SUGARCANE GROWN IN AN OXISOL AMENDED WITH SEWAGE SLUDGE AND VINASSE: NITROGEN CONTENTS IN SOIL AND PLANT

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ABSTRACT: Sewage sludge is a residue from waste water treatment plants and vinasse is a main effluent from alcohol distilleries. The main differences between them are observed in the nitrogen (N) and potassium (K) contents. Sewage sludge is poor in K, and the vinasse in N. This research was carried out to evaluate sewage sludge and vinasse effects on the nitrogen contents of the plant-soil system and the effects of their application on planted-cane and 1st. ratoon-cane under field conditions, on a Typic Haplustox, in Pontal, State of São Paulo, Brazil, using the sugarcane cultivar SP81-3250. A randomized blocks experimental design was used with 13 treatments and three replications. The results were organized in a 3 × 2 × 2 factorial scheme (three residue forms, two application modes and two rates of N or K) and a control treatment (mineral fertilization). Sewage sludge provided the highest N plant contents and the highest residual N soil contents. Sewage sludge and vinasse can replace mineral fertilization for both planted-cane and 1st. ratoon-cane.
Key words: agricultural reuse, residue, productivity, vinasse, sludge

CANA-DE-AÇÚCAR CULTIVADA NUM LATOSSOLO QUE RECEBEU LODO DE ESGOTO E VINHAÇA: TEORES DE NITROGÊNIO NO SOLO E NA PLANTA

RESUMO: O lodo de esgoto é um resíduo obtido em Estações de Tratamento de Esgoto. A vinhaça constitui-se no principal efluente das destilarias de álcool. A principal diferença entre ambos está nos conteúdos de nitrogênio (N) e potássio (K), sendo o lodo de esgoto pobre em K e a vinhaça pobre em N. O objetivo deste trabalho foi avaliar o efeito do lodo de esgoto e da vinhaça sobre o nitrogênio no sistema solo-planta e os reflexos na produtividade da cana-de-açúcar por dois anos consecutivos. O experimento foi conduzido em um Latossolo Vermelho Amarelo Distrófico plintico, localizado no Município de Pontal, SP. A cultivar de cana-de-açúcar testada foi a SP81-3250. Os fatores de estudo foram três resíduos (lodo de esgoto, vinhaça e lodo de esgoto+vinhaça), dois modos de aplicação (linha de plantio e área total), duas doses (100 e 200% do N e K necessários à cultura) e um tratamento testemunha (adubação mineral). O lodo de esgoto proporcionou maior acúmulo de N na planta e maior teor residual de N no solo. A aplicação de lodo de esgoto e vinhaça na cultura da cana-de-açúcar pode substituir a adubação mineral, tanto para cana-planta quanto para cana-soca.
Palavras-chave: reuso agrícola, resíduo, produtividade, vinhoto, esgoto

INTRODUCTION

The municipal waste water treatment produces a gummy material, consisting of organic matter, water and mineral elements, called sewage sludge. About 33 to 50% of the total nitrogen from the sewage sludge is available to plants in the first year after soil amendment (Marques, 1996). Soil nitrogen suffers rapid alterations in the soil depending on organic matter content, aeration, moisture, temperature and nutrients, and therefore it is very difficult to estimate soil nitrogen availability to plants, several evaluation methods being in discussion (Gianello et al., 2000). For sewage sludge it is very important to know the rate of transfer of its nitrogen to plants in order to reduce application rates and diminish the risk of environmental pollution.

Vinasse is a residue from alcohol distilleries generated in great amounts (12-15 liters per liter of alcohol), containing water, organic matter, macronutrients, mainly K, and other trace elements (Rosseto, 1987).

The area cropped with sugarcane (*Saccharum* spp.) in Brazil is about 6 million hectares and most of them are suitable to receive residues. Sugarcane producers know how to use residues with low risks to the environment. The sugarcane crop undergoes mainly the industrialization process, which diminishes the direct risk to man and animal health and to environment pollution. The objective of this study was to evaluate the use of residues, alone or combined, as sources of N and K for the sugarcane plant, focusing the effects of rates and application forms on yield, soil and plant N, also considering the transfer rate of the nutrients from the sewage sludge to the sugarcane plant.

