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Changes in soil chemical reactions in response to straw sugar cane and vinasse

Alteração na reação química do solo influenciada pela palha de cana-de-açúcar e vinhaça

Gisele Silva de Aquino[1*]; Cristiane de Conti Medina[2];
Osmar Rodrigues Brito[2]; Inês Cristina de Batista Fonseca[2]

Abstract

Sugarcane harvesting is predominantly mechanical because of environmental restrictions, reduced requirements for manpower, and the quest for improved efficiency. Therefore, large amounts of straw remain available in the soil. Vinasse, a liquid waste, is a main byproduct of the sugar and alcohol industry, in addition to sugarcane straw. Both accumulate in sugarcane fields; however, the effects of their interaction are unclear. In this study, the effects of applications of sugarcane straw and vinasse on the pH and the potassium (K), calcium (Ca), and magnesium (Mg) concentrations of a dystroferric Red Nitosol with a high base saturation were examined. The profiles of soil samples from sugarcane plantations collected at depths of 0-0.05, 0.05-0.10, 0.10-0.20 and 0.20-0,30 m were reproduced in 64 polyvinyl chloride (PVC) columns with dimensions of 0.036 × 0.30 m (diameter × height). The soils were treated with doses of 0, 125, 250, and 500 m^3 ha^{-1} sugarcane vinasse and 0, 3, 6, and 9 t ha^{-1} sugarcane straw and incubated for 60 days. Following the analysis, by layer, the data were subjected to analysis of variance by partitioning the degrees of freedom into orthogonal polynomials. The pH and the Ca, Mg, and K concentrations increased throughout the soil profile upon vinasse application. An acid-base imbalance was observed in the topsoil layers in association with the high K saturation. The application of sugarcane straw enhanced the effects of the vinasse across all of the depths analyzed but did not increase the pH. The best results were obtained when applying a dose of 300 m^3 ha^{-1} vinasse and 6 t ha^{-1} sugarcane straw.

Key words: Green cane, cations, agricultural waste, *Saccharum* spp., soil

Resumo

Devido às restrições ambientais, falta de mão-de-obra e a busca por melhor eficiência, a colheita de cana-de-açúcar tende a ser mecanizada, fazendo com que grande quantidade de palhada esteja disponível no solo. Somada à palha, a vinhaça é o principal resíduo líquido da indústria sucroalcooleira. Ambos são depositados a campo; porém, o efeito da interação entre os mesmos, ainda não está esclarecido. Avaliou-se a influência da aplicação de palha de cana-de-açúcar e vinhaça no pH e nos teores de potássio (K), cálcio (Ca) e magnésio (Mg) em Nitossolo Vermelho distroférrico de alta saturação por bases. Em 64 colunas de PVC de 0,036 × 0,30 m (diâmetro × altura) foram reproduzidos perfis do solo coletados nas profundidades 0-0.05, 0.05-0.10, 0.10-0.20 e 0.20-0,30 m, em área de cultivo. Os solos foram tratados com vinhaça, em doses equivalentes a 0, 125, 250 e 500 m^3 ha^{-1} e 0, 3, 6 e 9 t ha^{-1} de palha de cana-de-açúcar e submetidos à incubação por 60 dias. Após as análises por camada, os dados foram submetidos à análise de variância com desdobramento dos graus de liberdade em polinômios ortogonais. Com a

[1] Discente do Curso de Doutorado do Programa de Pós-Graduação em Agronomia, Deptº de Agronomia, Universidade Estadual de Londrina, UEL, Londrina, PR, Brasil. E-mail: gisele.s.aquino@hotmail.com

[2] Profs. Drs., Deptº de Agronomia, UEL, Londrina, PR, Brasil. E-mail: medina@uel.br; osmar@uel.br; inescbf@uel.br

[*] Author for correspondence

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aplicação de vinhaça, houve elevação do pH e dos teores de Ca, Mg e K, com distribuição em todo o perfil. Observou-se desequilíbrio de bases nas camadas superficiais devido à alta saturação de K. A palha de cana-de-açúcar potencializou o efeito da vinhaça em todas as profundidades analisadas, mas não foi suficiente para aumentar o pH. Melhores resultados foram obtidos com as doses de 300 m^3 ha^{-1} de vinhaça e 6 t ha^{-1} de palha de cana-de-açúcar.

Palavras-chave: Cana crua, cátions, resíduo agrícola, *Saccharum* spp, solo

Introduction

The area of sugarcane production subjected to mechanical harvesting has been increasing rapidly in Brazil. Estimates indicate that 80% of the most productive areas of Brazil will be subjected to management involving mechanical harvesting by 2023 (CERRI et al., 2003). Brazil supplied 659 million tons of sugarcane and 24 billion liters of ethanol to the marketplace following the 2013/2014 harvest, generating over 140 million tons of sugarcane waste (a mixture of leaves, tops, stalk pieces, and other crop residues) and 10 to 15 liters of vinasse per liter of ethanol produced, totaling approximately 310 billion liters (CONAB, 2013).

Under this new harvesting system, the dry leaves, tops, and green leaves are cut and cast onto the soil surface, supplying 10 to 30 t ha^{-1} dry matter. The deposition and the maintenance of this sugarcane waste on the soil surface causes changes in the chemical, physical, and biological conditions of the agricultural environment (GAVA et al., 2003; FAGERIA et al., 2013). This layer of plant material increases the infiltration of water into the soil, increases the soil organic matter content, decreases erosion, decreases evaporation, improves the soil structure, and increases the cation-exchange capacity (CEC). Sugarcane residues are also a source of nutrients for the soil macro- and microfauna and for the sugarcane crop itself. Oliveira et al. (2003) studied the contribution of sugarcane waste to the increase in soil nutrients and determined that the dry matter production (15.6 t) contributed mean N, K, Ca, and Mg accumulations of 55, 130, 60, and 20 kg ha^{-1}, respectively.

