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Sources of phosphorus with sugar cane filter cake on the nutritional status and productivity of sugar cane (*Saccharum officinarum* L) cultivated in red-yellow latosoil

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Abstract

Limited sources and phosphorus dynamics in tropical soils justify the search for alternative sources of the element, especially in sugar cane culture. The sugar cane filter cake, a by-product of sugar cane juice filtration is one option, which contains appreciable concentrations of various nutrients including phosphorus, an adequate complement on the use of mineral fertilizers. The effects of phosphorus sources application in different doses combined with sugar cane filter cake were evaluated in sugar cane culture by phosphorus concentrations in soil, plant nutritional status, and stalk productivity. The sugar cane (variety RB86 7515) was cultivated in median texture Dystrophic Red-Yellow Latosoil in an experiment laid out in a randomized complete block design with three replica disposed in a 3x4x2 factorial pattern, comprising three phosphorus sources [Triple Superphosphate (TS), Natural Reactive Bayovar Phosphate (BP) and Natural Araxa Phosphate (AP)], four doses of phosphorus as P_2O_5 [(0, 90, 180 and 360 kg ha^{-1})], combined or not with sugar cane filter cake (7.5 t ha^{-1}, dry weight). Applications of phosphorus and sugar cane filter cake increased nutrient concentrations in soil, leaves and plant aerial parts by 47.2% (15.4 mg dm^{-3}), 7.1% (1.4 g kg^{-1}) and 36.3% (10.6 kg ha^{-1}), respectively. The sugar cane filter cake alone increased stalk production by 3.4% (122.6 t ha^{-1}). TS with sugar cane filter cake combined or its higher doses stood out in all determined properties with the exception in stalk production, which was higher (126.7 t ha^{-1}) by application of BP (360 kg ha^{-1}).

Keywords: Araxa phosphate; Bayovar phosphate; Triple superphosphate; phosphorus accumulation; stalk production.
Abbreviations: AP_araxa phosphate; BP_bayovar phosphate; CHB_climatic water balance; O.M._ organic matter; SB_sum of bases; T_cation exchange capacity at pH 7; TS_triple superphosphate; V%_base saturation.

Introduction

In tropical soils, labile phosphorus (P) readily available to plants is low due to high adsorption, favored by soil is intense acidity. Agricultural expansion is limited by low phosphorus availability in tropical areas, especially concerning sugar cane culture that occupy vast territorial areas. In the absence of phosphorus, sugar cane plants are usually short and show low diameter stalks with smaller inter-nod distances (Haag et al., 1987; Rossetto et al., 2009). Adequate P concentrations increase sugar cane productivity and also improve quality of the juice and sugar (Korndörfer, 1994; Santos et al., 2010; Caione et al., 2013). Using the right phosphorus source (mineral, organic or organo-mineral) improves management of tropical soil fertilization. Highly soluble sources are more efficient in the short term but not for longer periods (Horowitz and Meurer, 2004). The alternative use of reactive phosphates has shown satisfactory results in P availability, especially when associated to organic residues (Houssain et al., 2001). Using natural phosphates implies the action of microorganisms that are responsible for a higher P liberation, thus increasing long term efficiency (Vassilev et al., 2006). Concerning the need of increasing liberation of P to the soil, an important organic product should be considered, the sugar cane filter cake, produced in great quantities, rich in organic matter and in macronutrients, especially P. The soil is capacity of absorbing P requires high fertilizer doses as shown in several reports employing nutrient sources with different solubilities (Santos et al., 2009; Caione et al., 2011; Simões Neto et al., 2012). The sugar cane filter cake has an important role in increasing soil P availability in sugar cane culture by liberating organic acids that compete for the same P adsorbing sites (Andrade et al., 2003; Souza et al., 2006), and increasing stalk and sugar productivity (Fravet et al., 2010; Santos et al., 2010). The effective correction of soil acidity by the use of sugar cane filter cake must be considered in addition to the improved soil fertility by increased levels of macro and micronutrientes. In contrast, increased acidification was shown by the use of mineral fertilizers (Almeida Júnior et al., 2011). According to Santos et al. (2012) the organic P found in sugar cane filter cake is gradually released by mineralization and action of soil microorganisms. Organic-mineral fertilizers reduce the dependence on mineral sources of P and also promotes productivity and technological quality gains in sugar cane culture. However, the incipiency of the studies on this matter must be regarded when one considers that it is necessary to know the potential of use of an organic product in this culture and if phosphate fertilizers are a necessary complement to maintain the initial nutritional plant cycle. It is important to verify the contribution of the sugar cane filter cake - an alternative and P-rich source, to the levels of nutrients in soil, plants and sugar cane culture productivity when combined with different sources and doses of mineral phosphates. This study aims to evaluate the sources of P with sugar cane filter cake on soil P concentrations, nutrition status of plants and productivity in sugar cane (*Saccharum officinarum* L) cultivated in Red-Yellow Latosoil.

