Acta Scientiarum

http://www.uem.br/acta
ISSN printed: 1679-9275
ISSN on-line: 1807-8621
Doi: 10.4025/actasciagron.v36i3.17791

The effect of filter cakes enriched with soluble phosphorus used as a fertilizer on the sugarcane ratoons

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ABSTRACT. The objective of this work was to evaluate the effect of fertilization with filter cakes enriched with soluble phosphate on sugarcane ratoons. The experiment was performed from November 2007 to December 2009 at Presidente Prudente, São Paulo State, Brazil, in a completely randomized block design in a 4 x 4 factorial arrangement, with the first factor consisting of doses of filter cake (0, 1, 2 and 4 Mg ha^{-1}) and the second doses consisting of phosphorus fertilizer (0, 50, 100, 200 kg ha^{-1} of P_2O_5) with 4 replicates. The following variables were evaluated: the number of tillers per meter, the leaf area index, soluble solids (ºBrix), stalk and sugar yield in the second crop cycle. We found a residual effect in the sugarcane ratoon after applying filter cakes enriched with soluble phosphate in the planting furrow. The initial tillering, leaf area index, stalk and sugar yield in the cane ratoon benefit from the application of filter cakes and soluble phosphate in the planting furrow. The best combination is filter cakes at a dose between 1.0 and 2.0 mg ha^{-1} with 100 to 200 kg ha^{-1} soluble phosphate applied at planting. This method obtains higher stalk and sugar yields for sugarcane ratoons.

Keywords: *Saccharum* spp., organo-mineral fertilizers, triple superphosphate, sugarcane ratoon.

Efeito da torta de filtro associada à fósforo solúvel na soqueira da cana-de-açúcar

RESUMO. O objetivo deste trabalho foi avaliar a cana-de-açúcar no ciclo de cana soca em função da adubação de plantio com torta de filtro enriquecida com fosfato solúvel. O experimento foi realizado entre novembro de 2007 e dezembro de 2009, em Presidente Prudente, Estado de São Paulo, em blocos ao acaso, no esquema fatorial 4 x 4, sendo o primeiro fator doses de torta de filtro (0; 1,0; 2,0 e 4,0 t ha^{-1}) e o segundo doses de fósforo (0, 50, 100, 200 kg ha^{-1} de P_2O_5), com 4 repetições. As variáveis avaliadas foram números de perfilhos por metro, índice de área foliar, sólidos solúveis (ºBrix), produtividade de colmos e de açúcar no segundo corte. Houve efeito residual no ciclo seguinte da cana-de-açúcar com aplicação de torta de filtro enriquecida com fosfato solúvel no sulco de plantio. O perfilhamento inicial, o índice de área foliar, a produtividade de colmos e a de açúcar da cana soca foram beneficiados pela aplicação de torta de filtro e de fosfato solúvel no sulco de plantio. A melhor associação foi torta de filtro na dose 1,0 e 2,0 t ha^{-1} com fosfato solúvel entre 100 e 200 kg ha^{-1} no sulco de plantio em relação à produtividade de colmos e de açúcar na cana soca.

Palavras-chave: *Saccharum* spp., adubação organomineral, superfosfato triplo, cana-soca.

Introduction

As an important macronutrient and structural component of macromolecules and adenosine triphosphate, phosphorus is considered an essential element for plants and is found in low concentrations in Brazilian soils, which are mostly characterized as sharply weathered with low cation-exchange capacity and high anion adsorption (SANTOS et al., 2010). These conditions provide a reduction in the saturation condition of bases, with gradual increases in the retention of anions such as phosphate, sulfate and molybdate, among others (BENEDITO et al., 2010). Consequently, the soils gradually change from being phosphorous sources to phosphorus sinks.

The presence of phosphorus is necessary for the synthesis of phosphorylated compounds, and a lack of this nutrient immediately disturbs plant metabolism and development (SANTOS et al., 2010). According to Bastos et al. (2008), when applying a water-soluble phosphorus to a particular soil in Brazil, more than 90% of the total amount applied was already adsorbed in the first hour of contact with the ground. Novais (1980) also reported that the longer the contact with the soil, the less available the phosphorus is for plants because of the soil's high solubility.