MATERIAL AND METHODS

The experiment was set up on April 7, 2000, in Pontal, São Paulo State, Brazil (21º01' S, 48º02' W, 515 m altitude), on a Typic Haplustox with the following chemical characteristics: pH ($CaCl_2$ 0.01 mol L^{-1}) = 5.0, organic matter (OM) = 25 g dm^{-3}, Kjeldahl-N= 1.31 g kg^{-1}, P = 20 mg dm^{-3}, K = 1.2 $mmol_c$ dm^{-3}, Ca = 20 $mmol_c$ dm^{-3}, Mg = 6 $mmol_c$ dm^{-3}, H+Al = 28 $mmol_c$ dm^{-3}. The area used in this experiment was under rest during the last ten years.

The sugarcane cultivar used as test plant was the SP81-3250. Sewage sludge presented the chemical composition shown in Table 1. Vinasse came from wine distillation made in a conventional distillation apparatus and analyzed by the same methods used for the sewage sludge. Its chemical composition is shown in Table 1.

The treatments resulted from the combination of three types of amendments: sewage sludge, vinasse and sewage sludge + vinasse; two application methods: in the planting furrow for the planted-cane or spread on the soil surface at the side of the plants for the 1st ratoon-cane, and spread on the total area for both the croppings; and two application rates: sewage sludge to supply 100 and 200% of the nitrogen requirement and vinasse to supply 100 and 200% of the potassium requirement. A control treatment was also used, which received limestone and mineral fertilization according to Raij et al. (1996). The other nutrients were supplied by mineral fertilization. The experiment was installed in a randomized block design arranged in a 3 × 2 × 2 factorial scheme, with an additional control and three replications. Each experimental plot contained five 10 m long sugarcane rows spaced by 1.50 m and the useful area was formed by the three central rows, discarding 1 m at each row end.

The equivalent rates corresponded to 5 and 10 t ha^{-1} sewage sludge (dry basis), 115 and 230 m^3 ha^{-1} of vinasse for the palnted-cane; 7 and 14 t ha^{-1} sewage sludge (dry basis), 117 and 234 m^3 ha^{-1} vinasse for the 1st ratoon-cane. For the 1st ratoon-cane, the rates were calculated based on soil the chemical analysis made after the planted-cane harvest in the control treatment, which was: pH ($CaCl_2$) = 4.7; OM = 24 g dm^{-3}; P = 10 mg dm^{-3}; K = 0.8 $mmol_c$ dm^{-3}; Ca = 25 $mmol_c$ dm^{-3}; Mg = 7 $mmol_c$ dm^{-3}; H+Al = 64 $mmol_c$ dm^{-3}. The plots of the 1st ratoon-cane control were limed with 1.8 t ha^{-1} dolomitic limestone. The treatments with sewage sludge alone were complemented with K (potassium chloride) and the treatments with vinasse alone were complemented with nitrogen (urea).

Plants were sampled for chemical analysis in June, 28, 2001 (planted-cane) and August, 3, 2002 (ratoon-cane) collecting three plants from the useful area. Plants were washed, separated in leaves, stalk and heart, and weighed. The stalks were shredded, homogenized and samples were dried in a forced air oven at 60-70°C until constant weight, weighed, ground and analyzed for Kjeldahl-N (Sarruge & Haag, 1974).

For harvest, the plants in the useful area of the plots were burnt (as usually done in Brazilian tradicional harvests), harvested (July, 5, 2001 for the planted-cane and August, 8, 2002 for the 1st ratoon-cane) and weighed. The sugarcane yield was obtained adding to this weight the weight of the stalks collected for chemical analysis. Soil samples were collected after harvest on the planting rows and between-rows, at the depths 0-20, 20-40 and 40-60 cm, air dried, sieved (2 mm) and analyzed for Kjeldahl-N (Melo, 1974).