Results and Discussion

Effects of inorganic fertilizers and sugar cane filter cake on phosphorus concentrations in soil

Phosphorus soil levels (0.20-0.40 m layer) were altered by the interaction by sugar cane filter cake with doses and sources of phosphorus (Table 2). Linearly adjusted P soil levels increased with phosphorus doses (average of P sources) and sugar cane filter cake, emphasizing the positive effects of the combinations (Figure 2a). The P dose of 360 kg ha^{-1} (P_2O_5) associated to sugar cane filter cake produced a P content of 38.8 mg dm^{-3} ($P \leq 0.05$), interpreted as an average level (16-40 mg dm^{-3}) according to Raij et al. (1997). The increased P levels in soil treated with sugar cane filter cake may be due to the liberation of high concentrations of the element from the organic product (Santos et al., 2010) as well as other compounds as humic substances, which by saturating adsorption sites optimize P availability to soil. (Lee and Kim, 2007). Higher P doses (average in presence and absence of sugar cane filter cake) linearly increased soil content of P, highlighting TS in relation to BP and AP (Figure 2b). The highest dose of TS and of BP produced P levels of 37.1 and 18.8 mg dm^{-3}, respectively ($P \leq 0.05$), an average level stated previously. The importance of TS as a P fertilizer in sugar cane culture has been widely reported in the literature (Korndörfer and Melo, 2009). The use of AP produced lower soil P levels probably due to high soil pH (6.1), which is known to reduce solubility of calcium phosphate present in this fertilizer. It is suggested that soil P levels are dependent on soil chemical characteristics, phosphorus sources and solubility.

Effects of inorganic fertilizers and sugar cane filter cake on phosphorus concentrations in sugar cane leaves

Concentrations of P in sugar cane leaves were affected by the interaction of sources and different doses of the mineral with sugar cane filter cake (Table 2). The sugar cane filter cake associated to TS and BP increased P concentrations on the leaves of sugar cane plants when compared to AP (average of P doses) (Figure 3a). The highest value (1.7 g kg^{-1}) was observed with TS in the presence of sugar cane filter cake, presenting an adequate concentration (1.5-3.0 g kg^{-1}) for sugar cane culture according to Raij and Cantarella (1997).

The positive effect caused by the association of TS and sugar cane filter cake on P foliar level was not observed by Bokhtiar et al. (2008) when compared with the exclusive use of the phosphate fertilizer. In contrast, applying sugar cane filter cake associated to sugar cane bagasse in cultivation of the variety RB86 7515 in Dystrophic Red-Yellow Latosoil showed increased foliar P levels, higher than the ones obtained by the association of organic products and mineral fertilizers (Lima, 2011). In this study, phosphorus doses (average of P sources) increased, with linear adjustment, the content of foliar P in the presence of sugar cane filter cake (Figure 3b). The highest P dose with sugar cane filter cake promoted a foliar content of 1.7 g kg^{-1}, reflecting the increased soil P concentration shown in this treatment (Figure 2a). The results confirmed the potential of sugar cane filter cake as a complement to mineral fertilization. In its absence, the highest P fertilizer dose produced a foliar content of 1.5g kg^{-1}, which is lower then the one found by Santos et al. (2009). The authors reported a P foliar content of 4.0 g kg^{-1}, by using 120 kg ha^{-1} (P_2O_5) in cultivation of variety RB75125 in Dystrophic Yellow Latosoil.

Effects of inorganic fertilizers mixed with sugar cane filter cake on phosphorus accumulation in sugar cane plants

