} with the highest rate applied (360 kg ha^{-1} of P_2O_5) (Fig 1A), whereas in the presence of filter cake no significant effect was observed. P levels in the soil at the depth mentioned, near the rate of 180 kg ha^{-1} of P_2O_5, are within the range considered average by Spironello et al. (1997), which varies from 16 to 40 mg dm^{-3}. At the 20-40 cm depth the presence of filter cake increased soil P levels up to the rate of 90 kg ha^{-1} of P_2O_5; with 180 kg ha^{-1}, the highest level was observed in the treatment without filter cake, and at the highest rate there was no difference between the absence and presence of filter cake (Fig 1B). There was a linear adjustment for the soil P content in the presence of filter cake as a function of P rates, reaching the level of 50.8 mg dm^{-3} with 360 kg ha^{-1} of P_2O_5. However, without filter cake P levels in the soil increased by quadratic adjustment as a function of P rates, reaching a maximum equal to 56.2 mg dm^{-3} of P at the rate of 250.6 kg ha^{-1} of P_2O_5 (Fig 1C).

Soil P content in Haplustox

In Haplustox, an increasing linear adjustment was observed in the presence of the filter cake at the P-resin level in the 0-20 cm layer, reaching the maximum with the highest rate (360 kg ha^{-1} of P_2O_5). On the other hand, a quadratic increase was observed in the absence of filter cake and the curve kept below the line represented by the presence of filter cake, with the maximum point equal to 70.8 mg dm^{-3} at the rate of 280.6 kg ha^{-1} of P_2O_5 (Fig 2A). In the 20-40 cm layer P levels in the soil increased with increases in P_2O_5 rates with linear adjustment both in the absence and presence of filter cake reaching the highest value with the highest rate of P_2O_5 applied (360 kg ha^{-1}); 62.9 and 52.7 mg dm^{-3} in the absence and presence of filter cake, respectively (Fig 2B). P rates combined with filter cake increased P-resin levels in both soils (Figs 1A; 1C and 2A; 2B). Several factors such as soil texture, clay type and content, soil organic matter, among others affect soil P availability. In this sense, some authors attribute the increased availability of soil P to P application associated with an organic product (Gichangi et al, 2009; Santos et al, 2009; Takeda et al, 2009; Krey et al, 2013).

In both experiments, increases in P-resin with the application of filter cake can also be attributed to P supplied by the filter cake, once it has 1.86 and 2.30% of total P_2O_5. Elsayed et al. (2008) also reported similar effect. They found an increase in P content in the soil jumping from 14 to 94 mg kg^{-1} when evaluating the application of filter cake (100 t ha^{-1} on a dry basis) in a Vertisol. Organic residues usually contain considerable amounts of soluble inorganic P, which contribute to immediate release of P after incorporation into the soil (Krey et al, 2013). In another study, Shankaraiah and Murthy (2005) reported increases in soil fertility related to chemical fertilization using 15 t ha^{-1} of filter cake (wet basis), an indicative of higher nutrient absorption by the plant. Results showed that the addition of organic materials reduced P fixation in the soil with increases in the labile P fraction. The incorporation of P in the microbial biomass stimulated by the presence of the organic compound could have also immobilized a large amount of P not converted to less labile fractions and later recycled and absorbed by plants (Gichangi et al, 2009). The application of compost could have enhanced the acid phosphatase activity in this study. These organic amendments are likely to have stimulated soil microorganisms to produce phosphatase enzymes (Takeda et al, 2009).

Nutritional status

In Kandiudalf, when triple superphosphate and Araxá phosphate were applied associated with filter cake P levels were higher in the leaf but when Gafsa phosphate was used, no effect was observed (Fig 3). Phosphorus availability to plants in soils is influenced by the addition of this element through phosphorus fertilization and regulated by the phenomenon of P sorption by the soil. This phenomenon occurs on the surface of Fe and Al oxides. Ions from the soil solution replace OH groups reducing their concentration in the solution (Afif et al, 1995; Andrade et al, 2003). Humic substances present in the filter cake organic matter can reduce P adsorption by the soil (Aguilera et al, 1992; Lee and Kim, 2007), competing for the same phosphate adsorption sites (Borggaard et al., 1990). The association of filter cake with different sources of phosphate may have raised the levels of humic substances acting on the sorption of phosphorus that promote the interaction of the phosphorus sources and the filter cake for P content. Thus, there was an increase in the P absorption efficiency by the phosphorus sources when associated with the organic compound compared to its isolated application because the increase in the soil organic compounds reduced P adsorption, increasing its availability in the soil and its uptake by the plant.