Sugarcane straw (leaves and tops) is an inexpensive and readily available raw material, produced in large quantities, that acts as a source of renewable lignocellulosic biomass for bioethanol production (DAWSON; BOOPHATY, 2007; FAGERIA et al., 2013). Hence, understanding the dynamics of straw decomposition and the effects of its removal and its interactions with other crop residues on soil quality in this new production system is necessary, especially to establish the trust of the international market for which the premise of a sustainable model of ethanol production is mandatory.

Thus, studies must be conducted to define the amount of straw that should be left in the field to ensure soil sustainability, especially when applied together with other crop residues, as well as the amount of this crop residue that may be used for the direct production of bioethanol or bioenergy. Vinasse, a liquid waste, is a main byproduct of the sugar and alcohol industry, in addition to sugarcane straw. The application of this waste on sugarcane plantations via fertigation is a practice that has been adopted by the majority of sugarcane mills in response to the large volume of vinasse generated (BRITO et al., 2007).

The use of vinasse is advantageous because it contains significant amounts of chemical elements [especially K and micronutrients (Zn, Fe, Mn and Cu), and at lower levels, Ca, Mg, and N] essential to plants, and vinasse applications can supply the majority of mineral fertilization nutrient requirements, with several studies reporting increased sugarcane productivity in response to vinasse applications (MEDINA et al., 2002; RESENDE et al., 2006).

However, vinasse may cause nutrient and cation-exchange capacity (CEC) imbalances and induce soil saturation when applied without criteria, causing problems such as the leaching of its constituents into groundwater. Furthermore, its application with other residues, including sugarcane waste, may cause changes in soils, even enhancing the effects already known to occur.

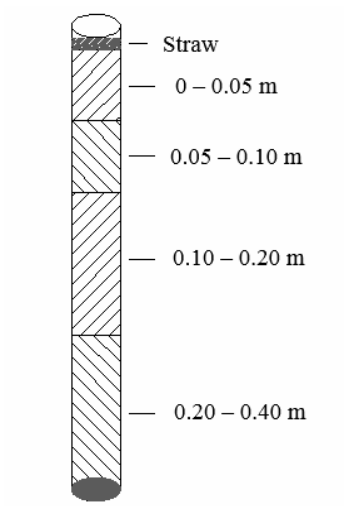
Pioneering studies on the use of vinasse incorrectly recommended the application of excessive amounts of vinasse to soils, recommending doses ranging from 500 to 1,000 m^3 ha^{-1} vinasse (FREIRE; CORTEZ, 2000), thus leading to unexpected results. Medina et al. (2002) reported that applying doses higher than 300 m^3 ha^{-1} caused a decrease in sugarcane productivity. Thus, the study of the interactions of vinasse with soils and with other crop residues, including sugarcane straw, is crucial to enabling assertive and consistent decision-making regarding the application of this byproduct.

This study aimed to assess the effects of applying sugarcane straw and vinasse on soil pH and on soil potassium, calcium, and magnesium concentrations in a dystroferric Red Nitosol with a high base saturation.

Materials and Methods

The experiment was conducted at the Soil Laboratory of the Department of Agronomy, Londrina State University (Universidade Estadual de Londrina). The experimental units consisted of PVC columns, with a 0.036-m internal diameter and a 0.30-m height, that were filled with 0.305 kg of fine, air-dried soil with a density of 1.2 kg dm^{-3}. Inert foam placed at the bottom of the tubes was used to prevent soil losses (Figure 1). The experimental design was completely randomized with four replicates.

Figure 1. Detail of column with each layer, imitating the soil profile.



The soil, classified as a dystroferric Red Nitosol (EMBRAPA, 2013), was collected from an area belonging to the COROL Sugar and Alcohol Mill (Usina de Açúcar e Álcool COROL), located in the city of Rolândia, Paraná (PR), Brazil. Trenches measuring 1.00 × 0.70 m were opened and samples were collected from the following depths: 0-0.05, 0.06-0.10, 0.11-0.20, and 0.21-0.30 m. Subsamples were collected from each layer and subjected to soil chemical and particle size analyses according to the methods described by EMBRAPA (1997). The results, assessed for the chemical analyses by layer, are outlined in Table 1. The particle size analysis produced the following results: sand = 196 (g kg^{-1}); silt = 1.8 (g kg^{-1}); clay = 802.2 (g kg^{-1}).

Table 1. Chemical analysis of soil in each layer, before treatments application.

Layer (m)	CTC pH 7	pH $CaCl_2$	cmol$_c$ dm^{-3}					Saturation index		
			Ca^{+2}	Mg^{+2}	K^+	Al^{+3}	H^+	K%	Mg%	Ca%
0-0.05	17.05	4.98	9.11	2.43	1.14	0.05	4.29	6.70	14.25	53.43
0.06-0.10	17.95	5.12	10.50	2.57	0.83	0.00	4.03	4.63	14.31	58.48
0.11-0.20	15.18	5.27	8.69	2.01	0.69	0.00	3.77	4.55	13.24	57.24
0.21-0.30	13.78	5.46	8.31	1.95	0.31	0.00	3.20	2.25	14.15	60.29

Each column was coated with a low-density polyethylene material to avoid contact between the soil and tube and to facilitate soil removal following the incubation period. The columns were then filled according to the layers collected in the field, i.e., 0-0.05, 0.05-0.10, 0.10-0.20 and 0.20-0,30 m. The first two layers received 0.508 kg of soil, and the other layers received 0.102 kg (Figure 1).

Straw derived from the sugarcane variety RB 83-5054 was randomly collected from an area subjected to manual harvesting. The straw was cleaned and oven-dried at 65°C to a constant weight, weighed, ground, sieved through a 1.0-mm mesh (EMBRAPA, 1997), and then stored in cardboard boxes.