The accumulation of P in aerial parts of plants was influenced by the interaction of sugar cane filter cake with doses and sources of phosphorus (Table 2). The combination of sugar cane filter cake and TS (average of P doses) produced the highest accumulation in the aerial parts, with 2.99 kg ha^{-1} (Figure 4a), as indicated by the foliar P content (Figure 3a). Exclusive use of TS produced an accumulation of 1.9 kg ha^{-1}, which is lower than the one obtained by Franco et al. (2008), with 4 kg ha^{-1} in cultivation of sugar cane variety SP81 3250 using the same source of nutrient in Dystrophic Red Latosoil. The same authors showed that accumulation of P decreased to 2 kg ha^{-1} in Dystrophic Red-Yellow Latosoil. The phosphorus doses (average of P sources) linearly increased the accumulation of P in the aerial parts of sugar cane plants in the presence of sugar cane filter cake (Figures 4b and 5a). The highest accumulation of 12.3 kg ha^{-1} ($P \leq 0.01$), was obtained by associating 360 kg ha $^{-1}$ (P_2O_5) with sugar cane filter cake and probably reflects the increased P in the soil (Figure 2a) and foliar nutrients content (figure 3b). In the absence of sugar cane filter cake, P highest dose promoted an accumulation of 8.8 kg ha^{-1}, a lower value than that obtained by Franco et al. (2008), which was 12 kg ha^{-1} (variety SP81 3250) cultivated in Dystrophic Red-Yellow Latosoil using the quantity of 120 kg ha^{-1} of P_2O_5. The same authors obtained an accumulation of 26 kg ha^{-1} in aerial parts of the same variety cultivated in Dystrophic Red Latosoil. The phosphorus accumulation in aerial parts of sugar cane plants was higher with TS when compared to other sources (Figures 4c and 5b). The application of 360 kg ha^{-1} (P_2O_5) of the TS (average in presence and absence of sugar cane filter cake) produced an accumulation of 21.8 kg ha^{-1}, being this value related to the increase in soil P (Figure 2b). In this experiment, P accumulation in aerial parts is lower than the one obtained by Caione et al. (2013), who observed an accumulation of 26.3 kg ha^{-1} in the aerial parts of sugar cane cultivated in Dystrophic Red-Yellow Latosoil by applying 100 kg ha^{-1} (P_2O_5) as Triple Superphosphate resulting in a production of 142.3 t ha^{-1} in stalks. However, P accumulation was higher than the one reported by Korndörfer and Melo (2009), who obtained a P accumulation of 15 and 14 kg ha^{-1} in a production of 132 and 153 t ha^{-1}, respectively, by cultivating variety SP71 1406 in Dystrophic Red-Yellow Latosoil. The differences in P accumulation may be due to distinct cultivation conditions, sugar cane cultivars and soils.

Effects of inorganic fertilizers and sugar cane filter cake on phosphorus concentrations in sugar cane stalks

The stalk production was also influenced by the interaction of sugar cane filter cake with doses and sources of phosphorus (Table 2). There was linearly adjusted in stalk production (t

Table 1. Chemical and granulometric analysis of soil in the experimental area, Fazenda Santo Antônio, Itajobi , SP, Brazil.

Deepness (m)	pH $CaCl_2$	O. M. g dm^{-3}	P mg dm^{-3}	K	Ca	Mg	H+Al	SB	T	V %
				-----------------mmolc dm^{-3}-----------------						
0.00-0.20	6.1	10.0	5.0	1.1	29.0	13.0	10.0	42.3	52.3	81
0.20-0.40	5.6	10.0	4.0	0.9	25.0	9.0	12.0	34.8	46.8	74
Deepness (m)				Granulometry						
0.00-0.20	Clay		Silt		Fine Sand			Coarse Sand		
	-- g kg^{-1}--									
	209		40		464			287		

O.M : organic matter; V%: base saturation

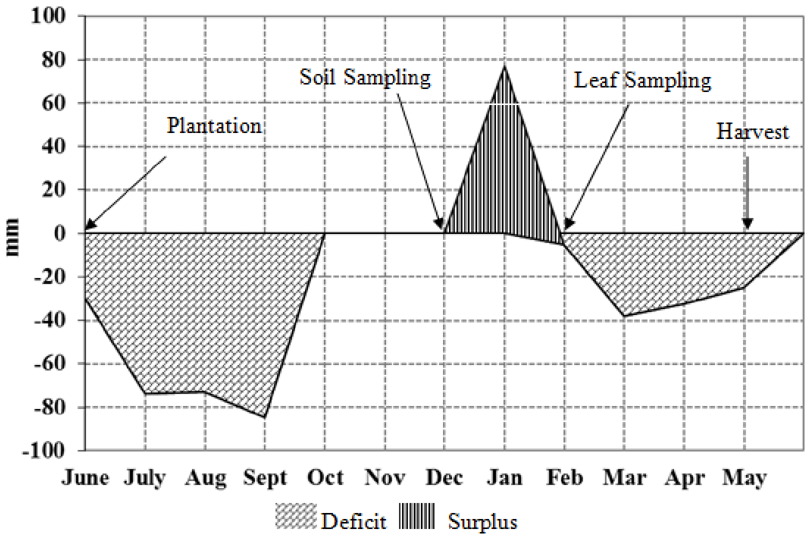

Fig 1. Water balance registered in the city of Catanduva, State of São Paulo during the period of June 2011 to May 2012.