Yield of sugarcane in Kandiudalf

Interaction between sources and rates of P for P accumulation and stalk production was observed in Kandiudalf (Table 2). Regarding P accumulation in the stalk, the factors source within each P rate showed that in the absence of P and at the rate of 90 kg ha^{-1} of P_2O_5 differences among sources were not observed, but at 180 kg ha^{-1} the Araxá source presented lower values for P accumulation, and at the rate of 360 kg ha^{-1} the highest value was achieved with triple superphosphate. In reverse, rates within each source, triple superphosphate showed a linear increase in P accumulation with increasing doses of P. Gafsa phosphate presented a quadratic behavior and there was no adjustment for Araxá phosphate (Fig 4A, 4B). At intermediate rates (90 and 180 kg ha^{-1} of P_2O_5) Gafsa phosphate provided higher stalk production, but at rates within each source Gafsa phosphate showed a quadratic behavior with increasing rates of P (reaching the highest production of 214.0 t ha^{-1} at the rate of 209.5 kg ha^{-1} of

Table 1. Analysis of variance of P-resin levels in the soil at 0-20 and 20-40 cm depth and foliar P in Kandiudalf and Haplustox soils cultivated with sugarcane, variety RB 855453, with different sources and levels of phosphorus in the presence and absence of filter cake in the cities of Santa Adélia and Santa Albertina-SP, Brazil, 2013.

	Kandiudalf			Haplustox		
	P-resin		P	P-resin		P
	0-20cm	20-40cm	foliar	0-20cm	20-40cm	foliar
Sources of P (F)	1.83^{ns}	0.79^{ns}	1.40^{ns}	0.17^{ns}	2.24^{ns}	0.56^{ns}
Rates of P_2O_5 (D)	8.65**	29.79**	0.25^{ns}	18.43**	12.83**	0.83^{ns}
Filter cake (T)	0.97^{ns}	5.81*	7.92**	19.16**	0.99^{ns}	0.74^{ns}
Int F x D	1.85^{ns}	2.12^{ns}	0.35^{ns}	0.75^{ns}	1.32^{ns}	0.54^{ns}
Int F x T	0.45^{ns}	0.47^{ns}	3.90*	1.03^{ns}	0.02^{ns}	0.55^{ns}
Int D x T	1.71^{ns}	10.34**	1.03^{ns}	2.59^{ns}	1.46^{ns}	0.89^{ns}
Int F x D x T	0.28^{ns}	1.34^{ns}	0.93^{ns}	0.52^{ns}	0.69^{ns}	0.59^{ns}
CV (%)	21.6	27.9	8.3	37.2	56.1	35.0

^{ns} – not significant; * - significant at 5% probability; ** - significant at 1% probability by the F test.

Table 2. Analysis of variance for P accumulation and production of straw and stalks of sugarcane, variety RB 855453 fertilized with different sources and levels of phosphorus in the presence and absence of filter cake, 360 DAP in Kandiudalf and Haplustox soils in the cities of Santa Adélia and Santa Albertina-SP, Brazil, 2013.

	Kandiudalf				Haplustox			
	P accumulation		Production		P accumulation		Production	
	Straw	Stalk	Straw	Stalk	Straw	Stalk	Straw	Stalk
	kg ha^{-1}		t ha^{-1}		kg ha^{-1}		t ha^{-1}	
Source of P (F)	0.76^{ns}	8.91**	1.29^{ns}	5.75**	1.22^{ns}	1.39^{ns}	1.91^{ns}	0.13^{ns}
Rates of P_2O_5 (D)	0.19^{ns}	17.33**	1.86^{ns}	12.46**	4.90**	5.08**	3.53**	6.62**
Filter cake (T)	0.48^{ns}	39.84**	1.52^{ns}	4.39*	1.27^{ns}	31.05**	1.99^{ns}	19.59**
Int F x D	1.42^{ns}	5.30**	1.47^{ns}	2.60*	0.85^{ns}	0.49^{ns}	0.81^{ns}	0.24^{ns}
Int F x T	0.85^{ns}	0.24^{ns}	0.17^{ns}	0.77^{ns}	4.04*	1.06^{ns}	1.12^{ns}	3.19^{ns}
Int D x T	1.19^{ns}	0.26^{ns}	2.33^{ns}	1.53^{ns}	1.01^{ns}	0.31^{ns}	1.57^{ns}	0.57^{ns}
Int F x D x T	0.28^{ns}	0.42^{ns}	0.33^{ns}	0.24^{ns}	1.16^{ns}	1.58^{ns}	1.59^{ns}	3.76^{ns}
CV (%)	55.0	20.1	24.2	15.1	51.3	29.4	32.7	21.0

^{ns} – not significant; * - significant at 5% of probability; ** - significant at 1% probability by the F test.

