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Maize Growth and Changes in Soil Fertility After Irrigation with Treated Sewage Effluent. I. Plant Dry Matter Yield and Soil Nitrogen and Phosphorus Availability

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Abstract: The objectives of this research were to 1) verify the potential use of the secondary-treated sewage effluent (STSE) as a source of water and nitrogen for maize and 2) evaluate nitrogen (N) and phosphorus (P) concentrations in soil, as well as their concentrations and contents in maize plants, treated with STSE. The treatments consisted of mineral fertilization and irrigation with the STSE, during 58 days. After this period, plants were harvested and processed for dry matter yield, and plant and soil analysis were realized. No variation in total carbon and P soil concentration was observed, but total nitrogen increased. Mineral fertilization plus STSE irrigation increased the plant's P content, but without any effect on dry matter yields. The STSE could completely substitute the water from irrigation, but it provided only part of the demanded nitrogen and other nutrients for the maize plants in the treatments with no mineral fertilizer added.

Keywords: *Zea mays* L., sewage residues, sewage effluent, source of nutrients, soil disposal

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INTRODUCTION

The wastewater and sewage treatment in stabilization ponds has been a widely used practice in small to medium size municipal districts (Feigin et al. 1991), like the countryside towns of the State of São Paulo (Brazil). This technique for sewage treatment originates two residue types: the biosolid (sewage sludge) and the treated sewage effluent (TSE). The sewage sludge, which is not the object of this research work, has been used in agriculture as a soil conditioner and a source of nutrients, mainly N and P (Cameron et al. 1997). However, the TSE has been disposed of, mainly in Brazil, into superficial streams, causing serious environmental damages such as the eutrophication of waters.

Several countries, from arid or humid regions, have successfully disposed of TSE in the soil for crop irrigation (Bouwer and Chaney 1974; Feigin et al. 1991). The treated sewage effluents are mineral enriched and are considered an alternative supply of water and nutrients, when destined to crop irrigation (Bouwer and Chaney 1974; Bouwer and Idelovitch 1987), particularly to maize crop (Karlen et al. 1976; Al-Jaloud et al. 1995; Overman et al. 1995; Vazquez-Montiel et al. 1996).

Nitrogen (N) is the major nutrient present in TSE in higher concentrations, mainly in the form of $NH_4^+{-}N$ (Bouwer and Chaney 1974; Feigin et al. 1991; Pescod 1992). The amount of N added to the soil by means of effluent irrigation may be close to or higher than that required for the crop (Feigin et al. 1978). Thus, nitrogen is a matter of great concern about soils irrigated with TSE, being the subject of study in several research works aiming to understanding the effluent-N transformations, as well as the plant N use efficiency when irrigated with TSE (Feigin et al. 1978; 1981; 1984).

Phosphorus (P) is a plant nutrient also present in TSE, whose concentration varies in the range from 6 to 17 mg total $P\,L^{-1}$ (Bouwer and Chaney 1974; Feigin et al. 1991). In most situations, the amount of P added to the soil by TSE irrigation has not been excessive. Nevertheless, an increase in soil available P has been observed in the superficial layers (Johns and McConchie 1994) and also in deeper soil layers of agricultural areas submitted to TSE irrigation (Latterell et al. 1982; Mohammad and Mazahreh 2003). It is pointed out that such effects were observed in medium to high natural fertility soils, which is an unusual characteristic of Brazilian soils. Evidently, more information is necessary concerning the TSE potential use as a source of N and mainly the overall effect of this wastewater on the crop productivity and soil fertility (Mohammad and Mazahreh 2003), mainly in variable charging soils (tropical soils).

The objectives of the present study were to 1) verify the potential use of the secondary-treated sewage effluent (STSE) as a source of water and N to a maize crop and 2) evaluate the nitrogen and phosphorus concentration in soil samples from a Typic Haplustox, as well as these nutrient concentrations and contents in maize plants, treated with STSE irrigation.