In addition to its benefits in the field, phosphorus is also of great importance for the quality of sugarcane. According to Korndörfer (2004), low-broth-containing P_2O_5 flocculation is problematic, and the settling of impurities is poor. Cloudy juice in sugar production implies lower quality and is therefore of low commercial value.

Filter cakes are an industrial waste byproduct composed of a mixture of ground and crushed sediment and sludge from the sugar clarification process. For each ton of sugarcane, 30–40 kg of cakes can be produced. Korndörfer and Anderson (1997) reported that filter cakes, which contain high levels of organic matter and phosphorus, are rich in nitrogen and calcium and contain considerable levels of potassium, magnesium and micronutrients. Additionally, they are an excellent product for the recovery of depleted organic soils or soils of low fertility. The phosphorus in the filter cake is organic, and the release of phosphorous and nitrogen takes place gradually by mineralization and by soil microorganism activities (TORRES et al., 2012).

Recently, these filter cakes have been applied in sugarcane fields is for use as fertilizer (SANTOS et al., 2010, 2012). Many studies have shown the value of filter cakes for sugarcane nutrition, with substantial increases in production. Penso et al. (1982) suggested the possibility of applying a form of filter cakes in agriculture mixed with phosphates, as the filter cakes would improve the solubility of these compounds, rendering the phosphorus more readily available compared with standard application without filter cakes. Filter cakes also protect against the leaching away of phosphorous (BITTENCOURT et al., 2006). Being an organic material, filter cakes have a high capacity to retain water at low tensions, and this property contributes both to increasing the productivity of sugarcane, especially under non-irrigated conditions, and to ensuring maximum budding from plantings made during poor seasons.

This study aimed to evaluate the residual effect of using fertilizer filter cakes enriched with soluble phosphate in furrows on the tillering, leaf area index and productivity of sugarcane ratoons. Because typical sources of phosphorus have low efficiencies in tropical soils, our hypothesis was that the mixture of filter cakes with a phosphate source would improve the plant's utilization of phosphorus; in other words, a carrier was tested that protects organic phosphorus fixation and ensures its absorption by plants over a long period of time.

Material and methods

The experiment was conducted under field conditions at the experimental field of Universidade do Oeste Paulista (Unoeste), located at 51°26'00" longitude and 22°07'30" latitude at an altitude of 433 meters, in the city of Presidente Prudente, São Paulo State, from November 2007 to December 2009. The climate, according to Köppen, is Cwa, meaning that it is tropical with a well-defined hot, rainy season between the months of September and March. Additionally, the study area has a dry winter with mild temperatures during the months of April to September.

The soil of the study area has been characterized by Embrapa (2006) as typic dystrophic Argisoil (Rhodustults-PVd) and is wavy with good drainage. Samples were collected to characterize the soil's chemistry and the grain sizes at the 0-20 and 20-40 cm layers. The respective results as follows: pH 5.9 and 5.2 ($CaCl_2$ 1 mol L^{-1}); 18 and 11 g dm^{-3} of OM; 16 and 7 mg dm^{-3} of P_{resin}; 2.7 and 3.6 $cmol_c$ dm^{-3} of H+Al; 0.1 and 0.1 $cmol_c$ dm^{-3} of K; 3.8 and 2.0 $cmol_c$ dm^{-3} of Ca; 1.2 and 6.0 $cmol_c$ dm^{-3} of Mg; 5.2 and 2.7 $cmol_c$ dm^{-3} of SB (sum of bases); 6.9 and 6.3 $cmol_c$ dm^{-3} of CEC (cation exchange capacity); 74 and 43% base saturation (V); 740 and 760 g kg^{-1} sand; 80 and 30 g kg^{-1} silt; and 180 and 210 g kg^{-1} clay.