P_2O_5). On the other hand, triple superphosphate increased stalk production linearly with increasing levels of P. For Araxá phosphate, the production of stalk did not fit into any equation with no significant effect for this variable (Fig 4C, 4D). The granulation of products of low solubility in water results in slower dissolution in the soil and reduction in its efficacy in the year of application compared to finely ground forms. Highly reactive sedimentary rock phosphates (FNR) such as North Carolina's and Gafsa, among others are currently imported. Gafsa phosphate fine-grained was marketed in Brazil in the seventies and tests with annual crops in several regions showed that its effectiveness is similar to those water-soluble phosphates in the first year of application when broadcasted and incorporated into soils with pH below 6.0. Currently these products are marketed as non-ground, which facilitates its application, but results in lower agronomic efficacy in the first year (Sousa and Lobato, 2003). However, Brazilian natural phosphates (Araxá, Patos de Minas and Catalão, among others), whose dissolution in the soil is very slow, especially under conditions of corrected acidity (pH in water around 6.0), have low agronomic efficacy in the first year compared to water-soluble phosphates (Sousa and Lobato, 2003). The simple linear correlation test was performed and it was found that stalk yield was correlated with the soil P content (resin) in both depths (r = 0.29*; r = 0.45**, 0-20 and 20-40 cm, respectively), with the accumulation of P in stalks (r = 0.75**), production of straw (r = 0.27*) and P accumulation in the straw (r = 0.37*).

Yield of sugarcane in Haplustox

In Haplustox the accumulation of P in the straw (leaves + pointers) varied with P rates and in the absence of filter cake a quadratic increase in the P content was observed as rates increased; however in the presence of the cake significant effects were not observed (Fig 5B). There was effect in the interaction of P sources and filter cake for the same variable (Table 2), thus in the absence of filter cake P accumulation was lower in the straw when Gafsa phosphate was applied; on the other hand, in the presence of filter cake there was no difference among P sources. Conversely, no difference in the variable tested was observed when the effects of the presence and absence of filter cake within each source were checked (Fig 5A). The filter cake factor alone affected P accumulation in the stalks (Table 2), and the content of the nutrient was higher in the presence of filter cake. Also there was effect of P rates on this variable, and in the absence and presence of filter cake a linear increase in P accumulation in stalks was observed with increasing doses of P; however the presence has always remained above the absence of the cake (Fig 5D). There was effect of P rates in the production of straw (Table 2) and a linear increase in straw production was observed in the presence of the filter cake with increased levels of P, on the other hand there was no adjustment as a function of P rates in the absence of filter cake (Fig 5C). P rates also affected stalk production, but the production increased linearly with increased levels of P, both in the absence and presence of filter cake, (Fig 5E). In this soil higher accumulation of P in the stalks with the application of this nutrient in the presence of the filter cake was observed due to increased P-resin availability in the soil (Fig 2), favoring a higher P accumulation in the plant (Fig 5). Therefore, there are higher rates of energy stored in the plant, once the nutrient is part of the synthesis of ATP and other phosphorylated compounds (Prado, 2008). In addition, there is a greater root growth, increased tillering and higher yield (Devi et al., 2012), because the combination of a source of