The vinasse collected at the mill was sent for chemical analysis. The applied doses (0, 125, 250, and 500 m^3) were determined based on the amount of vinasse typically applied by mills, 250 m^3 ha^{-1}. The results from the vinasse chemical analysis were as follows: nitrogen, 490.28 (mg N L^{-1}); organic matter, 13,062.50 (mg L^{-1}); phosphorus, 36.36 (mg P L^{-1}); potassium, 1,450.00 (mg K L^{-1}); calcium, 658.50 (mg Ca L^{-1}); magnesium, 155.80 (mg L^{-1}); sulfur, 522.70 (mg S L^{-1}).

The sugarcane straw was then added to the topsoil of each column at doses corresponding to 0, 3, 6, and 9 t ha^{-1}. Vinasse and distilled water were applied using a surface drip system set to apply 0.5 ml min^{-1} to ensure that all treatments would receive a volume corresponding to 1 pore volume (105 ml column^{-1}; FIORETTO, 1999). Each tube was wrapped with plastic film and sealed to prevent water loss by evaporation after applying the treatments. The material was incubated for 60 days to allow for stabilization before subsequent chemical analyses.

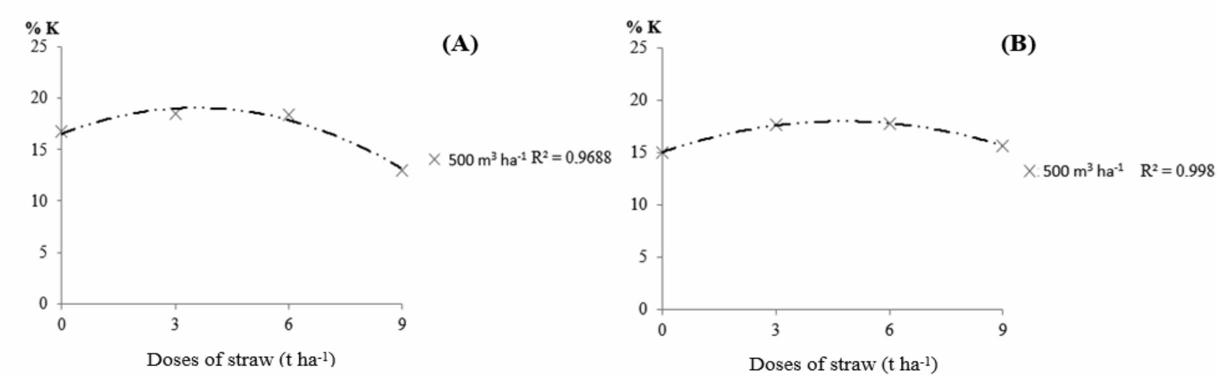
The soil was then removed from the columns and divided into the 0-0.05, 0.06-0.10, 0.11-0.20, and 0.21-0.30-m layers and placed into Petri dishes to air-dry. The clods were then broken apart before the chemical analysis of pH in $CaCl_2$ and of calcium, magnesium, and potassium according to the method described by Pavan et al. (1992).

The data were subjected to analysis of variance (ANOVA), F test, and the partitioning of the degrees of freedom into orthogonal polynomials at the 1% significance level.

Results and Discussion

The mean values of K, Ca, Mg, and pH for the 0-0.05 to 0.20-0.30-m layers, 60 days after applying the treatments, are presented in Figures 2 to 8. The analysis of variance indicates a significant (p=0.01) effect of the interaction of all of the variables studied (straw × vinasse and vinasse × straw), and the results are described considering this interaction order. When applied with 500 m^3 ha^{-1} vinasse, sugarcane straw promoted an increase in potassium saturation in the exchange complex to the depth of 0.10 m. No significant treatment effect was observed in the other layers or at the other vinasse doses (Figure 2).

Figure 2. Straw application effect under vinasse doses on potassium content at 0 – 0.05 m (A) and 0.06 – 0,10 m (B) depths.



The low contribution of the sugarcane straw to the potassium concentration may result from the relatively short incubation period (60 days) of the plant material, combined with the fact that microbial activity was not favored under the laboratory conditions because of the controlled factors, including temperature and irrigation, which were lower than in the field, thus preventing the full release of potassium. Yaday et al. (1987) reported that sugarcane straw incubated at 28 °C released 35% of the potassium in the first 15 days of incubation and that only 70% of all of the total K contained in this crop residue had been released at the end of the experimental period (120 days). Oliveira et al. (2003) observed that after a long period of time, the dry matter yield, ranging from 15.6 to 18.5 t, had a mean K accumulation of 130 kg per hectare.

A significant and increasing effect on the calcium concentration was observed for applications of 3 to 6 t ha^{-1} sugarcane straw in all layers, and the concentration of Ca decreased above that dose as a result of its translocation (Figure 3). The impacts of the sugarcane straw were enhanced when applied together with vinasse. The dose of 250 m^3 ha^{-1} vinasse produced the best effects.

The Mg concentration decreased significantly with an increase in the amount of sugarcane straw in and above the 0.20-m layer, while magnesium accumulated in the 0.20-0.30-m layer; the highest dose (9 t ha^{-1}) resulted in the highest concentration in the latter layer (Figure 4). As expected, the 500 m^3 ha^{-1} vinasse dose resulted in the highest Mg concentration. The presence of Ca and Mg in deeper layers (0-0.30 m; Figures 3 and 4) may be explained by the complexation by organic ligands in systems with high inputs of organic waste. The net charges of those cations are altered by the formation of MgL^0 and CaL^0 complexes, where L = organic ligand (COO^-). These complexes are preferentially leached into the deepest layers because of the negative net charge of the soil, corroborating the findings reported by Watanabe et al. (2004).

Ca and Mg typically increase in solution when plant residues are added to soils with pH values lower than 6.0 (PAVINATO; ROSOLEM, 2008). The releases of calcium and magnesium reach relatively high percentages because these elements are partially bound to soluble ionic and molecular compounds.