MATERIALS AND METHODS

Handling and Characterization of the Substrate

The experiment was conducted in a greenhouse of the Department of Soils and Plant Nutrition of the University of São Paulo (ESALQ-Campus at Piracicaba, State of São Paulo, Brazil), during March 2001. The soil samples were collected from the 0- to 20-cm soil layer of a Typic Haplustox, clayey medium texture, in a fallow area close to the Sewage Treatment Plant of Lins municipal district (22°21′S, 49°50′W), State of São Paulo, Brazil. Prior to the experiment, the soil samples were air dried, crushed to pass a 4-mm screen, and chemically and physically analyzed according to the procedures reported by Raij et al. (2001) and Camargo et al. (1986), respectively, showing the following attributes: pH ($CaCl_2$) = 4.2; organic matter (O.M.) = 15 g dm^{-3}; P, sulfur (S), and boron (B) = 2, 16, and 0.13 mg dm^{-3}, respectively; aluminum (Al), calcium (Ca), magnesium (Mg), and potassium (K) = 7, 11, 4, and 1.7 $mmol_c\, dm^{-3}$, respectively; base- (V) and Al-saturation = 43 and 30%, respectively; effective CEC = 38.7 $mmol_c\, dm^{-3}$; soil granulometric fractions = 780, 60, and 160 g kg^{-1} of sand, silt, and clay, respectively. The soil samples were amended to bring them to 65% base saturation and pH 7.0. Thus, the equivalent to 0.94 Mg ha^{-1} dolomitic lime (containing 30.8% CaO and 19.8% MgO) was calculated to be added to each experimental unit soil sample. The precise quantity of lime to amend each experimental unit was corrected by taking into account the soil sample density (1370 kg m^{-3}). The bulk density was determined by using the test tube method reported by Embrapa (1997). After liming, soil samples were thoroughly mixed in a soil mixer and incubated during 21 days under greenhouse conditions with adequate moisture to allow lime/soil reaction. Following this period, soil samples were air dried again, fertilized, and potted. Prior to the seeding procedure, soil samples were chemically analyzed and results are in Table 1.

Characterization of the Treated Sewage Effluent

The effluent was collected from the Wastewater Treatment Plant of Lins municipal district, operated by Sabesp (Company for basic sanitation of the State of São Paulo). This sanitation plant is constituted by stabilization ponds, three anaerobic and three facultative ponds. The average period for the effluents to stay in the anaerobic ponds has been 5 days and 10 days in the facultative ponds. The average plant capacity has been about 500 $m^3\, h^{-1}$ of STSE. The Sabesp has monitored the district wastewater treatment system, during the period of August 1997 to July 2000, by means of the effluent outflow determination, the electrical conductivity (EC), the total P content, total solids (TS), biochemical oxygen demand (BOD) and chemical

Table 1. Results of chemical analysis of soil used in the experiment

pH	5.2
TC[a] ($g\,kg^{-1}$)	8.4
TN[b] ($g\,kg^{-1}$)	0.7
P ($mg\,dm^{-3}$)	3
S ($mg\,dm^{-3}$)	21
Ca ($mmol_c\,dm^{-3}$)	14
Mg ($mmol_c\,dm^{-3}$)	7
K ($mmol_c\,dm^{-3}$)	1.5
Na ($mmol_c\,dm^{-3}$)	0.3
Al ($mmol_c\,dm^{-3}$)	0
H + Al ($mmol_c\,dm^{-3}$)	16
CEC[c] ($mmol_c\,dm^{-3}$)	38.8
V[d] (%)	59
B ($mg\,kg^{-1}$)	0.39
Cu ($mg\,kg^{-1}$)	0.4
Fe ($mg\,kg^{-1}$)	73
Mn ($mg\,kg^{-1}$)	0.8
Zn ($mg\,kg^{-1}$)	0.3

[a]TC, total carbon.

[b]TN, total nitrogen.

[c]CEC, cation exchange capacity at pH 7.0 → CEC = Ca + Mg + K + Na + H + Al.