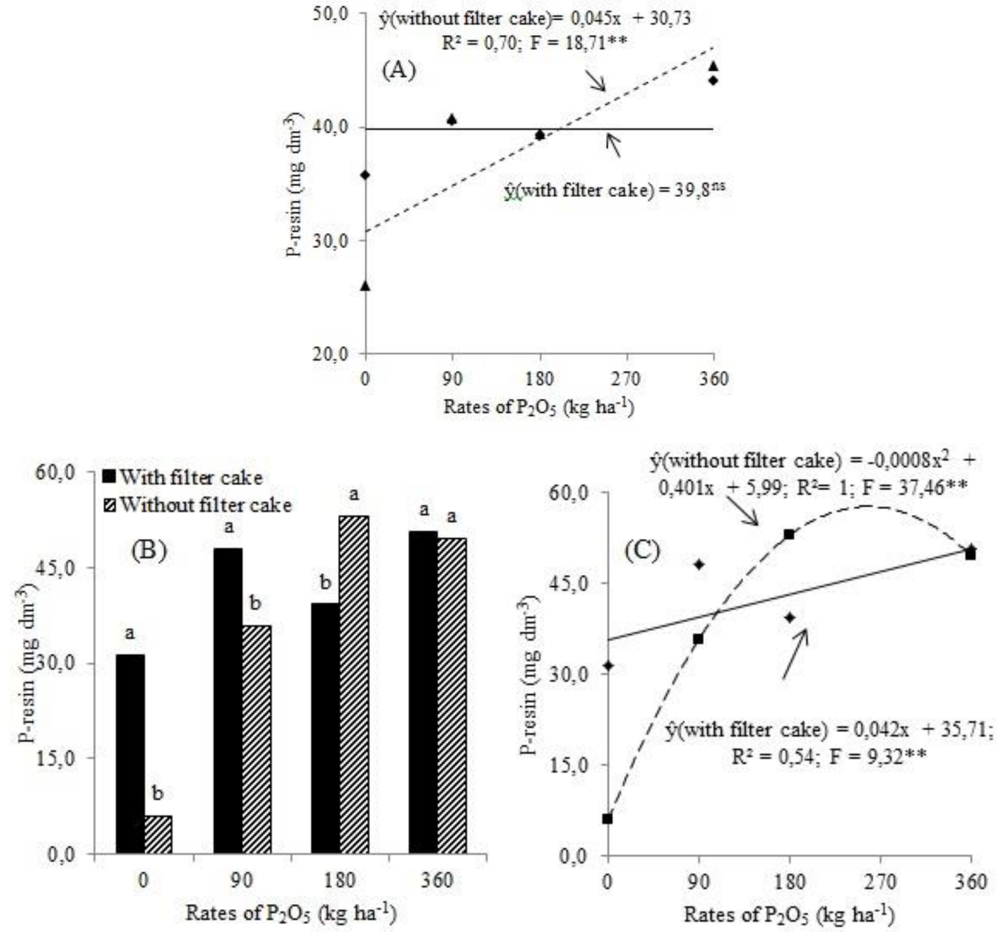

Fig 1. P-resin at 0-20 cm (A) and 20-40 cm depths (B and C) as a function of P_2O_5 rates and in the presence and absence of filter cake, 180 DAP in a Kandiudalf soil, Santa Adélia-SP, Brazil, 2013. Means followed by the same letter are not significant different by the Tukey test at 5% probability.

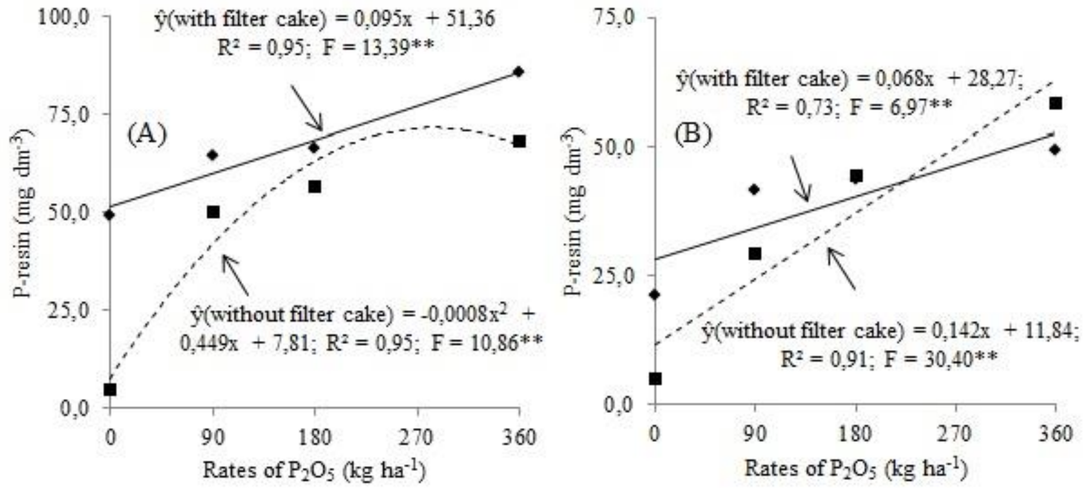

Fig 2. P-resin in 0-20 (A) and 20-40 cm (B) depths as a function of P_2O_5 rates in the presence and absence of filter cake, 180 DAP in a Haplustox soil, Santa Albertina-SP, Brazil, 2013.

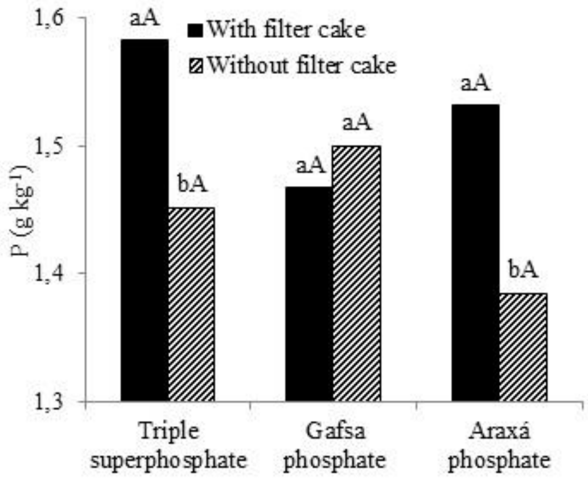

Fig 3. P content in sugarcane leaves as a function of P sources and filter cake, 240 DAP in a Kandiudalf soil, Santa Adélia-SP, Brazil, 2013. Means followed by the same lowercase letter (for filter cake within each P source) and same uppercase letter (for P sources within the filter cake) are not significantly different by the Tukey test at 5% probability.