Figure 3. Straw application effect under vinasse doses on calcium content at 0 – 0.05 (A), 0.06 – 0.10 (B), 0.11 – 0.20 (C) and 0.21 – 0.30 m (D) layers.

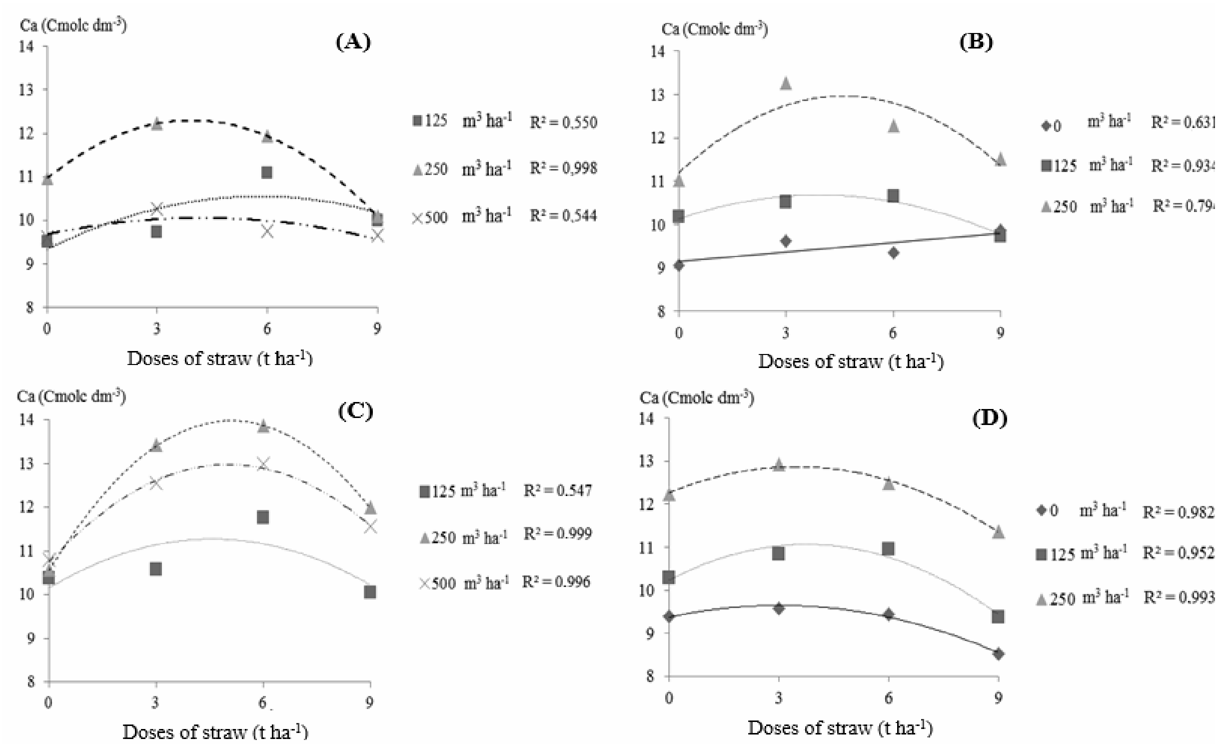
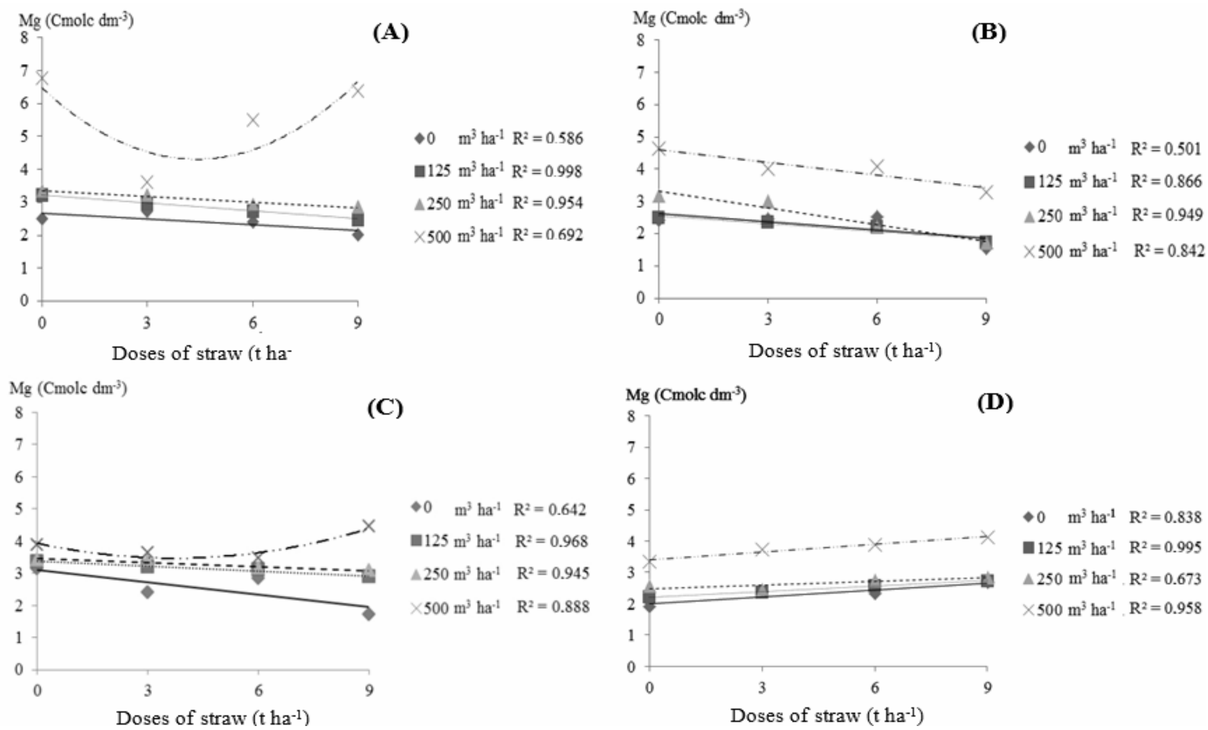


Figure 4. Straw application effect under vinasse doses on magnesium content at 0 – 0.05 (A), 0.06 – 0.10 (B), 0.11 – 0.20 (C) and 0.21 – 0.30 m (D) depths.