ha^{-1}) in the presence or absence of sugar cane filter cake and doses of P (average of P sources) are shown (Figure 6a). The dose of 360 kg ha^{-1} (P_2O_5) produced 118 t ha^{-1} of stalk in the absence of sugar cane filter cake, this result contrasts with the effects of sugar cane filter cake in the accumulation of P in the aerial parts of plants (Figures 4b and 5a). Interestingly, the production of stalks was higher when sugar cane filter cake was used alone, with the production of 123 t ha^{-1}, probably due to the P content in the used sugar cane filter cake (equivalent to 52 kg ha^{-1} in P_2O_5) and also the organic P content in soil which comprises 20 to 80% of the total P (Steffens et al., 2010). It should be noted that the highest stalk production obtained with the use of sugar cane filter cake only was observed in the cane-plant system (harvest at 12 months), implying that ratoon culture evaluations remain necessary. Santos et al. (2010) observed that the association of Triple Superphosphate (200 kg ha^{-1} P_2O_5) and sugar cane filter cake (4 t ha^{-1}, dry weight), produced higher amounts of stalks (155 t ha^{-1}) in sugar cane cultivated in Red Latosoil. In this study, doses of P arising from different mineral sources mixed or not with sugar cane filter cake showed a variable production (linearly adjusted) of stalks, BP and TS are more efficient when compared to AP (Figure 6b). Higher doses of BP and TS produced 127 and 126 t ha^{-1}, respectively ($P \leq 0.01$). No effect was shown with use AP, the highest stalk production obtained by the use of BP and TS may be correlated to similar increases in soil P (Figure 2b) and accumulation of the element in aerial parts (Figures 4c and 5b) with 15.7 and 21.8 kg ha^{-1}, respectively. Calheiros et al. (2012) observed an accumulation of 25.6 kg ha^{-1} of P in aerial parts associated to a stalk production of 89.6 t ha^{-1}.

Materials and Methods

Experimental site, soil and plant characteristics

The experiment was conducted under field conditions in the period of June 2011 to May 2012 at the Santo Antônio Farm, Catanduva Mill (Group of Virgolino de Oliveira), in the city of Itajobi, State of São Paulo, Brazil. The local coordinates are 21^{o} 11´ S and 49^{o} 1´ W, altitude 469 m. The area is characterized by rainy summers and dry winters, with an average annual temperature of 23.2 ^{o}C and annual average pluvial precipitation of 1.328 mm (CEPAGRI, 2011). The sugar cane variety used (RB86 7515) is fast growing with erect, tall plants and good sucrose levels, as well as agricultural productivity (PMGCA, 2008). Meteorological data from a nearby station to the experimental site, at the city of Catanduva, SP, Brazil, (Figure 1), indicated that during planting and tillering periods, culture was submitted to a drought, which was repeated after a short period of water surplus (Figure 1). The soil in the experimental area was classified as median texture, Dystrophic Red-Yellow Latosoil (EMBRAPA, 2006). Chemical and granulometric soil analysis were made according to Raij et al. (2001) and Camargo et al. (2009), respectively (Table1).

Treatment details, inorganic fertilizers and sugar cane filter cake application

The P doses used in treatments were chosen in reference to a dose of 180 kg ha^{-1} (P_2O_5) recommended for the State of São Paulo (Spironello et al., 1997).

Table 2. Average values of P concentrations in soil and sugar cane leaves, accumulation of P in plant aerial parts (leaves and stalks) and stalk production as a function of fertilization with different sources and doses of P in the absence and presence of sugar cane filter cake.

Treatments	P conc. in Soil	P conc. in Leaves	Ac. in Aerial Parts		Stalk Production
	mg dm^{-3}	g kg^{-1}	kg ha^{-1}		t ha^{-1}
Sugar cane filter cake (F)					
Presence	16.7	1.56a	2.68a	10.27a	120.8a
Absence	14.6	1.46b	1.30b	9.03b	112.8b
F test	2.34^{NS}	37.61**	269.04**	15.08**	13.48**
Sources (S)					
Triple Superphosphate (TS)	19.9^{a}	1.61a	2.42a	11.90a	117.5
Bayovar Phosphate (BP)	15.2b	1.49b	1.81b	9.03b	115.9
Araxa Phosphate (AP)	12.1b	1.42c	1.73b	8.02c	117.0
F test	10.52**	47.13**	26.78**	53.00**	0.18^{NS}
Doses (D)					
0 kg ha^{-1} as P_2O_5	6.7	1.27	0.36	5.67	105.1
90 kg ha^{-1} as P_2O_5	13.8	1.42	1.50	8.51	110.7
180 kg ha^{-1} as P_2O_5	14.8	1.51	1.97	9.65	117.1
360 kg ha^{-1} as P_2O_5	18.5	1.58	2.50	10.80	122.6
F test	3.81*	30.54**	47.55**	17.29**	10.13**
	--------------------------		F Test		-------------------------------
(F) x (S)	1.07^{NS}	4.17*	6.08**	3.07^{NS}	1.39^{NS}
(F) x (D)	10.61**	5.64**	16.97**	12.21**	11.88**
(S) x (D)	4.11**	2.47^{NS}	12.69**	6.47**	12.19**
(F) x (S) x (D)	5.60**	1.12^{NS}	1.18^{NS}	4.19**	8.66**
C.V. (%)	13.7	4.0	16.4	12.4	6.8