[d]V, base-saturation → V = (Ca + Mg + K + Na) ∗ 100/CEC.

oxygen demand (COD), using the methods described in the American Public Health Association (1994). Samples of STSE were taken for the characterization of the effluent used in the experiments from the stabilization facultative ponds in July 2000. Simple samples were collected from each effluent emission point of the stabilization ponds. These samples were filtered through cellulose ester membranes, with 45-mm and 90-mm diameters and 8-μm, 0.45-μm and 0.22-μm pores. The samples were preserved according to the procedures described in the American Public Health Association (1994).

Several effluent filtrate aliquot samples were taken for the determination of alkalinity (like $CaCO_3$), anions (by liquid chromatography-HPLC), and cations [by inductively coupled plasma optical emission spectrometry (ICP-OES)]. Total element concentrations were obtained by acid digestion. The determination of total carbon (TC), total nitrogen (TN), ammonium nitrogen (NH_4^+–N), nitric nitrogen (NO_3^-–N), and pH were obtained for the non filtered STSE, using the procedures described in Kiehl (1985). Thus, the TC percent was determined by dry ashing at 550°C, after the previous obtention of the solid residue by drying the effluent at 110°C. The TN concentrations were determined by sulfuric acid digestion and titration by the semimicro-Kjeldahl method.

The NH_4^+–N and NO_3^-–N + NO_2^-–N concentrations were determined by vapor distillation with MgO and Devarda's alloy, respectively.

The effluent collected for plant irrigation was conserved under refrigeration in cold chamber at 0°C, and around half an hour before plant irrigation, the effluent was left under room temperature. The characteristics of the effluent used for plant irrigation is in Table 2.

Experimental Design and Handling of Treatments and Plants

The experimental design used was a randomized complete block with five replications and five treatments, as follows: T1 = irrigation with deionized water and complete mineral fertilization, except N; T2 = irrigation with deionized water and complete mineral fertilization; T3 = only irrigation with effluent, without addition of mineral fertilizer; T4 = irrigation with effluent and complete mineral fertilization, except N; T5 = irrigation with effluent and complete mineral fertilization.

Each experimental unit consisted of a 12.5-L plastic pot containing 10 kg soil sample previously amended with dolomitic lime. Pots were seeded with maize (single hybrid Avant) in March 26, 2001, using 12 seeds per pot. After seedling emergence, 5 days after planting, four seedlings per pot were left.

Soil sample fertilization was done according to the recommendation of Malavolta (1980) for pot experiments, as follows: 300 mg kg^{-1} of N (as urea, 45% N); 200 mg kg^{-1} of P (as simple superphosphate, 18% P_2O_5); 150 mg kg^{-1} of K (as potassium chloride, 60% K_2O); 0.5 g kg^{-1} of B (as boric acid, 17% B); 1.5 mg kg^{-1} of copper (Cu) (as cupric sulfate pentahydrate, 25% Cu); 5.0 mg kg^{-1} of iron (Fe) (as iron-EDTA, 5000 mg kg^{-1}); 3.0 mg kg^{-1} of manganese (Mn) (as manganese chloride tetrahydrate, 28% Mn); 0.1 mg kg^{-1} of molybdenum (Mo) (as molybdic acid, 48% Mo); and 5.0 mg kg^{-1} of zinc (Zn) (as zinc sulfate heptahydrate, 22% Zn). All the simple superphosphate and one-third KCl were thoroughly mixed with the soil samples before sowing using a soil mixer. The other nutrients were applied in the irrigation solution, dissolved in deionized water or in the effluent, as follows: 1) one-third N -fertilizer and all micronutrients (B, Cu, Fe, Mn, Mo, and Zn) at sowing; 2) one-third N and one-third K were applied twice, at 20 and 40 days after seedling emergence, in the irrigation solution.

The soil moisture lost by evapotranspiration was replaced to the experimental units, using deionized water or effluent, to bring the soil humidity to 70% of the potted soil sample moisture capacity (230 mL kg^{-1}). The potted soil sample moisture capacity was determined by using the soil moisture saturation technique according to Embrapa (1997). The average daily air temperature in the greenhouse was 27.5 ± 7.8°C during the experiment period.

