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Carbon and nitrogen cycling in a tropical Brazilian soil cropped with sugarcane and irrigated with wastewater

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ABSTRACT

Carbon (C) and nitrogen (N) dynamics in agro-systems can be altered as a consequence of treated sewage effluent (TSE) irrigation. The present study evaluated the effects of TSE irrigation over 16 months on N concentrations in sugarcane (leaves, stalks and juice), total soil carbon (TC), total soil nitrogen (TN), NO_3^--N in soil and nitrate (NO_3^-) and dissolved organic carbon (DOC) in soil solution. The soil was classified as an Oxisol and samplings were carried out during the first productive crop cycle, from February 2005 (before planting) to September 2006 (after sugarcane harvest and 16 months of TSE irrigation). The experiment was arranged in a complete block design with five treatments and four replicates. Irrigated plots received 50% of the recommended mineral N fertilization and 100% (T100), 125% (T125), 150% (T150) and 200% (T200) of crop water demand. No mineral N and irrigation were applied to the control plots. TSE irrigation enhanced sugarcane yield but resulted in total-N inputs (804–1622 kg N ha^{-1}) greater than exported N (463–597 kg N ha^{-1}). Hence, throughout the irrigation period, high NO_3^- concentrations (up to 388 mg L^{-1} at T200) and DOC (up to 142 mg L^{-1} at T100) were measured in soil solution below the root zone, indicating the potential of groundwater contamination. TSE irrigation did not change soil TC and TN.

1. Introduction

Treated sewage effluent (TSE) is increasingly used as a source of water and nutrients (mainly nitrogen) in crop production in Brazil (da Fonseca et al., 2007a). However, the country lacks a long-term tradition on the agricultural use of such residues, so that national legal regulations and general guidelines for its sustainable application are still in development. For these reasons, scientific experimentation concerning the major implications of effluent irrigation under the local tropical conditions is highly required, in order that TSE may be used as part of a rational and sustainable agricultural planning.

Carbon (C) and nitrogen (N) cycling in agro-systems can be altered by TSE irrigation, mainly in the long-term (da Fonseca et al., 2007a). Several studies have shown increased total carbon (TC) and total nitrogen (TN) contents in the soil due to C and N input by TSE irrigation (Friedel et al., 2000; Ramirez-Fuentes et al., 2002). Other studies have found decreased contents of soil TC and TN (Speir et al., 1999; Snow et al., 1999), mainly attributed to enhanced mineralization and nitrification processes under effluent irrigation (da Fonseca et al., 2007a).

Of greater concern, increasing concentrations of nitrate (NO_3^-) in soil solution due to TSE irrigation have often been reported (Polglase et al., 1995; Smith and Bond, 1999), representing one of the main challenges for the sustainable land application of effluents (Bond, 1998; da Fonseca et al., 2007a). Also increases in dissolved organic carbon (DOC) in soil solution were reported after effluent irrigation (Bhandral et al., 2007; Gloaguen et al., 2007). The DOC fraction represents an important indicator of soil quality (Silveira, 2005) and may play an important role as a carrier of metals and pollutants in the soil profile due to its high mobility (Ciglasch et al., 2004).

Sugarcane (*Saccharum* spp.) may represent an attractive crop for TSE irrigation in Brazil, because of the following characteristics:

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(i) predominance of non-irrigated plantations with large potential for the adoption of irrigation practices; (ii) high demand of N (one of the main nutrient in TSE); (iii) perennial crop fitted to full mechanization, without direct contact to farm workers; (iv) major commodity for ethanol production in Brazil. These characteristics may result in agronomic, economic and environmental benefits, however, detailed studies on TSE irrigation in sugarcane agro-systems are lacking.

The purpose of this study was to evaluate the effects of short term TSE irrigation (16 months) on N uptake by sugarcane, N and C accumulation in soil and NO_3^- and DOC leaching.

2. Materials and methods

The experimental area is situated near the city of Lins, State of São Paulo (longitude: 49°50′W; latitude: 22°21′S; average altitude of 440 m), Brazil, adjacent to the municipal wastewater treatment plant (stabilization ponds system). Mean annual temperature is 23 °C and precipitation was 1292 mm during the experimental period (16 months). Monthly rainfall and the amounts of TSE applied as irrigation throughout the experiment are presented in Fig. 1. The soil was classified as Typic Haplustox (Soil Survey Staff, 1999), sandy clay loam. The soil mineralogy of the area is dominated by quartz and kaolinite, and subordinately by hematite, magnetite and/or maghemite. The dominance of these minerals, commonly occurring in highly weathered and acid tropical soils, results in low cation exchange capacity (CEC) (Table 1).

The chemical and physical soil characteristics found at the beginning of the experiment (Table 1) are usual for most Brazilian agro-systems cropped with sugarcane. Available calcium (Ca), magnesium (Mg), potassium (K) and phosphorus (P) were found in adequate concentrations for sugarcane growth due to previous liming and addition of mineral fertilizers at the beginning of the experiment.