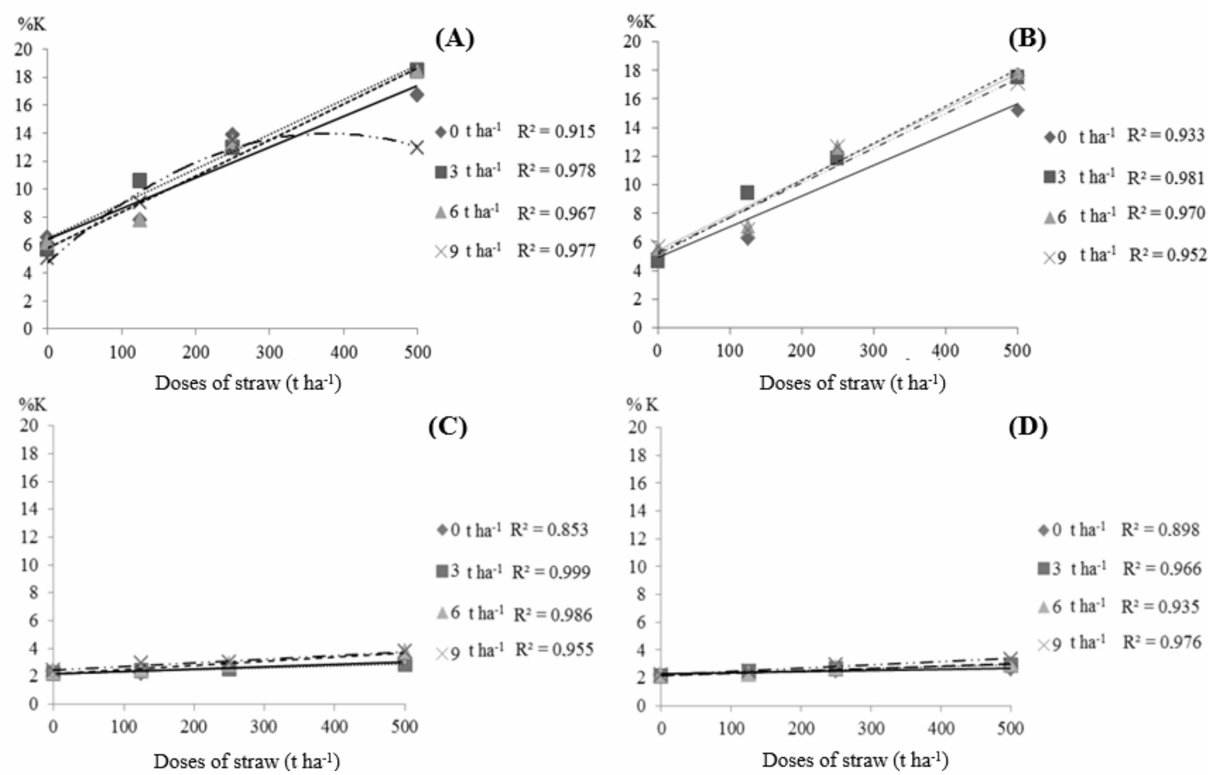


Fioretto (1999) tested the contribution of sugarcane straw to soil fertility in PVC columns and observed Ca, Mg, and K leaching to a depth of 0.30 m. Similar results were reported by Oliveira et al. (2003), who noted increased calcium and magnesium concentrations in deeper soil layers when testing the effects of sugarcane straw on soils, corroborating the findings of the present study.

These results indicate the importance of postharvest sugarcane straw management because water-soluble compounds may allow for the movement of calcium into the subsurface. The lack of this cation in the deepest layers may severely restrict sugarcane crop growth by limiting the cell permeability of roots. The sugarcane straw applications had no significant effect on pH, at any amount tested. For an experiment on the effect of sugarcane straw throughout the first sugarcane ratoon cycle, Leme Filho (2009) also reported no significant effect on pH.

Applications of vinasse promoted an increased concentration and distribution of K throughout the soil profile (Figure 5), with the highest mean percentage observed at a dose of 500 m^3 ha^{-1} vinasse, suggesting the occurrence of leaching to a depth of 0.30 m. The percentage of K saturation increased significantly in the exchange complex to values as high as 18% for the 0-0.05 and 0.05-0.10 m layers (Figure 5A and 5B), promoting a base imbalance. The highest values were 3.80 and 3.33% for the depths of 0.11-0.20 and 0.21-0.30 m, respectively (Figure 5C and 5D).

Figure 5. Straw application effect under vinasse doses on potassium concentration at 0 – 0.05 m (A), 0.06 – 0.10 (B), 0.11 – 0.20 (C) and 0.21 – 0.30 m (D) depths.



The application of sugarcane straw together with vinasse increased the potassium concentration across all depths, albeit more sharply for the 0-0.05-m layer, which increased from 17% saturation at the 0 t ha^{-1} sugarcane straw dose to 19% at the doses of 3 and 6 t ha^{-1} sugarcane straw, and from 15.2% to 18% in the 0.05-0.10-m layer upon sugarcane straw application regardless of the dose applied. The increases were of lower magnitude at the other depths, with the highest concentrations observed for the applications of 6 and 9 t ha^{-1} sugarcane straw. Therefore, when performing the potassium fertilization calculation, it is important to consider whether the vinasse is being applied together with sugarcane waste and to consider the contribution of sugarcane residues to soil saturation. The presence of K in the deepest layers is favored by the formation of organic compounds with other elements; thus, percolation of this cation to other layers is facilitated because the exchange complex is saturated (FRANCHINI et al., 2003).