The transfer rate of nitrogen from the sewage sludge to the sugarcane; (T%) was estimated by:

Table 1 - Chemical composition of the sewage sludge and the vinasse

Residue	N	P	K	Ca	Mg	Cu	Mn	Zn	Fe
Sewage sludge	----------	----------	g kg^{-1}	----------	----------	----------	mg kg^{-1}	----------	----------
Planted-cane	79.5	10.6	0.63	nd	nd	225	400	1,000	26,391
1st ratoon-cane	52	3.4	1.96	4.25	0.56	380	98	658	29,350
Vinasse	----------	----------	----------	----------	mg L^{-1}	----------	----------	----------	----------
Planted-cane	0.35	0.13	1.39	0.42	0.07	0.17	4.48	0.82	59.89
1st ratoon-cane	0.29	0.20	1.11	0.85	0.22	0.12	4.21	0.76	63.42

nd = not determined.

$$T\% = \frac{Nc}{Ns + Nl - Nr} * 100 \quad (1)$$

where Nc = plant nitrogen (kg ha^{-1}); Ns = soil nitrogen before sewage sludge application (kg ha^{-1}); Nl = nitrogen added by sewage sludge (kg ha^{-1}); Nr = soil nitrogen after sugarcane cropping (kg ha^{-1}).

To calculate sugarcane nitrogen only the contents of the stalk were considered. The data were submitted to the variance analysis (F test) and the Tukey test was used for mean comparison ($p < 0.05$) when the F test was significant.

RESULTS AND DISCUSSION

Soil nitrogen

The residual Kjeldahl-N after planted-cane cropping (Table 2) was not affected by the treatments in all positions or sampling depths, as also reported by Oliveira (2000). Considering that 55% of the sugarcane roots are located in a 30 cm radius from the planting line (Sampaio et al., 1987), it was expected that the residual N should be higher between lines, a fact that was really observed. Kjeldahl-N ranged from 597 mg kg^{-1} (40-60 cm layer) to 1190 mg kg^{-1} (0-20 cm layer) for samples from between rows. Oliveira et al. (2001) also found a decrease in total-N with soil depth in an Oxisol. Lara Cabezas et al. (1994) applied vinasse and urea to an Oxisol and an Ultisol and found total-N contents ranging from 167 to 563 mg kg^{-1}, highlighting the importance of the nature of the soil on total-N content.

The lack of differences among residue types and application methods suggested that the mineral fertilization of planted-cane could be completely replaced by correctly applied residues.

The nutrients in the residues were in the organic form, so that they become available to plants only after mineralization. The residual contents of N in the samples collected on the planting rows were not different among treatments, regardless of the depth. This suggests that for the treatments that received higher levels of waste the losses of N were higher despite the fact that the N concentration in the stalks of the plants that received more N were also higher (Table 4). This behavior is different from that observed by

Table 2 - Kjeldahl-N in soil samples after applying sewage sludge and vinasse to planted-cane.

	Row			Between-rows		
	Depth (cm)					
Factors	0-20	20-40	40-60	0-20	20-40	40-60
	mg kg^{-1}					
Control (C)	1,013	1,013	835	1,190	882	597
Factorial (F)	935	933	865	1,089	1,009	658
Sewage Sludge (SS)	991	963	886	1,077	1,054	674
Vinasse (V)	979	981	821	1,049	991	659
SS + V	837	855	889	1,141	984	639
Furrow	919	933	887	1,059	1,033	640
Total Area	952	933	844	1,118	985	675
100% rate	940	954	878	1,038	1,020	635
200% rate	931	912	852	1,140	999	681
Statistic (F test)						
Blocks	1.02^{NS}	1.17^{NS}	0.07^{NS}	0.16^{NS}	1.00^{NS}	5.31^{NS}
F × C	0.44^{NS}	0.50^{NS}	0.07^{NS}	0.68^{NS}	1.78^{NS}	1.09^{NS}
Residues (R)	2.37^{NS}	1.59^{NS}	0.52^{NS}	0.65^{NS}	0.71^{NS}	0.40^{NS}
Application Mode (AM)	0.27^{NS}	0.00^{NS}	0.49^{NS}	0.76^{NS}	0.81^{NS}	1.20^{NS}
Rates (Rt)	0.02^{NS}	0.44^{NS}	0.18^{NS}	2.28^{NS}	0.16^{NS}	2.06^{NS}
R × AM	1.85^{NS}	1.54^{NS}	1.45^{NS}	0.34^{NS}	0.41^{NS}	0.04^{NS}
R × Rt	0.37^{NS}	0.16^{NS}	0.74^{NS}	0.47^{NS}	0.01^{NS}	0.90^{NS}
AM × Rt	0.43^{NS}	0.62^{NS}	2.30^{NS}	0.61^{NS}	0.86^{NS}	0.10^{NS}
R × AM × Rt	1.63^{NS}	3.08^{NS}	0.01^{NS}	0.13^{NS}	0.11^{NS}	1.68^{NS}
CV (%)	20.51	19.92	21.22	18.58	15.85	14.70