**, * and ^{NS} – Significant with a 1 and 5% probability and not significant, respectively, according to the F test.

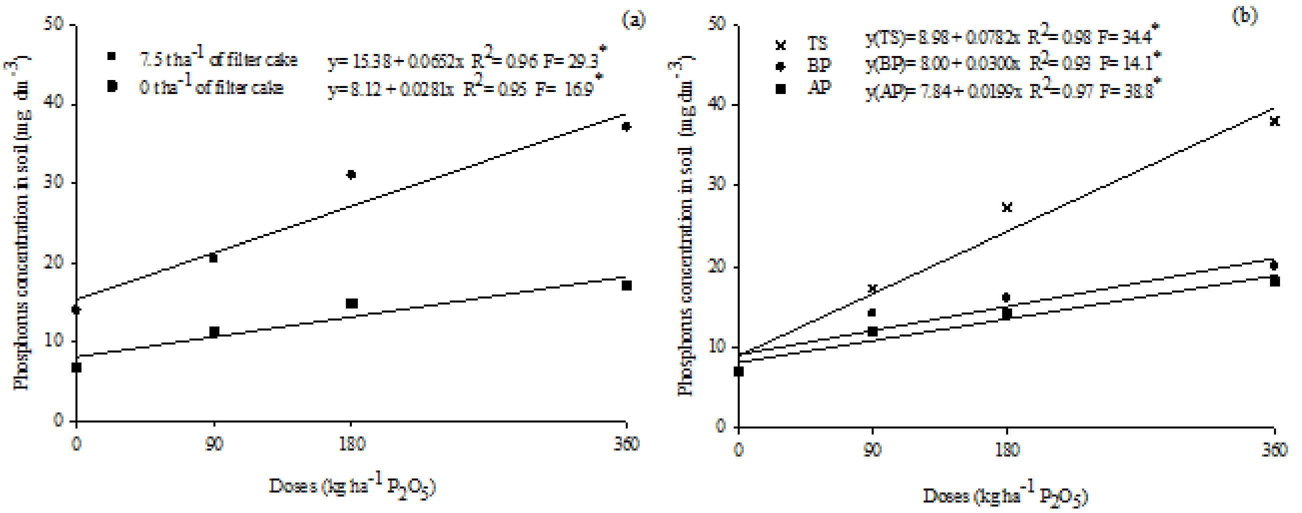

Fig 2. Phosphorus concentrations in soil (0.2-0.4 m layer) determined six months after planting of sugar cane, as a function of P fertilizer doses in absence and presence of sugar cane filter cake (average of P sources) (a) and of doses of P as Triple Superphosphate (TS), Bayovar Phosphate (BP), and Araxa Phosphate (AP) (average in presence and absence of sugar cane filter cake) (b). * - Significant by the F test, 5% probability.

The experiment was laid out in a randomized complete block design with three replica in a 3x4x2 factorial pattern, including three P sources: Triple Superphosphate-TS (41% of P_2O_5 soluble in 2% citric acid), Natural Reactive Bayovar Phosphate-BP (14% P_2O_5 soluble in 2% citric acid), and Natural Araxa Phosphate-AP (4% P_2O_5 soluble in 2% citric acid); four P doses as P_2O_5, soluble in citric acid (0, 90, 180, and 360 kg ha^{-1}), mixed or not with sugar cane filter cake (7.5 t ha^{-1}, dry weight). The basic culture fertilization, as recommended by (Spironello et al., 1997) was composed of 151.1 kg ha^{-1} of ammonium sulfate, 204.4 kg ha^{-1} of potassium chloride and 24.8 kg ha^{-1} of zinc sulfate. Coverage fertilization used 30 kg ha^{-1} of nitrogen (as urea) and 160 kg ha^{-1} K_2O (as potassium chloride). Each unit in the experimental area (112.5 m^2) was divided into 5 lines, 15 m long and 1.5 m (interrow), only the three central lines (67.5 m^2) were used for evaluations. The sugar cane filter cake was chemically characterized according to Alcarde (2009) with the following results: N (total): 3.4 g kg^{-1}; P_2O_5 (total): 8.2 g kg^{-1}; P_2O_5 (soluble in 2% citric acid): 7.8 g kg^{-1}; K_2O: 2.2 g kg^{-1}; CaO: 12.2 g kg^{-1}. Walkley and Black (1934) method was used to determine organic matter levels: 304.7 g kg^{-1}.