Table 2. Characteristics of secondary-treated sewage effluent produced in Lins Treatment Sewage Plant (State of São Paulo, Brazil)

Constituent	Concentration ($mg\,L^{-1}$)
Total solids	600.1 ± 69.5^a
Chemical oxygen demand	53.6 ± 19.2^a
Biochemical oxygen demand	220.0 ± 48.1^a
Alkalinity (like $CaCO_3$)	358^b
Total carbon	62.5^b
Total–N	28.8^b
Organic–N	6.1^b
NH_4^+–N	21.6^b
NO_3^-–N + NO_2^-–N	1.1^b
Total–P	8.4 ± 1.9^a
Ca	8.1^c
Mg	1.5^c
K	10.9^c
Na	134^c
S	10.2^c
B	0.15^c
Cl	54^c
	$\mu g\,L^{-1}$
Cu	1.7^c
Fe	143.5^c
Mn	35.5^c
Zn	4.5^c
Cd	0.05^c
Cr	2.0^c
Ni	1.0^c
Pb	3.4^c
pH	7.7^b
C/N	2.2
Sodium adsorption ratio (SAR)	15.8^c
Electrical conductivity (EC), $dS\,m^{-1}$	0.84 ± 0.09^a

[a]Average values, obtained by Sabesp 12 samples between August 1997 and July 2000.
[b]Values obtained from raw sample (not filtrate).
[c]Average values obtained from filtrated sample in 0.22 μm.

Leaf Chlorophyll, Dry Matter Yield, Leaf and Plant Parts Nitrogen and Phosphorus Concentrations

Fifty-eight days after maize seedling emergence, when plants were in the V4 stage (male inflorescence), leaf chlorophyll content was indirectly evaluated by using a portable chlorophyll meter (Minolta-SPAD-502 Model), and four readings per experimental unit were taken. The readings were obtained from the medium part of the third completely expanded leaf, at 1.5 cm from the leaf edge. The leaf N concentrations chemically determined were related to the chlorophyll readings obtained with the portable chlorophyll meter for the same evaluated leaves. Plants were harvested in the same day, immediately after the readings, cut 1 cm above the substrate, separated into parts (leaves and culms), rinsed in distilled water and dried in a forced air oven at 60°C until constant mass for dry matter yield determination. Leaf and culm subsamples were ground in a Wiley-type mill to pass a 0.75-mm screen and stored in small capped plastic vials for N and P chemical analyses. N and P concentrations in plant parts were determined by using the methods described in Malavolta et al. (1997); N concentrations in dry tissues were determined by using sulfuric acid digestion and the semimicro-Kjeldahl method; and P concentrations were determined by nitric + perchloric acid digestion and molecular absorption spectrophotometry. N and P total content in plant parts (leave, culms, and leaves + culms) were calculated by multiplication of the dry matter yield and nutrient concentration of the respective plant parts.

Soil Analysis and Statistics

After plant harvesting, soil samples were air dried, crushed to pass a 2-mm screen, and laboratory procedures were followed for the determination of total nitrogen (TN), total carbon (TC), and available P concentrations. The TC and TN concentrations were obtained by furnace combustion according to Tabatabai and Bremner (1991). The soil available P was extracted by using ion exchange resin and determined by molecular absorption spectrophotometry according to Raij et al. (1986).

The experimental data were submitted to analysis of variance for randomized complete block design, and mean comparisons by Tukey test at 5% level, using the ESTAT computer program according to procedures described by Banzatto and Kronka (1995).

RESULTS AND DISCUSSION

Effluent Quality and Nutrient and/or Element Apposition by Irrigation

The secondary-treated sewage effluent (STSE) used in this experiment (Table 2) showed similar average composition in mineral nutrients and other components as that reported in the literature (Feigin et al. 1991; Pescod 1992). The values found for some components of the STSE used in this experiment were compared and evaluated by following the interpretation criteria for irrigation water quality presented by Ayers and Westcot (1985). The results of STSE analysis showed low B and Cl contents, which means no restriction for the effluent use as a source of water for plants. The same occurred with relation to the heavy metal concentrations that were well below the critical limits presented by Ayers and Westcot (1985). This is due to the fact that such effluent was derived from a nonindustrialized small countryside district (Lins) of the State of São Paulo. The low heavy metal concentrations found in the STSE from Lins represents a highly desirable aspect for the effluent soil disposal sustainability.