The filter cake was obtained from Destilaria Alvorada do Oeste, Santo Anastácio, São Paulo State, with a 34.85% dry weight according to a moisture content analysis by the Laboratory of Plant Tissue at Unoeste. The filter cake was then air dried for six days to achieve 80% dry matter. The results of an analysis of the organic fertilizer made by the Laboratory of Soil at Unoeste for the filter cake used in the experiment showed the following values, expressed as dry matter: pH 5.4 ($CaCl_2$ 1 mol L^{-1}); 70.70% lost moisture at 65°C; 57.25% of OM; 9.5 g kg^{-1} of N; 3.3 g kg^{-1} of P; 4.6 g kg^{-1} of K; 9.1 g kg^{-1} of Ca; 2.5 g kg^{-1} of Mg; 7.2 g kg^{-1} of S; 124 mg kg^{-1} of Cu; 758 mg kg^{-1} of Mn; 282 mg kg^{-1} of Zn; and 23808 mg kg^{-1} of Fe.

We performed conventional tillage with plowing and harrowing before planting. The minimum fertilization at planting was performed according to Raij et al. (1997) and consisted of 30 kg ha^{-1} of N (66.7 kg ha^{-1} of urea) and 100 kg ha^{-1} of K_2O (166 kg ha^{-1} of potassium chloride), with varying doses of P and filter cake in a randomized pattern.

Furrowing was conducted in the experimental area in November, 2007. Mixing of the fertilizer with the filter cake was performed with the aid of a mixer. The mixture was then evenly distributed along the furrows of each plot; planting was then performed in the conventional manner, adopting the sugar-year system. The sugarcane variety used was RB867515, based on the regional recommendation. At 60 days after planting, nitrogen application was performed with 100 kg ha^{-1} urea, following the recommendation of Raij et al. (1997).

Each plot consisted of 5 rows that were 5 m in length and were spaced 1.50 m apart. We configured the experimental design in a randomized complete block in a 4 x 4 factorial scheme, where the first variable consisted of levels of filter cake (0, 1, 2 and 4 Mg ha^{-1}) and the second variable was phosphorus levels (0, 50, 100, 200 kg P_2O_5 ha^{-1}). There were four repetitions, totaling 64 plots. For the purpose of evaluation, the three central lines of each plot were considered useful.

In November 2008, we performed a manual cut allowing new sprouting. Nitrogen application (with 100 kg ha^{-1} urea) was repeated 60 days after regrowth. The number of tillers per meter was estimated by counting within four feet along each line of a useful plot at 90, 120 and 360 days after the first cut. Counting was performed until 120 days, which is considered the limiting period for intense sugarcane tillering, which in turn is characterized by growth and profuse branching. After this stage, there is intense competition between tillers for light, water, nutrients and space, leading to decreased downtime (SILVA et al., 2008).

To determine the leaf area, we adopted the methodology described by Hermann and Câmara (1999) in a meter of furrow per plot at 120, 180, 240 and 330 days after regrowth. Knowing the average leaf area (LA) of each plant per plot, the leaf area index (LAI) was determined according to the equation: $LAI = MLF/A_{soil}$, where MLF is the mean leaf area of a plant (cm^2) and A_{soil} is the land area occupied by the plant.

The soluble solids content (°Brix) was determined in samples of broth prepared from five stem portions collected using a punch and read in a field refractometer (Atago, Master-α model, Tóquio, Japan).

In December 2009, the plots were harvested for the evaluation of manual production components and to estimate determinants of agricultural potential. Five consecutive stalks in each row were sampled to determine the following: stem height, measured from the stem base to the insertion of leaf 3; the average diameter of the stem, measured with calipers in the middle of the internode at the point given by one-third the length of the stem and the mass of the clipped stems. The number of stems in a plot was estimated by counting the number of stalks of all the lines. According to Landell and Silva (2004), if the stem density equals 1, then the cane production per hectare (TCH) can be estimated according to the following equation:

$$TCH = (d^2 \times C \times h \times 0{,}007854)/E$$

where d is the average diameter of the stem (cm), C is the number of tillers per meter, h is the average stem height (cm) and E is the spacing between the grooves, in this case 1.5 m. We obtained the sugar productivity (TPH) by multiplying the stalk yield (TCH) times the concentration of sucrose (in sugar) for each parcel divided by 100.