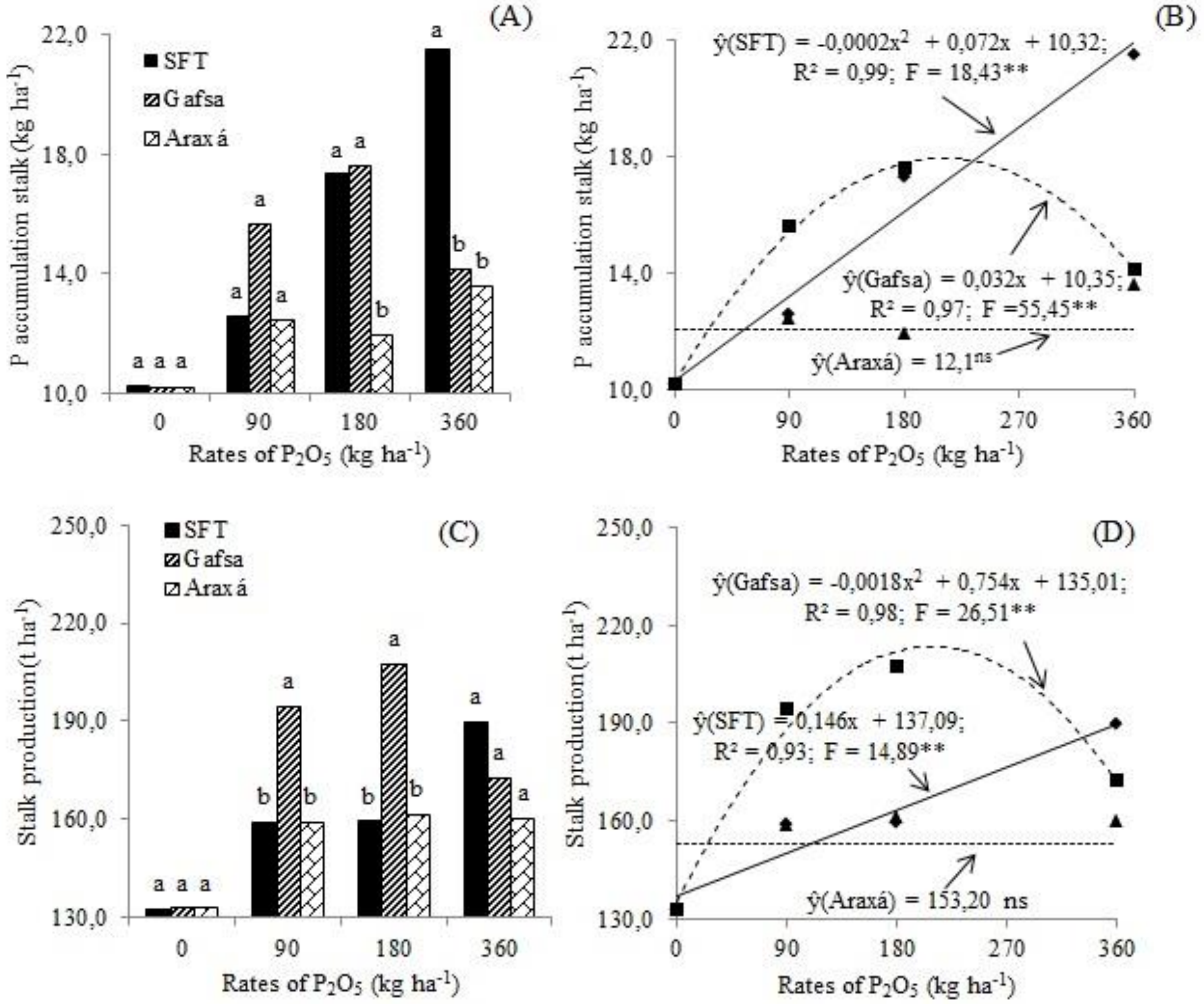

Fig 4. P accumulation in stalk and sugarcane stalk production as a function of P sources and rates of P_2O_5, 360 DAP in a Kandiudalf soil, Santa Adélia-SP, Brazil, 2013. Means followed by the same lowercase letter are not significantly different by the Tukey test at 5% probability.