The high concentration of sodium was responsible for the high sodium adsorption ratio (SAR) of the STSE (Table 2), inserting this effluent in a class with severe restriction for surface irrigation use, according to Ayers and Westcot (1985). The chemical analysis of the water from Lins revealed the following values: SAR = 21.6; Na = 111.3 $mg\,L^{-1}$; EC = 0.405 $dS\,m^{-1}$; and pH = 9.9. The high Na concentration found in the Lins water might be responsible for the high Na in the effluent, which would indicate that even the water destined for the population, if used for crop irrigation, would be a severe risk to soil permeability, according to Ayers and Westcot (1985).

The average quantity of deionized water applied to T1 and T2 treatments during the experiment was 29.6 and 40.0 $L\,pot^{-1}$, respectively. The T3, T4, and T5 treatments received an average of 19.6, 34.9, and 42.0 $L\,pot^{-1}$ of STSE, respectively. The different quantities of water or STSE applied to the experimental units can be explained by the fact that plants had differentiated growth depending on the treatment applied, and thus, the evapotranspiration rates were also different.

Assuming the STSE component concentrations presented in Table 2, the probable apposition of nutrients and toxic elements to the experimental units was calculated, considering irrigation with STSE from Lins. Even considering the highest transpiration rate obtained among the experimental units, the applied volume of STSE corresponded to less than half the adequate N rate reported by Malavolta (1980) for maize plants in potted experiments. The effluent disposal added 4.67 times more Na than N. From the point of view of plant mineral nutrition, if there is a low-K but high-Na effluent, this effluent disposal will only be sustainable by supplying K to the plants, especially to a maize crop, to achieve and maintain an adequate nutrient uptake rate and productivity (Karlen et al. 1976).

Effect of Effluent Irrigation on Total Carbon, Total Nitrogen, and Available Phosphorus Concentrations in Soil Samples

The TC concentrations were not affected by the treatments (Table 3), probably due to the experimental short term or to the fast decomposition of the effluent organic matter added to the pots. The moisture, temperature, and oxygenation conditions in the substrate, associated with the low C:N ratio of the effluent

Table 3. Effects of water sources for irrigation (effluent and deionized water) and fertilization in total carbon (TC), total nitrogen (TN), and available phosphorus (P) concentration in soil samples

Treatment	TC	TN	P ($mg\,dm^{-3}$)
	$g\,kg^{-1}$		
T1[a]	8.4 a[g]	0.65 b	70.8 a
T2[b]	9.2 a	0.73 ab	68.4 a
T3[c]	8.7 a	0.72 ab	6.2 b
T4[d]	9.4 a	0.76 ab	86.2 a
T5[e]	9.6 a	0.81 a	84.6 a
C.V. (%)[f]	12.2	9.8	19.4

[a]T1, irrigation with deionized water and complete mineral fertilization, except N.

[b]T2, irrigation with deionized water and complete mineral fertilization.

[c]T3, only irrigation with effluent, without (addition of) mineral fertilizer.

[d]T4, irrigation with effluent and complete mineral fertilization, except N.

[e]T5, irrigation with effluent and complete mineral fertilization.

[f]C.V., coefficient of variation.

[g]Data in a column followed by the same letter do not differ significantly by Tukey test ($p < 0.05$).

(Table 2) might have contributed to a fast degradation of the organic matter. Nevertheless, it has been reported in the literature that effluent irrigation caused alterations in the soil TC content. However, such research results were obtained from long-term experiments, with more than 2 years of effluent application (Feigin et al. 1978; Quin and Woods 1978; Latterell et al. 1982; Polglase et al. 1995; Friedel et al. 2000). Otherwise, it is also possible that the apposition of organic carbon was so small (Table 2) that it was not detectable by the analytical method used.

Soil TN concentrations changed little (Table 3). Higher TN concentrations were observed in T5-fertilized and effluent irrigated treatment than in T1 treatment (Table 3). Increases in soil TN and mineral–N (NH_4^+–N + NO_3^-–N) concentrations due to STSE irrigation have regularly been observed in areas that have received effluent, mainly for long periods (Quin and Woods 1978).