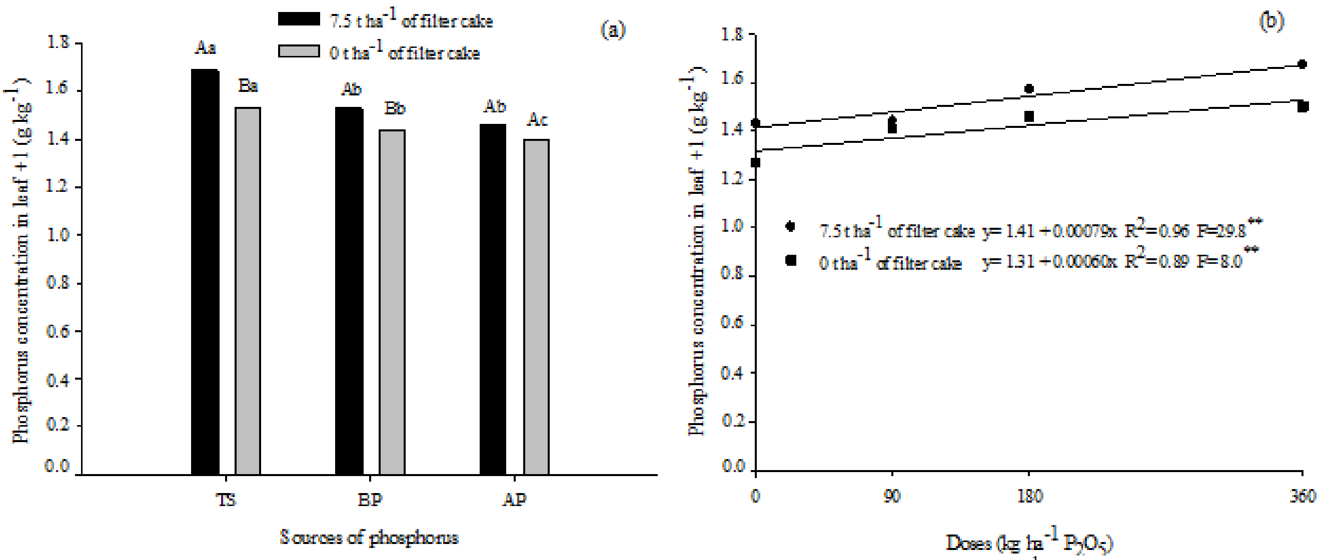

Fig 3. Phosphorus concentration in sugar cane leaves as a function of P sources in the absence (0 t ha^{-1}) and presence of sugar cane filter cake (7.5 t ha^{-1}) (average of P doses) (a) and P doses in the absence and presence of sugar cane filter cake (average of P sources) (b). Capital letters refer to the presence of sugar cane filter cake and lowercase ones refer to P sources, with significance by the F test (5% probability) and MSD (5%) for sugar cane filter cake (0.05) and P sources (0.06). ** - Significant by the F test, 1% probability.