NS - not significant.

Table 3 - Kjeldahl-N in soil samples collected after applying sewage sludge and vinasse to 1st ratoon-cane.

Factors	Row			Between-rows		
	Depth (cm)					
	0-20	20-40	40-60	0-20	20-40	40-60
	mg kg^{-1}					
Control (C)	859	985	535	1.055	974	513
Factorial (F)	1,187	955	587	1,077	965	553
Sewage sludge (SS)	1,275^{A}	963	558^{B}	1,118	922	533
Vinasse (V)	974^{B}	911	484^{B}	1,054	912	527
SS + V	1,311^{A}	991	720^{A}	1,061	981	599
Side of the plants	1,324^{A}	990	639	1,069	976	546
Total area	1,050^{B}	919	535	1,085	922	560
100% rate	1,109	858	533	1,022	902	515
200% rate	1,265	1,052	642	1,132	1,065	591
Statistic (F test)						
Blocks	0.13^{NS}	8.36**	2.58^{NS}	2.55^{NS}	1.69^{NS}	0.87^{NS}
F × C.	5.76*	0.06^{NS}	0.20^{NS}	0.02^{NS}	0.44^{NS}	0.40^{NS}
Residues (R)	7.94**	0.46^{NS}	4.07*	0.23^{NS}	0.82^{NS}	1.74^{NS}
Application (AM)	13.03**	1.06^{NS}	2.28^{NS}	0.03^{NS}	2.39^{NS}	0.16^{NS}
Rates (Rt)	4.21^{NS}	7.95**	2.49^{NS}	1.73^{NS}	1.20^{NS}	4.85^{NS}
R × AM.	4.68*	0.43^{NS}	1.51^{NS}	1.83^{NS}	0.61^{NS}	0.83^{NS}
R × Rt	1.99^{NS}	0.82^{NS}	2.37^{NS}	0.09^{NS}	0.12^{NS}	1.27^{NS}
AM. × Rt	0.20^{NS}	1.21^{NS}	0.40^{NS}	0.03^{NS}	1.33^{NS}	0.58^{NS}
R. × AM × Rt	0.08^{NS}	2.99^{NS}	1.12^{NS}	1.82^{NS}	5.03^{NS}	0.44^{NS}
VC (%)	19.58	21.52	35.51	23.45	12.04	18.88

NS not significant; *significant at $p < 0.05$;** - significant at $p < 0.001$.

Table 4 - Kjeldhal-N in different parts of plants treated with combinations of sewage sludge and vinasse.

Factors	Planted-Cane			1st Ratoon-Cane		
	Leaves	Stalks	Hearts	Leaves	Stalks	Hearts
	g kg^{-1}					
Control	9.06	2.36	20.97	12.17	3.29	23.34
Factorial	8.62	2.18	23.62	12.14	3.32	22.21
Sewage sludge (SS)	8.77	2.28	22.32	12.51	3.42	23.43
Vinasse (V)	8.50	2.15	23.92	11.57	3.33	21.00
(SS) + (V)	8.60	2.12	24.91	12.33	3.20	22.20
Furrow/Side of the plants	8.50	2.16	21.51	12.34	3.51	21.93
Total area	8.75	2.21	25.73	11.93	3.13	22.49
100% rate	8.44	1.91^{B}	21.75	12.02	3.50	21.81
200% rate	8.81	2.46^{A}	25.49	12.25	3.13	22.61

Araújo et al. (2001), who reported no reduction in the mineralization potential in a study of 10 years.