phosphate fertilizer with an organic residue enhance P uptake by plants, reflecting in higher yield gains (Almeida Júnior et al., 2011). The literature widely discusses increases in stalk yield as a function of sugarcane P fertilization (Shankaraiah and Murthy, 2005; Bokhtiar et al, 2008; Kumar and Sinha, 2008; Korndörfer and Melo, 2009; Santos et al, 2009; Santos et al, 2010; Devi et al, 2012; Tsado et al, 2013; Santos et al., 2014). In an experiment in India, the application of 52.5 kg of P ha^{-1} in the planting furrow resulted in an increase of 20.8% in yield compared to the treatments without phosphorous (Kumar and Sinha, 2008). In another study Tsado et al. (2013) evaluating the isolated effect of soil P levels in Nigerian soils with low P content obtained higher production of stalks (102.5 t ha^{-1}) with the application of 150 kg ha^{-1} of P_2O_5 as rock phosphate, while the control treatment yielded only 62.5 t ha^{-1}, equal to an increase of 64%. Among the major beneficial effects of P to plants, increased tillering is the production component that most contributes to raise sugarcane yields (Bokhtiar et al., 2008; Devi et al., 2012). Bokhtiar et al. (2008) reported increases of up to 191% in the number of tillers with 25% reduction in fertilizers of mineral source with the addition of 15 t ha^{-1} of filter cake, resulting in a higher stalk yield. These authors stated that the association of inorganic and organic fertilizers is essential to maintain high soil fertility to achieve high sugarcane yields. Elsayed et al. (2008) found increases in yield from 73 to 85 t ha^{-1} with a single application of filter cake (100 t ha^{-1} on a dry basis). Filter cake increased sugarcane yield (Table 2) in Kandiudalf (F = 4.39*) and in Haplustox (F = 19.59**), highlighting the importance of this organic compound in the production of stalks. It is a source of nutrients (P, Ca) and adds organic matter besides promoting cation exchange capacity (CEC). The microbial activity in the soil improves substantially due the addition of filter cake (Shankaraiah and Murthy, 2005). According to Santos et al. (2010), the most effective use of filter cake occurs when it is applied at planting, when the water in the filter cake promotes sprouting and the phosphorus to be mineralized is close to the roots. Thus, it is evident that the presence of filter cake raised P-resin levels in the soil and in the plant, resulting in higher nutrient accumulation and higher stalk yield. The linear correlation test showed a positive significant effect in stalk yield with P-resin at 0-20 and 20-40 cm depths (r = 0.34**, r = 0.24*, respectively); P accumulation in stalk (r = 0.85**); production of straw (r = 0.37**); P accumulation in straw (r = 0.24*), evidencing the great importance of phosphate nutrition in sugarcane stalk production.

Materials and Methods

Location and climate

Experiments were installed near the Colombo Mill in the cities of Santa Adélia and Santa Albertina, State of São Paulo, Brazil, with the following coordinates: latitude 21°16'49" S and 20º02'44" S, longitude 48º49'38" O and 50º37'55" O, at 590 and 490 m altitudes, respectively. According to Köppen, the prevailing climate in the region is Aw, tropical rainy with dry winters and the coldest month has an average temperature 18ºC. The driest month has less than 60 mm rainfall and the rainy season starts in the fall (October). The climate data are in Fig 6.

Soil classification and chemical properties

Soils are classified as Kandiudalf (Santa Adélia) and Haplustox (Santa Albertina) (Soil Survey Staff, 2010) with low natural P content. Evaluations were conducted in the fully developed plant at the first cut. Soil sampling was performed collecting 20 subsamples to compose the composite sample. Based on the analyses interpretation, amendment substances were applied 30 days before planting (limestone TNP = 70%; CaO = 24%; MgO = 17%; NP = 85%) to raise base saturation to 60%, as recommended by Spironello et al. (1997). The chemical characteristics, according Raij et al (2001), at 0-20 and 20-40 cm depths, respectively, were: pH ($CaCl_2$) = 5.6 and 5.3; O.M. (g dm^{-3}) = 11 and 9; P-resin = 5 and 2; K, Ca, Mg, Al, H + Al, SB and CEC ($mmol_c dm^{-3}$) = 0.6 and 1.1; 11 and 14; 5 and 6; 0 and 0; 14 and 16; 16 and 21; 30 and 37, respectively; V (%) = 56 and 57, corresponding to an area of sugarcane recovery in Santa Adélia, and pH ($CaCl_2$) = 4.6 and 4.5; O.M. (g dm^{-3}) = 17 and 12; P-resin = 4 and 5; K, Ca, Mg, Al, H + Al, SB and CEC ($mmol_c dm^{-3}$) = 1.2 and 0.6; 12 and 11; 12 and 8; 3 and 5; 35 and 39; 26 and 20; 61 and 59, respectively; V (%) = 41 and 33, in Santa Albertina in an area with pasture intended for sugarcane expansion.

Experimental design

The experimental design was a randomized block arranged in a 3x4x2 factorial with three sources of P [triple superphosphate (41% soluble in 2% citric acid); reactive Gafsa rock phosphate (14% soluble in 2% citric acid) and Araxá rock phosphate (4% soluble in 2% citric acid)]; four rates of P_2O_5 [0 (control), 90, 180 and 360 kg ha^{-1} of P_2O_5 soluble in 2% citric acid]; two rates of an organic compound [0 (control) and 7.5 t ha^{-1} of filter cake (a residue obtained from the filtering process of sugarcane juice) on a dry basis]. The P_2O_5 rate for planting under very low P levels (0-6 mg dm^{-3}) followed the fertilization recommendations for the state of São Paulo (180 kg ha^{-1}) (Spironello et al., 1997).

Filter cake chemical characteristics

The chemical analysis of the filter cake was performed according to Abreu et al. (2009), with the following results: moisture (%) = 69.7 and 73.6; N, P_2O_5, K_2O, O.M., CaO, MgO (%) = 2.22 and 2.39; 1.86 and 2.30; 0.70 and 0.65; 74.8 and 75.2; 2.34 and 2.29; 0.66 and 0.61, in Santa Adélia and Santa Albertina, respectively.