The data were subjected to analysis of variance and regression analysis by F test at a 5% probability.

Results and discussion

There was a significant effect of variable cake doses at planting in relation to tillering of the sugarcane during the first ratoon regrowth. The dose of phosphate at the time of planting, the days after regrowth and the interactions of phosphate multiplied by number of days, filter cake multiplied by number of days, and filter cake multiplied by amount of phosphate multiplied by number of days also showed significant effects. In contrast, the filter cake multiplied by degree of phosphate interaction showed no significant effect (Table 1).

Table 1. F values of variance analysis and regression for tillering and leaf area index (LAI) of sugar cane after regrowth, due to mixtures of doses of filter cake with doses of soluble phosphate applied in the furrows of planting.

Causes of variation	Tillering	LAI
Doses of Filter Cake	14.895**	17.050**
Doses of Phosphate	3.622*	0.771 ns
Days after planting	427.726**	136.240**
Cake x Phosphate	1.825 ns	1.287 ns
Cake x Days	6.542**	2.176*
Phosphate x Days	2.352*	0.754 ns
Cake x Phosphate x Days	1.776*	0.556 ns
CV (%)	7.55	14.37

The following averages for the same letter in the line do not differ for the test of Tukey to 5% of probability. * and ** significant at the 5 and 1% level of probability, respectively. ns: not significant.

Through the unfolding of the interactions, positive effects of filter cake dose and soluble P_2O_5 level applied to the planting furrows were found on the variable tillering during the days after regrowth (Figure 1). At both 90 and 120 days after regrowth, an increase in tillering was noted with the increase of filter cake and phosphate applied at planting. The greatest tillering at both times was observed, with a significant quadratic effect at a 5%

probability, when the application was 4.0 ton ha^{-1} filter cake with 200 kg P_2O_5 ha^{-1} (Figure 1D). After 360 days, however, there was a reduced number of tillers per meter of furrow in all treatments, with better responses obtained by the application of 2.0 ton ha^{-1} filter cake without the associated phosphate (Figure 1A).

Therefore, there was a beneficial residual effect of the association between filter cake and soluble phosphate upon tillering until four months after sprouting of the following ratoons. One of the reasons for this benefit would be the optimized use of phosphorus by the plant provided by the filter cake. According to Malavolta (2006), phosphorus increases the tendency of the grass to promote root growth, thus promoting the absorption of water and nutrients. Korndörfer and Alcarde (1992), studying the effects of phosphorus on the growth of sugarcane, found that this element resulted in increased tillering, leading to higher crop yields. Silva et al. (2007) reported that good tillering, reflected in increased productivity, has other desirable characteristics, such as greater protection by ground shading, reduced levels of weed competition and, consequently, reduced cost of production.

Significant effects in the leaf area index (LAI) were observed at a 1% probability level for the factors filter cake and days after regrowth and at a 5% probability level for the interaction of filter cake multiplied by number of days. No significant effects were found for the factors phosphate dose of, filter cake multiplied by phosphate, phosphate multiplied by number of days and filter cake multiplied by phosphate multiplied by number of days (Table 1).