The STSE disposal did not affect the soil sample P concentrations. Thus, the agent responsible for the increase observed in the soil sample P concentrations was the P fertilizer (Table 3). The experimental units without P treatment (T3), although showing lower available P (Table 3), presented higher P concentration in the end than in the beginning of the experiment (Table 1). Certainly, the apposition of effluent-P was significant for maize nutrition and growth (T3) (Figure 1B), despite their low dry matter yield (Figure 2). The increase in soil P, due to the effluent addition, as well as in the soil C concentration, has been regularly observed in effluent-treated

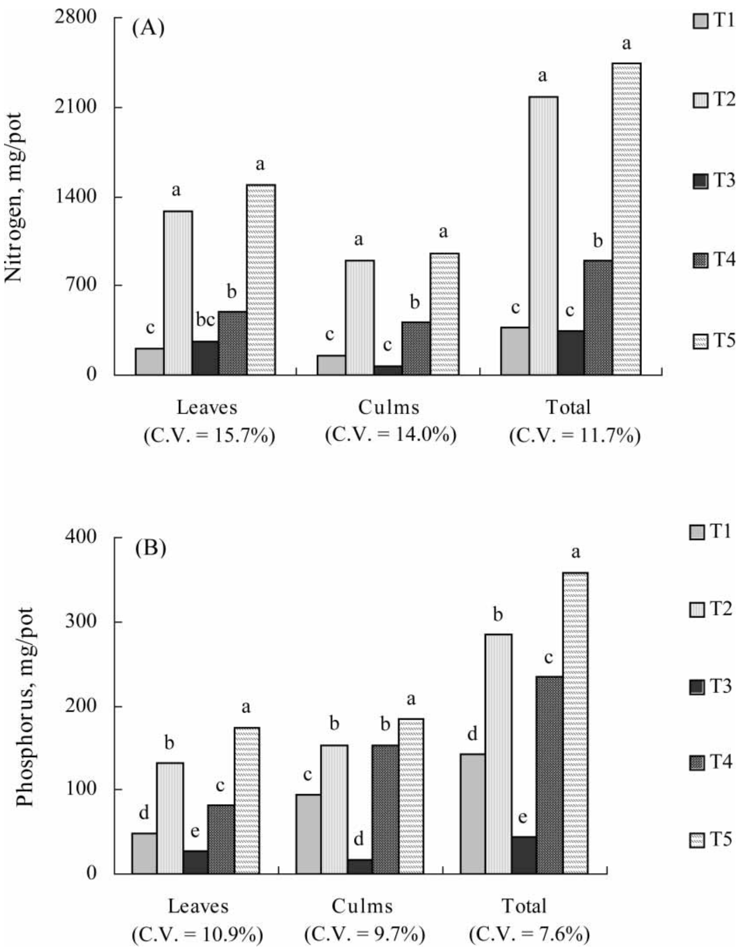

Figure 1. Nitrogen (A) and phosphorus (B) accumulation in corn plants following irrigation with different water sources (effluent and deionized water) and fertilization (T1 = irrigation with deionized water and complete mineral fertilization, except N; T2 = irrigation with deionized water and complete mineral fertilization; T3 = only irrigation with effluent, without (addition of) mineral fertilizer; T4 = irrigation with effluent and complete mineral fertilization, except N; T5 = irrigation with effluent and complete mineral fertilization). C.V. = coefficient of variation. Data followed by the same letter do not differ significantly by Tukey test ($p < 0.05$).