Crop managenment in the experimental areas

Soil tillage was performed by plowing and harrowing followed by 30 cm deep furrowing spaced 1.5 m and base fertilization applied according to recommendations by Spironello et al. (1997). The rates of phosphorus and filter cake were applied according to treatments, i.e. 100 kg ha^{-1} (Santa Adélia) and 80 kg ha^{-1} of K_2O (Santa Albertina). The treatments without filter cake were properly balanced for the values of N and K_2O according to the amount the filter cake provided, as were the nutrients that could potentially promote greater indirect effects, and Ca and Mg levels were raised with liming. Cover fertilization was carried out 30 days after planting with ammonium nitrate (50 kg ha^{-1}, 30% N), also recommended by Spironello et al. (1997). Plots consisted of five rows, 8 m long and the three central rows used for sampling, disregarding one meter at each end.

The fertilizers and the organic compound (filter cake) were mixed in a concrete mixer and placed into the furrows. Planting was performed disposing stem cuttings averaging 15 buds per meter through the distribution of stems in a tip to end crossing system followed by cutting the stalks in three

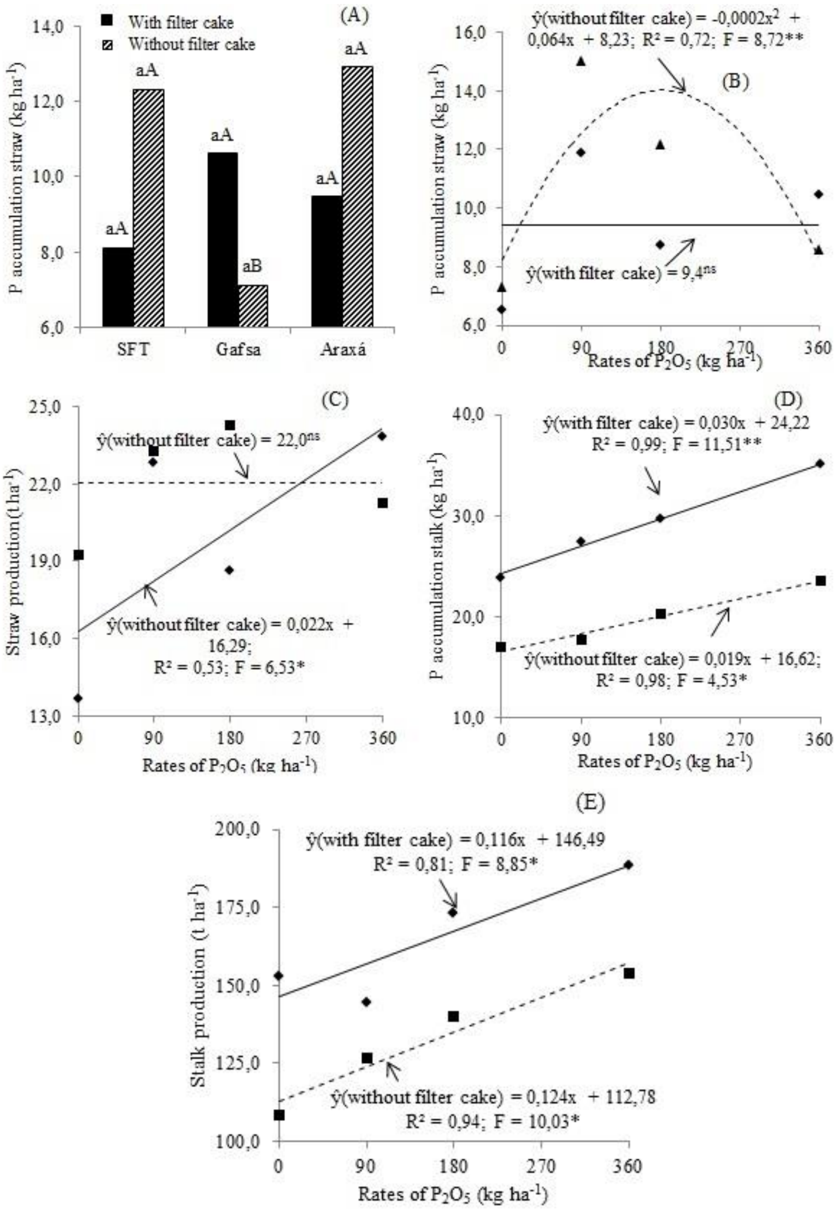

Fig 5. P accumulation in straw and stalk, straw and stalk production of sugarcane as a function of rates of P_2O_5 and filter cake, 360 DAP in a Haplustox soil, Santa Albertina-SP, Brazil, 2013. Means followed by the same lowercase letter (for filter cake within each source of P) and same uppercase letter (for sources of P within the filter cake) are not significantly different by the Tukey test at 5% probability.