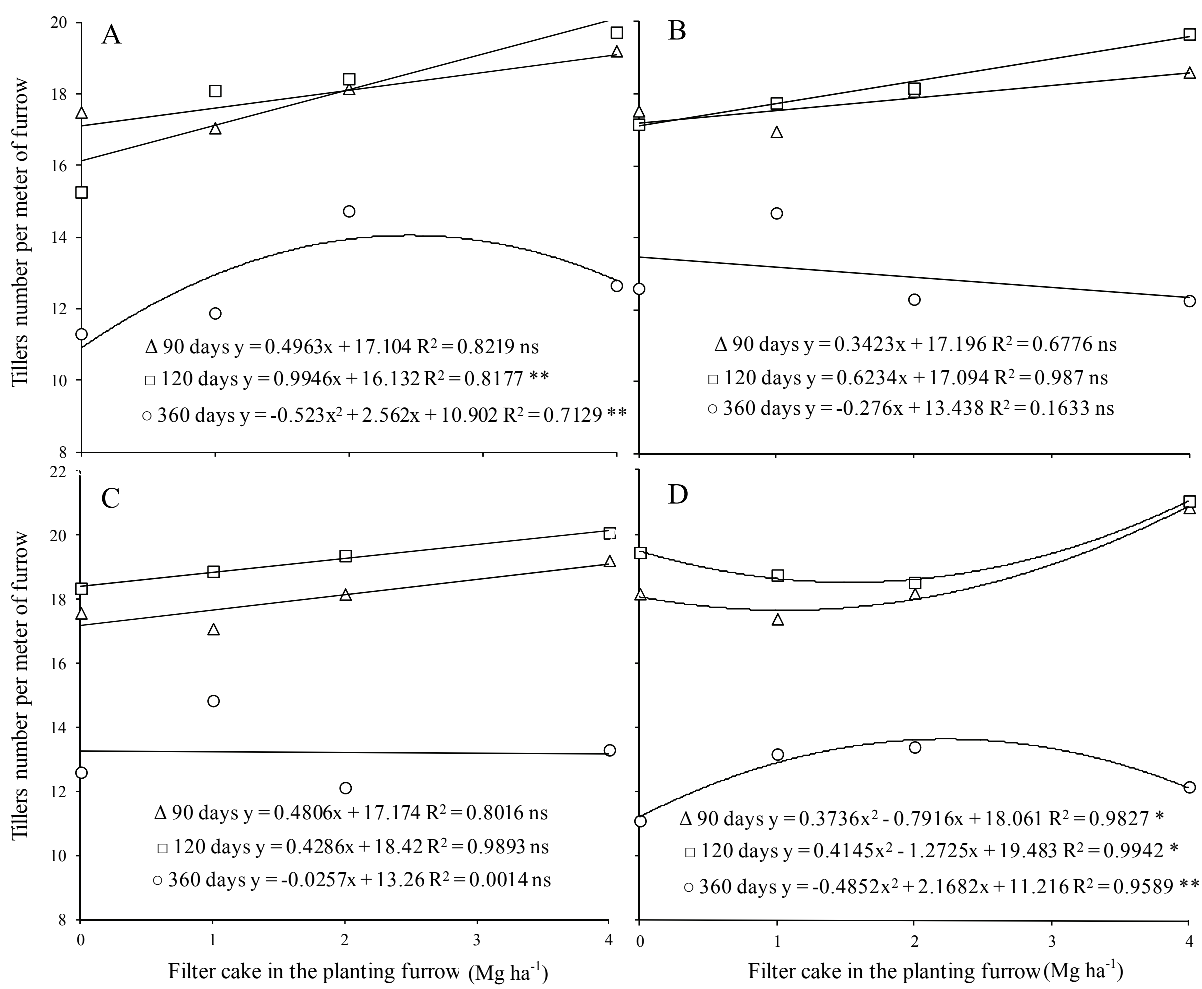

Figure 1. Tillering of sugar cane at 90 (Δ), 120 (□) and 360 (○) days after the first cut because of mixed doses of filter cake with 0 (A), 50 (B), 100 (C) and 200 (D) kg ha^{-1} of the P_2O_5 applied in the planting furrows. * and ** significant at the 5 and 1% level of probability, respectively. ns: not significant. (Presidente Prudente, São Paulo State, 2009).