After the 1st ratoon-cane cropping, Kjeldahl-N in the planting row of the control treatment tended to be lower at 0-20 cm compared to 20-40 cm (Table 3), probably caused by the greater concentration of the roots at that depth (Sampaio et al., 1987) associated to a greater mineralization rate of the organic-N in the surface layers (Salcedo et al., 1985) and a possible N leaching. Kjeldahl-N between-rows tended to increase, because the exploration of this area by sugarcane roots is less intense even in the top soil and decreased in the deeper layers, as similarly found after planted-cane cropping.

Soil N after the 1st ratoon-cane cropping varied from 513 mg kg^{-1} (between rows, 40-60 cm depth) to 1,187 mg kg^{-1} (on planting rows, 0-20 cm depth). Similar results were obtained by Oliveira et al. (2001) after planted-cane cropping.

The highest Kjeldahl-N in the planting rows after the ratoon-cane cropping occurred in the treatments with sewage sludge or sewage sludge+vinasse. This is expected since for calculating the rates of sewage sludge to be applied only 1/3 of the N was considered to be mineralized (Berton, 2000) in the first year. In this way, and considering that 10-20% of the N from the first application was mineralized during the ratoon-cane development (Andreoli et al., 1997), at least the double of the N required for sugarcane growth would remain in the soil.

Residual N, when the residues were applied into or at the side of planting rows, was higher than when the application was on the total area. This can be explained by the fact of this localized form of residue application which concentrates the nutrient at the sampling place. It may be considered that this N will be, at least in part, absorbed by the next ratoon-cane, since it is in the root zone, a decisive factor according to Sampaio et al. (1987).

Plant nitrogen

N in the different parts of the plants was not affected by the type and form of residue application, but the rates affected the content in the stalks (Table 4). In an experiment with sewage sludge, Dias (1994) found higher N content in plants treated with the residue as compared to plants treated with mineral fertilizers.

Leaf N contents in the planted-cane ranged from 8.6 and 9.0 g kg^{-1} and around 12.1 g kg^{-1}, in the 1st ratoon-cane. In a study with sewage sludge application, Marques (1996) applied rates of 0, 10, 20 and 40 t ha^{-1} of sewage sludge (dry basis) and reported leaf N contents between 7.0 and 8.2 g kg^{-1} for planted-cane. Silva et al. (1998) reported that the N content determined in the +3 leaf was 8.5 g kg^{-1} for the 1st ratoon-cane.

The N contents in the stalks varied between 2.18 and 2.36 g kg^{-1} the planted-cane and between 3.13 to 3.3 g kg^{-1} in the 1st ratoon-cane. Marques (1996) reported contents between 1.3 and 2.2 g kg^{-1} in a study with increasing rates of sewage sludge. According to Humbert (1984), the critical N level in this part of the plant is 2.5 g kg^{-1} and that values up to 60 g kg^{-1} are considered normal. In the hearts, the detected values for N oscillated form 21 to 23.6 g kg^{-1} in planted-cane and from 22.2 to 23.34 g kg^{-1} in 1st ratoon-cane, which are higher than those reported by Marques (1996).

In planted-cane, the content of N in the different parts of the plant tended to be higher when the residues were applied on the total area, while in the 1st ratoon-cane this tendency occurred when the residues were applied in the planting rows (Table 4). This behavior is explained by the poorer root system of the 1st ratoon-cane, which depends on the proximity of the fertilizer for its absorption (Carnauba, 1990).

N accumulated in planted-cane stalks was not affected by the treatments but in the 1st ratoon-cane it was higher when sewage sludge was applied (Figure 1). N assimilation was greater when the residues were applied at the side of the planting rows (1st ratoon-cane) as compared to the application on total area, confirming the weak root system vigor of the 1st ratoon-cane, which is more dependent on the proximity of the applied fertilizers (Carnaúba, 1990).