The results reported by Franchini et al. (2003) demonstrated that polyvalent cations (Ca, Mg, and Al) are preferentially leached into the soil profile compared to monovalent cations (potassium) in systems with a high input of organic residues. This preferential leaching might be explained by the zero or negative net charge of the organic complexes formed between organic anions of plant extracts and polyvalent cations, thus increasing their concentrations in the deepest layers. This mechanism explains the higher concentration of the potassium cation in the topsoil layer (0-0.10 m).

In studies applying different doses of vinasse to soils, Bebé et al. (2009), Brito et al. (2007), and Canellas et al. (2003) reported increased potassium concentrations in the top and deep soil layers that were proportional to the amounts applied, corroborating the results of the present study. Vinasse contributes significantly to reducing mineral fertilization requirements, and 150 m^3 ha^{-1} vinasse, on average, equates to 343 kg ha^{-1} K and 108 kg ha^{-1} Ca fertilization (MEDEIROS et al., 2003). Oliveira et al. (2003) reported that an input of 15.6 to 18.5 t ha^{-1} sugarcane straw dry matter resulted in mean accumulations of potassium, calcium, and magnesium of approximately 130, 60, and 20 kg ha^{-1}, respectively. However, the continuous application of vinasse to areas with high K concentrations may trigger a cation imbalance, causing qualitative and quantitative losses in field production.

K saturation should be 3 to 5% to achieve good nutritional soil conditions and satisfactory yield in terms of both quality and quantity, according to Tomé Júnior (1997) and regulation P4.231, which was created by the Brazilian Environmental Sanitation Technology Company (Companhia de Tecnologia de Saneamento Ambiental – CETESB) to establish criteria and procedures for the application of vinasse in the State of São Paulo.

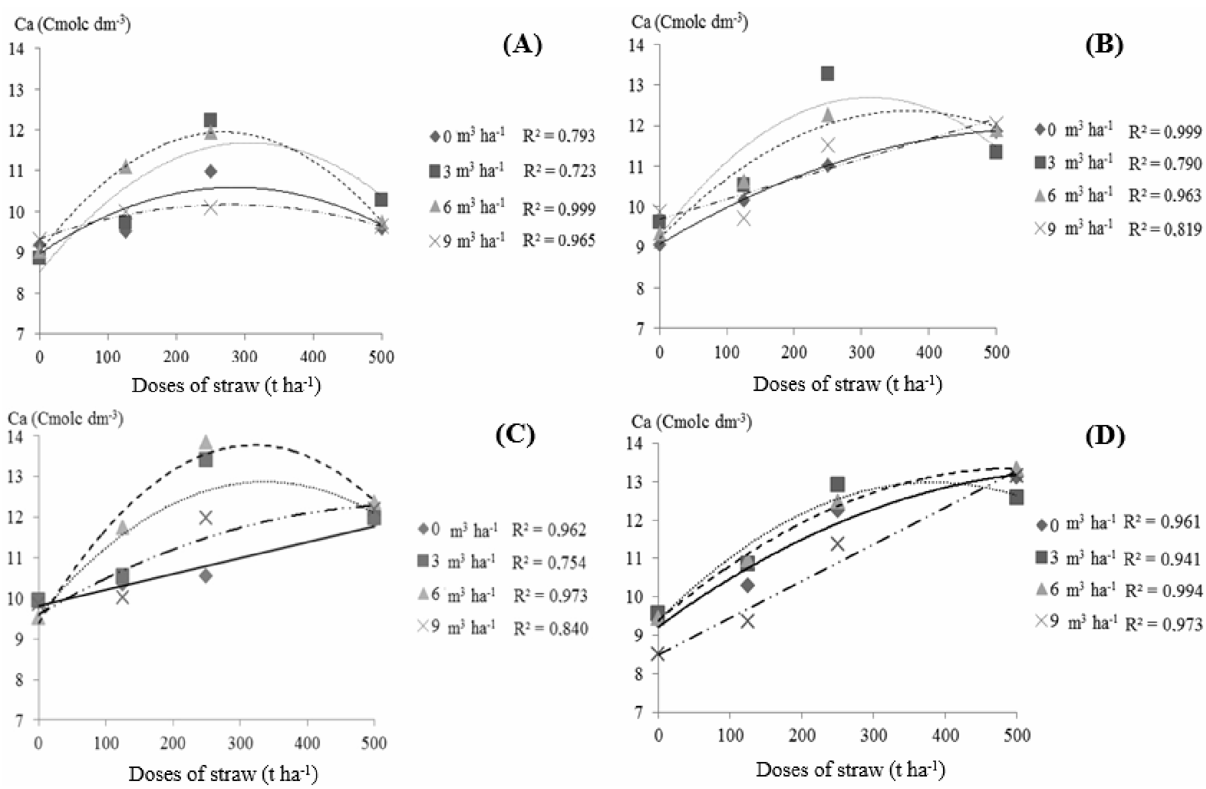
Barros et al. (2010) reported that the continuous application (10 years) of vinasse decreased the availability of micronutrients (copper, manganese, and zinc), thereby potentially compromising the yield. Medina et al. (2002) observed a decreased sugarcane yield when applying doses greater than 300 m^3 ha^{-1} vinasse. A similar finding was also observed by Zolin et al. (2011), who reported an increase in sugarcane crop yields until the third year of vinasse application and a decrease in productivity from 12 to 20 years of application of 150 m^3 ha^{-1} vinasse.

These results indicate that vinasse may promote improved soil fertility when applied to soils; however, when used for this purpose, the soil should be monitored and the application of vinasse should not exceed the ion retention capacity to prevent nutrient imbalances and consequent yield reductions.