The regression of the variable LAI due to the filter cake dose applied at planting mixed with soluble P_2O_5 (Figure 2) showed a higher LAI 120 days after regrowth at doses of 0 and 50 kg ha^{-1} P_2O_5, which is associated with 2 ton ha^{-1} filter cake with a quadratic effect at a 1% probability (Figure 2A and B). After 180 days of regrowth, there was no significant effect (Figure 2). At 240 days after regrowth, the highest LAI of the entire period, represented by a quadratic effect at a 5% probability, was observed in the 2 ton ha^{-1} filter cake with 50 kg ha^{-1} of associated P_2O_5 (Figure 2B). At the end of the assessment period (330 days), only the dose of 100 kg ha^{-1} P_2O_5 showed a significant quadratic effect at a 5% probability (Figure 2C), with higher values of LAI observed in association with the 2 ton ha^{-1} filter cake.

Therefore, the LAI clearly increased up to 240 days after sprouting and then declined through 330 days to values lower than those observed at 240 days. This phase coincides with the ripening of the cane sugar, so this reduction in LAI is understandable, considering the fact that with maturity and increasing senescence of the lower leaves, the trend is toward a decreased leaf floor area (ALMEIDA et al., 2008). During this period, the productive potential of the plant has already formed and, therefore, does not interfere with the crop yield.

The optimal use of solar radiation in photosynthetic processes is dependent on further development of the leaves, and the higher the photosynthetic rate, the higher the yield. Therefore, the results are promising because they indicate that the application of filter cake and soluble phosphate in the grooves at planting may improve the final production of stems in the next culture cycle.

The results of the analysis of variance showed that significant effects on sugarcane yield (TCH) and sugar (TPH) from the sugarcane ratoon were conferred by the levels of filter cake and phosphate applied at planting. However, there were significant effects of the filter cake multiplied by the phosphate interaction on these variables (Table 2). In the case of the soluble solids (ºBrix) in the juice from the cane field's ratoons, there was no effect of any of the factors or of the interaction of filter cake multiplied by phosphate.