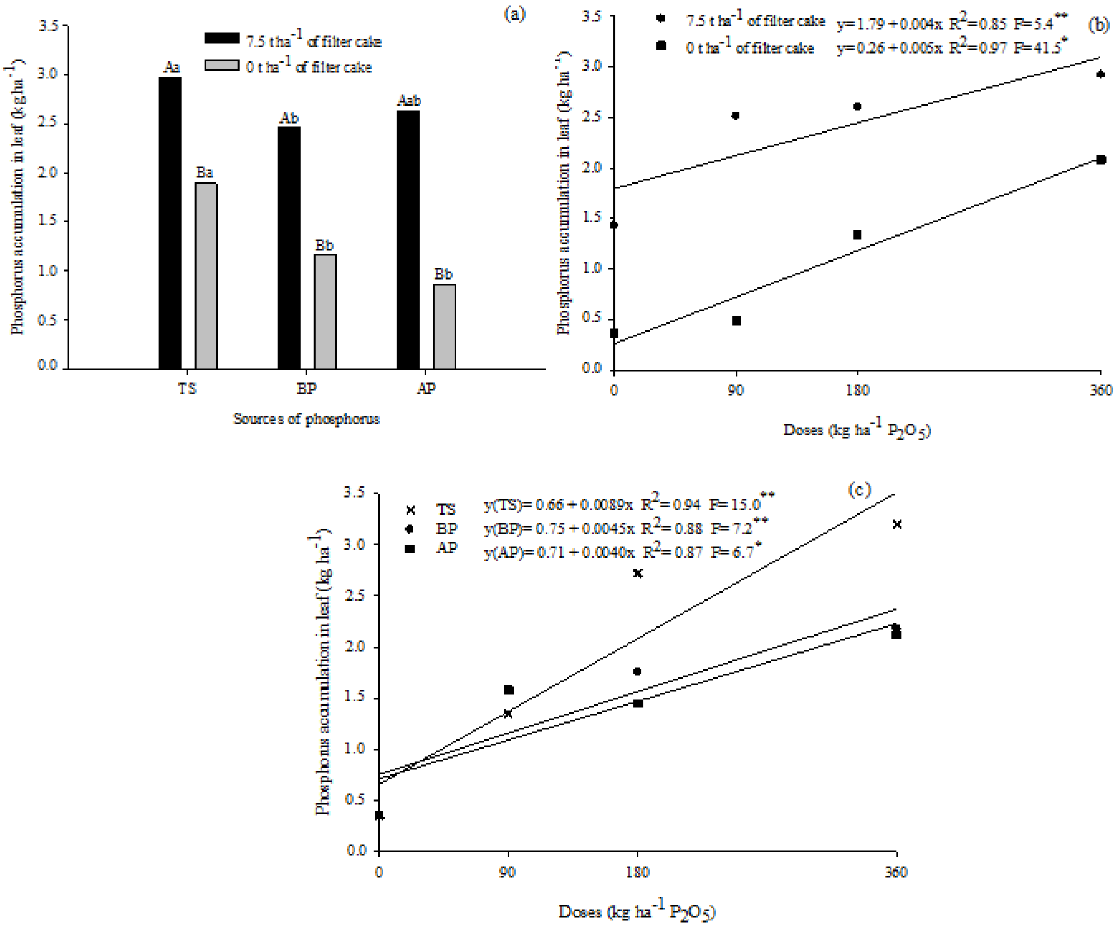

Fig 4. Phosphorus accumulation in sugar cane leaves, as a function of P sources in the absence and presence of sugar cane filter cake (average of P doses) (a) as a function of P doses in the absence (0 t ha^{-1}) and presence (7.5 t ha^{-1}) of sugar cane filter cake (average of P sources) (b), and as a function of P doses as Triple Superphosphate (TS), Bayovar Phosphate (BP) and Araxa Phosphate (AP) (average in the presence and absence of sugar cane filter cake) (c). Capital letters refer to sugar cane filter cake and lowercase ones refer to P sources by the Tukey test (5% probability) and MSD (5%) for sugar cane filter cake (0.29) and for P sources (0.35). ** and * - Significant by the F test, 1% and 5% probability, respectively.

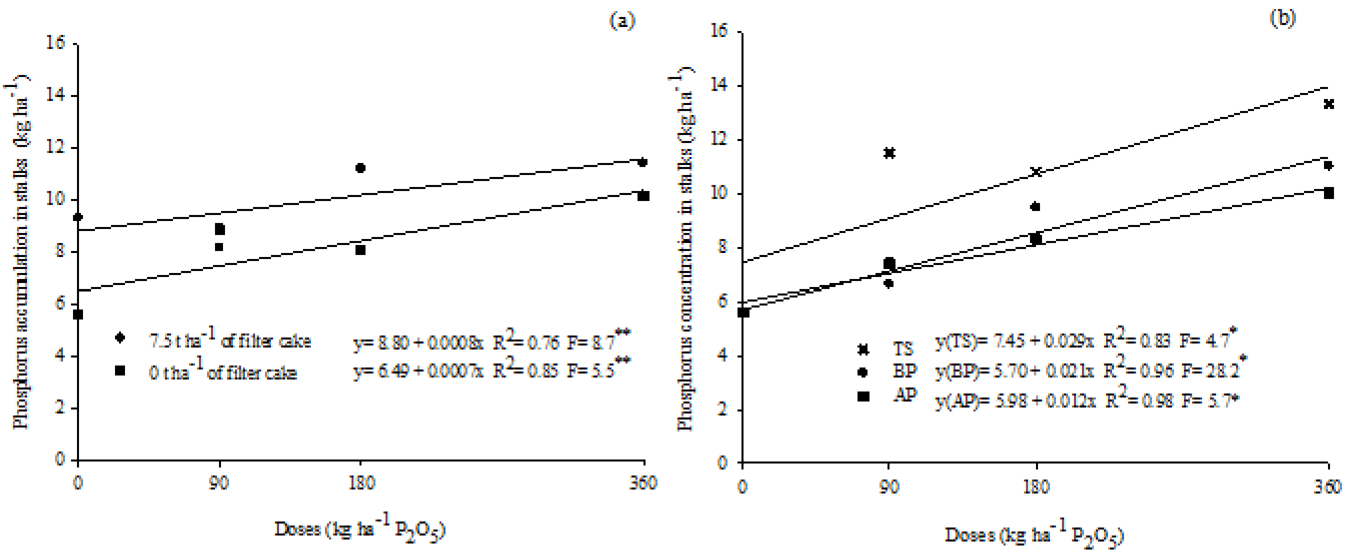

Fig 5. Phosphorus accumulation in sugar cane stalks as a function of P doses in the absence and presence of sugar cane filter cake (average of P sources) (a) and as a function of doses P as Triple Superphosphate (TS), Bayovar Phosphate (BP) and as Araxa Phosphate (AP) (average in the presence and absence of sugar cane filter cake) (b). ** and * - Significant by the F test with a 1 and 5% probability, respectively.