Doses should be measured according to the characteristics of the soil because of the variations in the amounts of mineral and organic elements and because leaching of several of these ions, especially nitrate and potassium, may occur (SILVA et al., 2007) and can result environmental damage.

The highest calcium concentrations were observed in response to the application of 500 m^3 ha^{-1} vinasse, except in the 0-0.05 layer, with values of 11.0, 12.0, and 13.3 $cmol_c$ dm^{-3} for the 0.06-0.10, 0.11-0.20, and 0.21-0.30-m layers, respectively. The highest calcium concentrations were recorded above the 0.20-m depth when applying 300 m^3 ha^{-1} vinasse and 6 t ha^{-1} sugarcane straw, with increases to 12.0, 12.8, and 13.9 $cmol_c$ dm^{-3} for the 0-0.05, 0.06-0.10, and 0.11-0.20-m layers, respectively (Figure 6).

Figure 6. Straw application effect under vinasse doses on calcium concentration at 0 – 0.05 (A), 0.06 – 0.10 (B), 0.11 – 0.20 (C) and 0.21 – 0.30 m (D) depths.

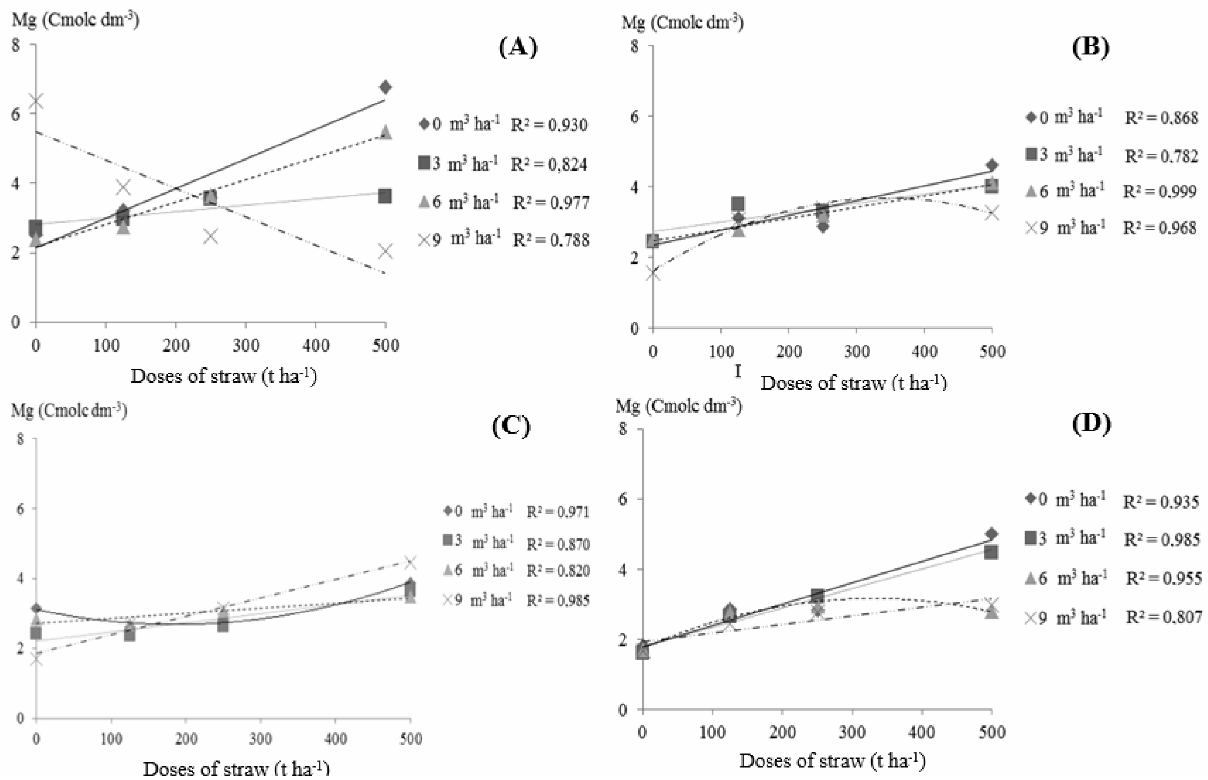


The application of the highest vinasse dose (500 m^3 ha^{-1}) promoted increases in the magnesium concentration to 6.8, 4.6, 3.9, and 2.7 cmolc dm^{-3} for the 0-0.05, 0.06-0.10, 0.11-0.20, and 0.21-0.30-m layers, respectively (Figure 7). When vinasse was applied together with sugarcane straw, magnesium leaching was also observed, particularly from the 0-0.05-m layer to the next deepest layer, and this effect was more marked for the dose of 9 t ha^{-1}, with magnesium accumulation occurring in the 0.11-0.20-m layer.

Despite the selectivity of inorganic soil surfaces for calcium and magnesium over potassium (FRANCHINI et al., 2003), the presence of the organic matter contained in vinasse and sugarcane straw alter their solubilities, promoting the distribution of these cations into the deepest soil layers (Figures 6 and 7).

These results corroborate the findings of Bebé et al. (2009), who assessed the effect of applying 300 m^3 ha^{-1} vinasse for several years to a depth of 1.5 m and observed increased calcium and magnesium concentrations in the soil profile, which were higher in the topsoil layers. Brito et al. (2007) also observed increased calcium and magnesium concentrations with an increase in vinasse when evaluating doses of 250 and 500 m^3 ha^{-1}. Canellas et al. (2003) applied vinasse doses of 120 m^3 ha^{-1} $year^{-1}$ for several consecutive years and observed increased calcium and magnesium concentrations in the topsoil and deep soil layers.

Figure 7. Straw application effect under vinasse doses on magnesium concentration at 0 – 0.05 (A), 0.06 – 0.10 (B), 0.11 – 0.20 (C) and 0.21 – 0.30 m (D) depths.