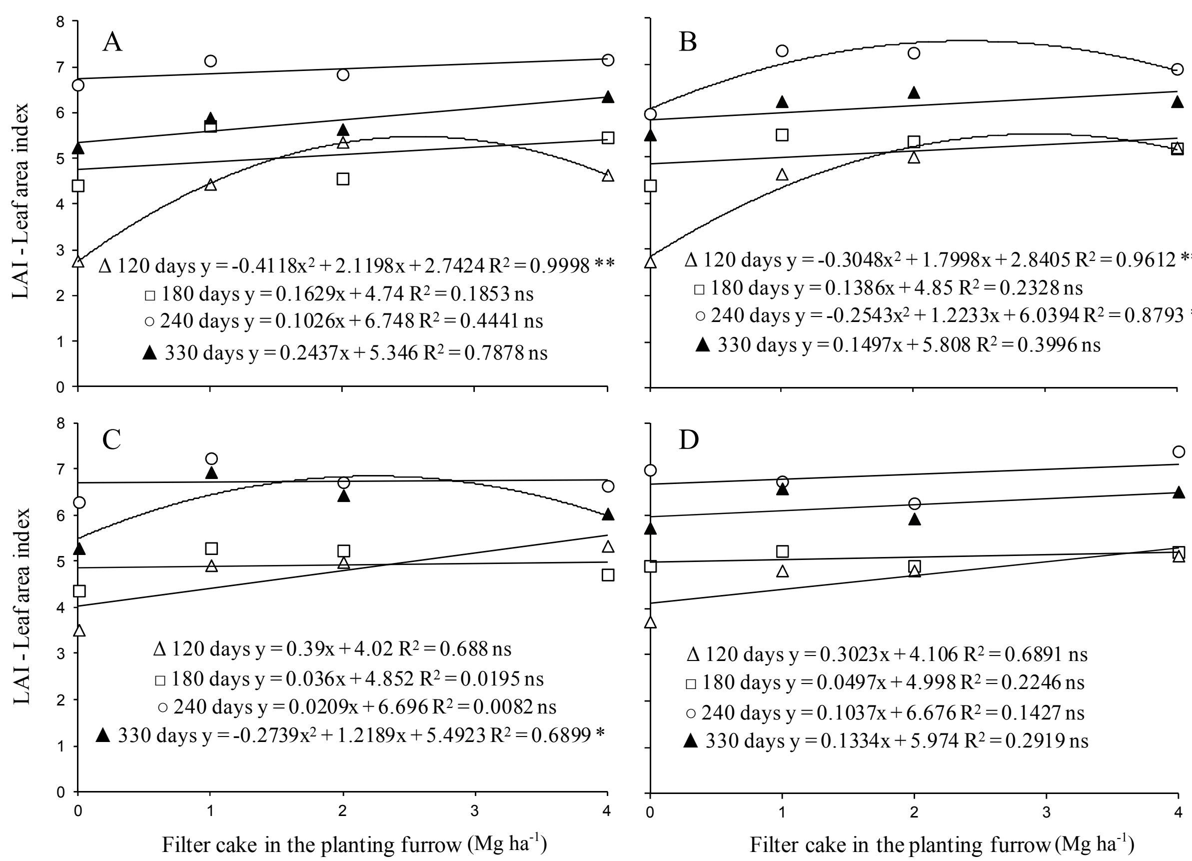

Figure 2. Leaf area index (LAI) at 120 (Δ), 180 (□), 240 (○) and 330 (▲) days of regrowth, due to mixtures of filter cake doses with 0 (A), 50 (B), 100 (C) and 200 (D) kg ha^{-1} of the P_2O_5 applied in the planting furrows. * and ** significant at the 5 and 1% level of probability, respectively. ns: not significant. (Presidente Prudente, São Paulo State, 2009).

Table 2. F values calculated by analysis of variance and average stalk yield (TCH), sugar yield (TPH) yield and °Brix, because doses of mixtures of soluble phosphate with doses of filter cake applied in the planting furrows.

Causes of variation	TCH	TPH	°Brix
F			
Doses of Filter Cake	3.41 *	3.36 *	0.63 ns
Doses of Phosphate	5.01 **	3.49 *	0.55 ns
Cake x Phosphate	1.50 ns	1.50 ns	0.55 ns
Doses of Cake (Mg ha^{-1})			
0.0	62.80 b	12.56 b	18.68
1.0	77.58 a	15.68 a	18.29
2.0	66.12 ab	13.31 ab	18.51
4.0	65.63 ab	12.50 b	18.43
Phosphate (kg ha^{-1})			
0	60.11 b	12.01 c	18.38
50	62.63 b	12.40 bc	18.60
100	72.80 ab	14.68 ab	18.62
200	76.61 a	14.96 a	18.32
CV (%)	20.81	24.11	4.47

The following averages for the same letter in the line do not differ for the test of Tukey to 5% of probability. *and **significant at the 5 and 1% level of probability, respectively. ns: not significant.

In terms of levels of filter cake, the largest sugarcane ratoon TCH, 77.58 ton ha^{-1}, was obtained with the application of 1.0 ton ha^{-1} in the furrow. There were no significant differences between treatments with 2.0 and 4.0 ton ha^{-1} filter cake, but all yields were superior to the treatment with 0 ton ha^{-1} filter cake. With respect to doses of phosphate, the highest TCH was observed with the application of 200 kg ha^{-1}, but no significant difference was seen with the dose of 100 kg ha^{-1}. The 0 and 50 kg ha^{-1} levels gave the lowest cane yields from ratoons.

The highest sugar yield (TPH) in the ratoon sugarcane, 15.68 ton ha^{-1}, was observed in the application of 1.0 ton ha^{-1} filter cake; this value did not differ significantly from the TPH obtained with a dose of 2.0 ton ha^{-1}. The highest TPHs (of 14.96 and 14.68 ton ha^{-1}) were found with applications of 200 and 100 kg ha^{-1} phosphate, respectively. The increase in sugar yield was a reflection of the positive influence of the filter cake treatment and of increased phosphate on TCH, as this is a result of both sugarcane yield and sucrose concentration.