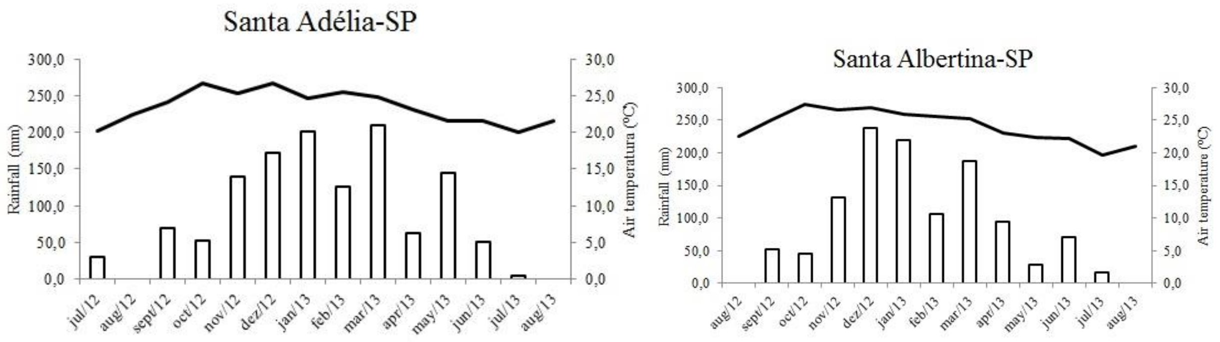

Fig 6. Accumulated rainfall and monthly average temperature during the experimental period in Santa Adélia and Santa Albertina-SP, Brazil.

gems pieces and covered with a soil layer on July 12, 2012 in Santa Adélia and on August 16, 2012 in Santa Albertina, characterized as winter planting with variety RB 855453. Herbicides (Tebutiron 500g L^{-1}, 1.8L h^{-1}; Ametrine, 500g L^{-1}, 5L ha^{-1}; Msma 720g L^{-1}, 1.6L h^{-1} and mineral oil 1.0L h^{-1}) were applied in all treatments. Borer (*Diatraea saccharalis*) was controlled releasing *Cotesia flavipes* with 0.06 kg ha^{-1} of Altacor and 1.2 kg ha^{-1} of boric acid by aerial spraying in March and April 2013

Soil and leaf sampling

Soil sampling was performed six months after the onset of treatments (180 days after planting - DAP), in the planting furrow at 0-20 and 20-40 cm depths, from 9 random sites in the three central rows. To determine P available, analyses were performed by the resin method (P-resin) according to methodology described by Raij et al (2001). To evaluate P nutritional status of plants, leaf+1 were sampled at the crop full development stage eight months after the onset of treatments (240 DAP) as suggested by Raij and Cantarella (1997). Fifteen leaves per plot were collected, excluding the center vein, washed, dried in oven at 65 °C and crushed. P content was determined following methodology proposed by Bataglia et al. (1983).

Stalk yield and phosphorus accumulation in plants

After twelve months, (360 DAP) sugarcane was harvested to evaluate the stalk and straw production. Two linear meters were collected in the three central rows of each plot, straw, pointers and stems were weighed separately with the aid of an electronic balance. The amount of P extracted by plants was estimated based on the nutrient concentration in the aerial portion (leaves and stems). P tissue determination followed the methodology described by Bataglia et al. (1983).

Statistical analysis

Data were subjected to the analysis of variance by the F test. The mean comparison test was applied for significant effects and the Tukey test ($p \leq 0.05$) for sources of qualitative variation, and the polynomial regression analysis for sources of quantitative variation using the software AgroEstat (Barbosa and Maldonado Jr., 2012). The simple Pearson correlation test was applied for the variables tested.

Conclusions

The application of phosphorus into the soil promoted increases in P-resins levels of 53 and 807% in the surface layer (0-20 cm) and of 839 and 432% in the sub surface layer (20-40 cm) regardless of the source of phosphorous in both Kandiudalf and Haplustox soils without filter cake, respectively. The increased availability of phosphorus in the soil with the application of phosphate promoted increments on this nutrient absorption by plants, reflecting in stalk yield gains, regardless of the soil evaluated. In Kandiudalf the Gafsa phosphate source promoted greater increases in stalk yield compared to the other sources, reaching 214 t ha^{-1} with 209 kg ha^{-1} of P_2O_5, while triple superphosphate yielded 190 t ha^{-1} with the highest rate of P-fertilizer (360 kg ha^{-1} P_2O_5), regardless of the presence or absence of filter cake. However, stalk production was not affected by the Araxá phosphate source, which produced an average stalk yield of 153 t ha^{-1}, regardless of the presence or absence of filter cake. In the Haplustox, stalk yield increased with the application of P-fertilizer (360 kg ha^{-1} P_2O_5) associated with filter cake, yielding 188.2 t ha^{-1}; 19.6% higher than without filter cake.

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