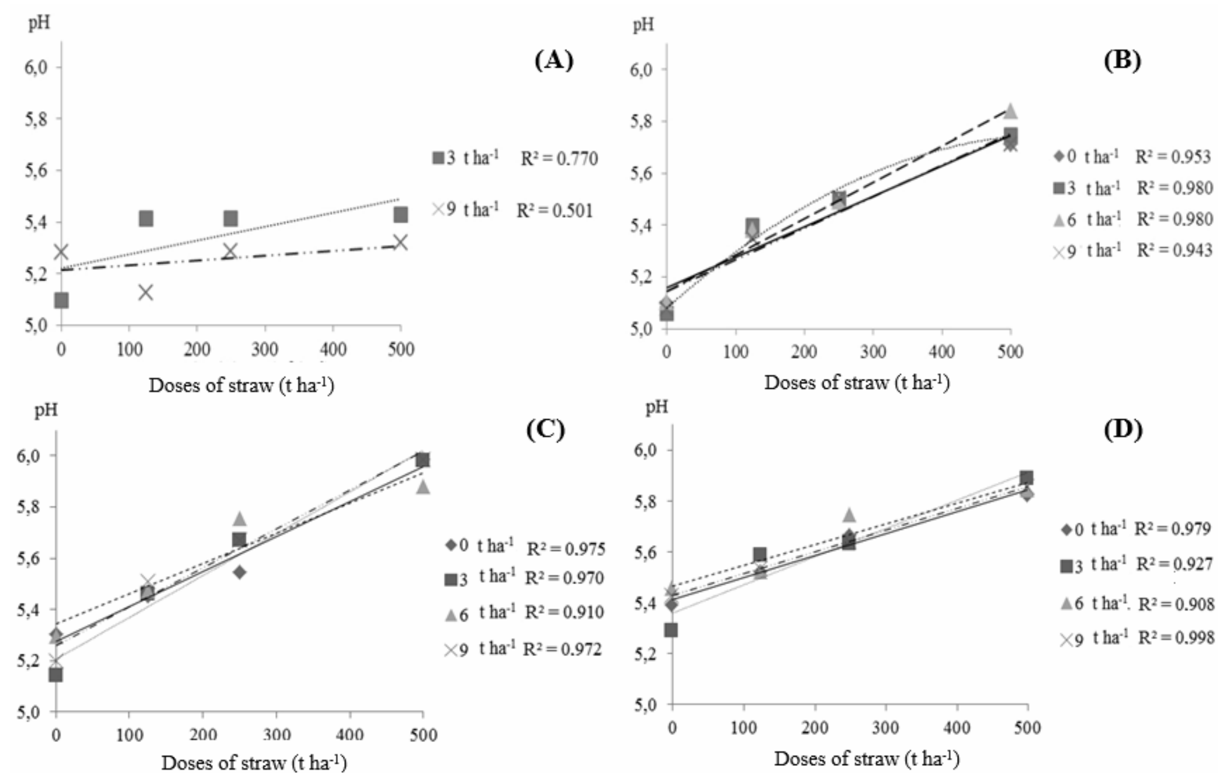


Vinasse had no significant effect on the pH of the 0-0.05-m layer (Figure 8), but it had a significant effect on the other layers with an increase in the dose, and the highest pH values were observed when applying 500 m^3 ha^{-1}. Although the pH remained below the adequate range for root growth, which is 6.5 (MEDINA, 1993), the increased pH resulting from the application of vinasse to the layer with the highest concentration of roots (0-0.25 m) (BALL-COELHO et al., 1992) is most beneficial to plant growth, expressed by the final yield.

The addition of sugarcane straw had a similar effect, increasing the pH at all doses applied (Figure 8). As soon as the organic matter contained in the vinasse is incorporated into the soil, it is colonized by fungi, which transform it into humus, neutralizing the acidity of the medium and thus increasing the soil pH (SILVA et al., 2007). Increases in pH in the deepest soil layers in response to vinasse applications have also been reported by Brito and Rolim (2003) and Brito et al. (2007).

Applying vinasse and maintaining sugarcane straw on the soil positively affect sugar production with gains in yield, indicating that both are essential to determining the crop yield and sucrose accumulation (RESENDE et al., 2006). Vinasse effectively meets the majority of plant nutrient demands in areas with low potassium concentrations, with greater effects when added together with sugarcane straw. Because of the variations in soil type and vinasse chemical composition, the results are quite variable across studies; however, there is agreement that its use should be based on the soil capacity to exchange and retain ions and that the local soil type, status, and applications of other residues must be considered because they affect the CEC and the soil storage and water infiltration capacities (SILVA et al., 2007).

Figure 8. Straw application effect under vinasse doses on soil pH at 0 – 0.05 (A), 0.06 – 0.10 (B), 0.11 –0.20 (C) and 0.21 – 0.30 m (D) depths.



A soil in chemical balance favors microbial reestablishment, which will also promote the degradation of sugarcane straw, thus releasing organic and inorganic constituents that will help in the conservation of this balance and promote good soil structure, essential conditions for good root growth and therefore plant growth.

Conclusions

Sugarcane straw increases soil potassium, calcium, and magnesium concentrations to a depth of 0.30 m and has no effect on pH at any depth.

Sugarcane straw applications enhance the effects of vinasse on the calcium, magnesium, and potassium concentrations and the pH across the soil profile.

The most effective vinasse dose is 300 m^3 ha^{-1}, applied together with 6 t ha^{-1} sugarcane straw.

The application of vinasse and sugarcane straw to a dystroferric Red Nitosol with a high base saturation promoted improved soil fertility, with increases in the soil Ca, Mg, and K concentrations and the soil pH. However, cation imbalances may occur in soils with high levels of potassium saturation, particularly in the top soil layers.

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