Penatti and Boni (1989) worked with increasing doses of filter cake (0, 3, 6 and 9 ton ha^{-1} at planting) with and without mineral fertilizer top dressing with nitrogen and potassium. Their results showed a positive response in the productivity of plants and ratoon cane with increasing doses of filter cake, but they did not show any effects of mineral fertilization on yield coverage. Fravet et al. (2010), in an experiment conducted on a Typic yellow soil in the municipality of Goianésia, Goiás State, also reported that sugarcane yield per hectare (TCH), as well as sucrose per hectare (TPH), increased as the filter cake doses increased. Likewise, Neto et al. (2009), reported an experiment conducted at Jaboticabal - São Paulo State, Brazil, noted that sugarcane and sugar yields were higher when this residue was used and supplemented with mineral springs. Demattê (2005), in turn, evaluated sugarcane yield in ratoon cane against different doses of P_2O_5 (100, 200 and 400 kg ha^{-1}) and saw no significant differences between different doses.

According to Torres et al. (2012), the release of phosphorus present in the filter cake to the ground is gradual, providing residual phosphorus for an average of two to three cuts, depending on the climate and location. In the study of Nunes Jr. (2008) in tropical climates, the filter cake remained for two years, and in warmer climates, such as the States of São Paulo and Paraná, the filter cake could act in the soil for three years.

These positive results in relation to the production of stalks and sugar are due to the organic material in the filter cake playing an important role in improving soil fertility and its physical properties, which must have remained for the following crop year, conferring beneficial effects on the ratoon sugarcane. According to Alleoni and Beauclair (1995), the organic matter in filter cake increases the water retention capacity of the soil because it is hygroscopic and able to retain water up to six times its own weight. By further reducing the density of the soil and increasing its porosity, the filter cake forms aggregates that are capable of reducing erosion and increasing the absorptive capacity of the soil. Additionally, filter cake supplementation can increase the soil's cationic exchange capacity due to the action of the humic colloidal micelles in the clays. Filter cake application also increases the levels of nitrogen, phosphorus and sulfur from the decomposition and mineralization of organic matter and promotes the reduction of setting phosphorus iron and aluminum oxides, blocking these minerals' attachment sites with organic radicals.

According to Rossetto et al. (2008), the use of this residue on sugarcane crops increases productivity by providing organic matter, phosphorus, calcium and other nutrients. The most efficient use of the filter cake is to apply it at planting, when the water contained in the filter cake promotes sprouting of the sugarcane and the phosphorus to be mineralized is close to the roots in training. Santos et al. (2010) also observed the increased production of stalks. However, the cane plant, supplemented with a filter cake in which the dose of 4.0 ton ha^{-1} was associated with different doses of soluble phosphorus, gave yields ranging from approximately 100 to 150 ton ha^{-1} stalk. Our results demonstrate the potential of filter cakes to confer beneficial effects on soil fertility for the production of stems from one year to another.

Although phosphorus actively participates in the formation of sucrose, other studies with phosphorus fertilization in the culture of sugarcane showed no positive responses compared with sucrose, even in plant cane (KORNDÖRFER; MELO, 2009; LIMA et al., 2006). Contrary to the observations made in this work, however, Santos et al. (2011) observed positive effects on the values of °Brix from the juice of cane plants with increasing doses of phosphorus, either via the filter cake, phosphate or the interaction between the two sources.

Conclusion

There are significant effects on the subsequent sugarcane cycle cultivation after applying filter cake associated with soluble phosphate in the furrows.

The initial tillering, leaf area index, sugarcane yield and productivity of sugarcane ratoon crops all benefit from the application of filter cake and soluble phosphate at the time of planting.

The best combination for the productivity of stalks and sugarcane ratoons was to apply filter cake at the time of planting at a dose between 1.0 and 2.0 ton ha^{-1}, with soluble phosphate between 100 and 200 kg ha^{-1}.

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Received on July 2, 2012.
Accepted on October 3, 2012.