Soil-plant system nitrogen

Considering the initial soil Kjeldahl N content of 2,616 kg ha^{-1} in the 0.0-0.20 m layer and through the equation (1), and based on the data presented in the Tables 1, 2, 3, 4 and 5, the N transfer rate (T%) was estimated for the planted-cane and 1st ratoon-cane plants: 33.11 and 16.40%, respectively. Trivelin (2000) assessed the contribution of the nitrogen fertilizer to planted-cane with the use of ^{15}N, and ascertained that mineral fertilization represented 11.5% of the total N accumulated by the plant. Values lower than 10% were

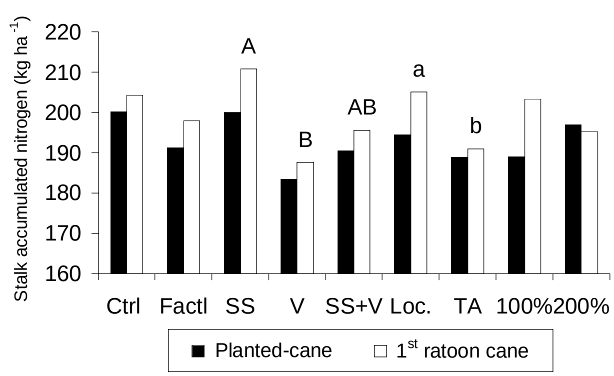

Figure 1 - Kjeldahl-N accumulated in sugarcane plants cultivated in soil amended with sewage sludge and vinasse.

Ctrl – control, Factl – mean of the plots in the factorial design, SS – sewage sludge, V – vinasse, SS + V – sewage sludge + vinasse, Loc – located application, TA – total area application, 100 % (NK=100 %), 200% (NK=200%). Uppercase compares types of residues and lowercase compares application methods (Tukey's test, $p < 0.005$).

reported by Sampaio et al. (1987). Carnaúba (1990) and Gava et al. (2001) also used ^{15}N and ascertained that for 1st ratoon-cane the contribution of the fertilizer to sugarcane nitrogen was 14 and 22%.

The results let us to conclude that the method used to estimate the contribution of sewage sludge to sugarcane was very simple and agreed with the more complex and expensive methods as those that use ^{15}N. Finally, the tested residues, except vinasse alone, showed a potential supply to all the nitrogen required by the crop, independently of the application form or rate.

Yield

The mean yield for planted-cane and the 1st ratoon-cane were 125.5 and 100.0 t ha^{-1}, respectively (Table 5), as expected for this cultivar (Copersucar, 1995). Planted-cane yield was not affected by the studied factors, that is, there was no difference between mineral fertilization and any of the residue combinations. Similar results were obtained by Marques (1996), who applied 10, 20 and 40 t ha^{-1} sewage sludge (dry basis), and Oliveira (2000), who applied 33, 66, and 99 t ha^{-1} sewage sludge.

Yield was higher for the 1st ratoon-cane when sewage sludge was applied (sewage sludge and sewage sludge + vinasse), a fact that could be attributed to the greater N accumulation in the plant (Figure 1), by the high potential of the sewage sludge to supply N and to the greater residual N accumulation in the soil (Table 3), reflecting a positive response from the nitrogen application through sewage sludge. Similar results were obtained by Silva et al. (1998). No characteristic symptoms of nitrogen deficiency (yellow older leaves) were observed in any of the treatments for the planted-cane and the 1st ratoon-cane. Thus, sewage sludge was able to supply plant N requirements.

Table 5 - Sugarcane yield when cropped in two consecutive years in a soil amended with sewage sludge and vinasse.

	Planted-Cane	1st Ratoon-Cane
	------------ Mg ha^{-1} -----------	
Control	125.7	105.6
Factorial	125.5	100.0
Sewage sludge (SS)	124.0	106.6^{A}
Vinasse (V)	125.9	94.3^{B}
SS + V	126.5	99.3^{AB}
Furrow/Side of the plants	125.8	99.7
Total area	125.2	100.3
100% rate	124.6	98.2
200% rate	126.4	101.9

*Uppercase compares means in the same column by the Tukey test at $p < 0.005$.

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