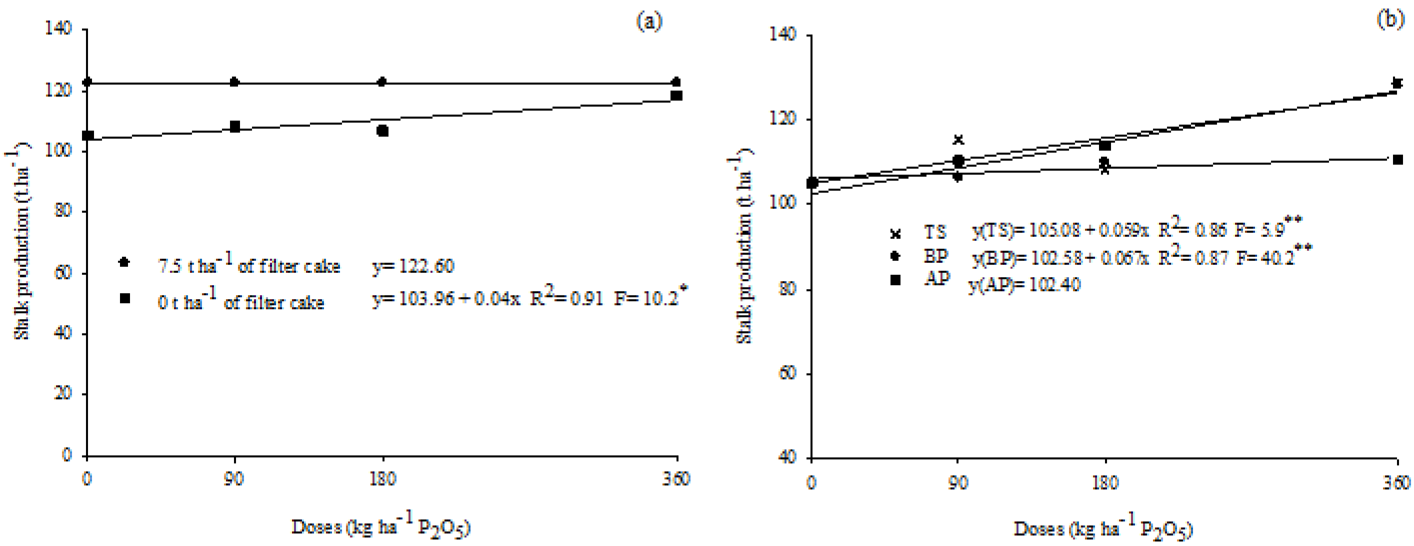

Fig 6. Stalk production by sugar cane as a function of P doses in the absence and presence of sugar cane filter cake (average of P sources) (a) and as a function of sources P as Triple Superphosphate (TS), Bayovar Phosphate (BP) and Araxa Phosphate (AP) (average in the presence and absence of sugar cane filter cake) (b). ** and * - Significant by the F test with a 1 and 5% probability, respectively.

The sugar cane filter cake was enriched with 800 ml of additive Bio Pack[sc], containing organic acids and P solubilizing microorganisms, a suggested amount for composting 8 tons of sugar cane filter cake. The treated organic product and basic fertilizers were mixed, homogenized and applied to the 0.3 m deep planting grooves.

Plant, soil sampling and chemical analysis

Six months after planting date, soil P was determined (resin method, Raij et al., 2001) using samples collected at 12 random spots in the unit areas, located in the fertilizing lines from layer 0.20-0.40 m deep. Eight months after planting date, samples of 15 leaves+1 were collected, the central rib removed and the median third of each leaf used at evaluate the nutritional status of the plant by P level (Raij and Cantarella, 1997). After drying to constant weight in a hot house (65°C), leaf samples were milled in a Willey type mill and P content determined as described by Bataglia et al. (1983). At harvest time at 12 months after planting, phosphorus accumulated in plant aerial parts (leaves and stalks) was calculated from the dry weight multiplied by the nutrient content, respectively. At harvest time, plants from the three middle lines were collected, separated into leaves and stalks and weighed to calculate the amounts corresponding to each unit and the total stalk productivity.

Statistical analysis

Results were subjected to analysis of variance (ANOVA) by the F test. The significant effects were compared by the Tukey test (P≤0.05) for qualitative source variation and by a polynomial regression for quantitative source variation utilizing the statistical program AgroEstat (Barbosa and Maldonado Junior, 2012).

Conclusion

Applications of phosphorus and sugar cane filter cake increased nutrient concentrations in soil, leaves and plant aerial parts by 47.2% (15.4 mg dm^{-3}), 7.1% (1.4 g kg^{-1}) and 36.3% (10.6 kg ha^{-1}), respectively. The sugar cane filter cake alone increased stalk production by 3.4% (122.6 t ha^{-1}). The TS with sugar cane filter cake or its higher doses stood out in all determined properties with the exception in stalk production, which was higher (126.7 t ha^{-1}) by application of BP (360 kg ha^{-1}).

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