Sugarcane was planted in March 2005 with a distance of 1.4 m between the rows. TSE irrigation was carried out from May 2005 till August 2006 (16 months). After this period irrigation was stopped because sugarcane needs water stress before harvest in order to concentrate sugar. Plants were irrigated when Ψ_m were less than −40 kPa. Harvest took place at the end of September 2006. Concerning mineral fertilizer application, all experimental plots received 15 kg ha^{-1} of N (ammonium nitrate, 50% of recommended mineral N), except the control plot; 52 kg ha^{-1} of P (simple superphosphate), and 66 kg ha^{-1} of K (potassium chloride), distributed manually to the furrows during planting.

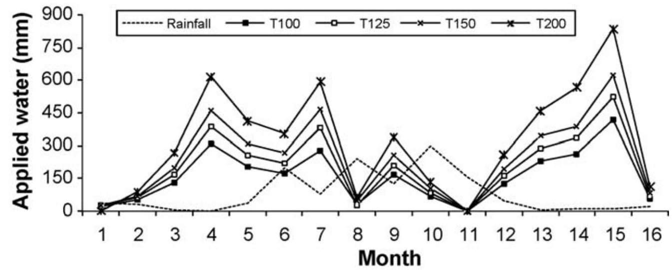

Fig. 1. Monthly amounts of applied water (rainfall and wastewater irrigation) during the experimental period. Month 1 corresponds to May 2005 and month 16 to August 2006. T100, T125, T150 and T200: Treated sewage effluent irrigation (TSE) supplying 100% (0% surplus), 125% (25% surplus), 150% (50% surplus) and 200% (100% surplus) of crop water demand.

Detailed information about irrigation and crop management are available in a previous work (Leal et al., 2009).

The experiment was arranged in a complete block design, with five treatments and four replications. The treatments consisted of: (i) control, without TSE irrigation and N fertilization; (ii) T100, T125, T150 and T200, with TSE irrigation supplying 100% (0% surplus), 125% (25% surplus), 150% (50% surplus) and 200% (100% surplus) of crop water demand, respectively. Total plot size was 280 m^2 (40 m × 7 m) with a useful area of 126 m^2.

The effects of effluent irrigation on carbon and nitrogen dynamics were evaluated by considering two application scenarios: (i) land application of TSE rates higher than 100% of crop water requirement (T125, T150 and T200) as a TSE disposal alternative, and (ii) TSE application according to crop water requirement (T100) to enhance agricultural production through the provision of water and nutrients.

Data about TSE constituents were taken from a previous detailed effluent characterization (da Fonseca et al., 2007b) because TSE quality has not changed considerably during the last five years (Leal et al., 2009). In average, TSE is characterized by: pH of 7.7; total-N concentration of 31.9 mg L^{-1}; 22.4 mg L^{-1} of NH_4^+-N (predominant N form); 0.6 mg L^{-1} of NO_3^--N; 65.28 mg L^{-1} of dissolved organic carbon (DOC); 301 mg L^{-1} of bicarbonate (HCO_3^-); 146 mg L^{-1} of Na and a sodium adsorption ratio (SAR) of 11.9 (mmol L^{-1})$^{0.5}$.

The total-C and total-N inputs to the soil–plant system via TSE irrigation (16 months) were calculated for each treatment. As a result, 4500, 5690, 6830 and 8430 kg ha^{-1} of total-C and 800, 1020,

Table 1
Chemical and physical soil properties at the beginning of the experiment (March 2005).

Layer (m)	pH	H + Al (mmol$_c$ kg^{-1})	Al (mmol$_c$ kg^{-1})	Ca (mmol$_c$ kg^{-1})	Mg (mmol$_c$ kg^{-1})	K (mmol$_c$ kg^{-1})	Na (mmol$_c$ kg^{-1})	CEC[a] (mmol$_c$ kg^{-1})	P (mg kg^{-1})	TC[b] (g kg^{-1})	TN[c] (g kg^{-1})
0–0.1	5.1	15.4	0.9	12.7	3.5	3.0	0.7	35.4	17.3	6.0	0.5
0.1–0.2	5.2	15.0	0.8	13.2	3.6	2.4	1.5	35.6	15.5	6.4	0.5
0.2–0.4	4.9	15.9	1.8	10.2	3.6	1.8	2.5	34.0	4.1	5.1	0.4
0.4–0.6	4.6	21.8	4.0	6.2	2.3	1.2	2.8	34.3	1.0	4.1	0.3

Layer (m)	BS[d] (%)	ESP[e] (%)	B (mg kg^{-1})	Cu (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	EC[f] (dS m^{-1})	Sand (g kg^{-1})	Silt (g kg^{-1})	Clay (g kg^{-1})
0–0.1	56.3	2.1	0.6	0.5	21.5	3.0	1.2	0.7	774	90	135
0.1–0.2	57.9	4.1	0.6	0.7	20.9	2.7	1.5	0.4	775	78	147
0.2–0.4	53.3	7.4	0.6	0.3	15.5	1.7	0.3	0.2	732	75	192
0.4–0.6	36.5	8.1	0.4	0.5	10.4	1.2	0.2	0.2	707	65	227

[a] Cation exchange capacity at pH 7.0 → CEC = Ca + Mg + K + Na + H + Al.
[b] TC = total carbon.
[c] TN = total nitrogen.
[d] Base saturation → BS = (Ca + Mg + K + Na) × 100/CEC.
[e] Exchangeable sodium percentage → ESP = Na × 100/CEC.
[f] EC = electrical conductivity.