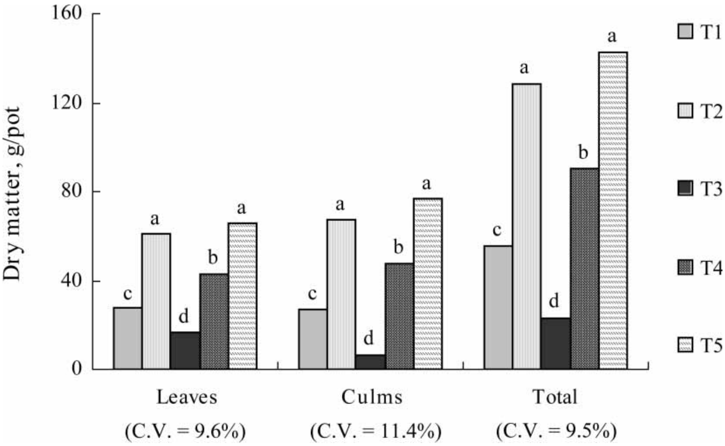

Figure 2. Dry matter yield of corn following irrigation with different water sources (effluent and deionized water) and fertilization (T1 = irrigation with deionized water and complete mineral fertilization, except N; T2 = irrigation with deionized water and complete mineral fertilization; T3 = only irrigation with effluent, without (addition of) mineral fertilizer; T4 = irrigation with effluent and complete mineral fertilization, except N; T5 = irrigation with effluent and complete mineral fertilization). C.V. = coefficient of variation. Data followed by the same letter do not differ significantly by Tukey test ($p < 0.05$).

soils during several years (Quin and Woods 1978), notoriously the increase in organic P (Latterell et al. 1982). Thus, long-term field studies are necessary to understand the processes, which control the effluent-P dynamics in the soil (Bond 1998), especially in variable charging soils. This is because it is supposed that the P retention soil capacity might contribute to avoid P lixiviation below the rhizosphere (Falkiner and Polglase 1997).

Effects of Effluent Irrigation on Maize Growth, Nitrogen, and Phosphorus Content and Dry Matter Yield

Plants from treatment T5 presented initially more vigorous growth, and this contributed to their higher demand for irrigation, due to the higher evapotranspiration. Thus, plants that received the highest quantity of nutrients from STSE were the ones showing also the fastest growth.

The maize plants from T2 and T5 presented normal aspect during the experiment up to 50 days after emergence, after which, visible symptoms of sodium toxicity were observed in the older leaves of some plants from T5, characterized by necrosis of leaf borders and edges. Eleven days after emergence, plants from T3 showed poor growth and typical visible symptoms of P deficiency, characterized by the violet pigmentation in the borders of older leaves and culms. Twenty-five days after emergence, these same plants were yellowing from the apical to the medium part of the older leaves, characterizing N deficiency symptoms. Treatments T4 and T5, which received the highest effluent rates, showed visible decreasing soil infiltration rates 17 days after emergence. From this date on, the STSE infiltration was gradually slower in these soil samples.

The use of STSE irrigation in maize crop resulted in changes in the N and P contents of leaves, culms, and whole plant shoots (Figures 1A and 1B). The effluent induced an increase in the N and P contents in plant parts, in the treatments that received mineral fertilizers (except for N-fertilizer, T1 and T4). In the experimental units with complete fertilization (T2 and T5), the effluent increased only P content in all plant parts (leave, culms, and whole shoots). The use of STSE without mineral fertilization (T3) resulted in lower P content in maize plants. However, plants from T3 accumulated similar quantities of N in the same parts, compared with the plants from the T1 treatment. Other variations on plant N and P contents were due to the presence or absence of the respective mineral fertilizers and not to the effluent irrigation applied.

In the experimental units adequately fertilized (T2 and T5), the STSE irrigation provided an increase in the plant P content (Figure 1B); however, it did not change either the soil nutrient concentration (Table 3) or the dry matter yield (Figure 2). Vazquez-Montiel et al. (1996) have also verified higher P accumulation in maize plants that received fertilizer and also effluent irrigation, and Al-Jaloud et al. (1995) observed increased maize leaf P concentration due to the effluent irrigation, which was attributed to the presence of P in the residual irrigation water.

The mineral N fertilization was the main agent for dry matter production, independently of the type of irrigation water used (Figure 2). This was inferred because the use of STSE in the adequately fertilized pots did not increase N content (Figure 1A), did not affect leaf N and chlorophyll concentrations (Table 4), did not affect dry matter yield (Figure 2), and did not change soil TN concentration (Table 3). Nevertheless, these results are in disagreement with the observations of Bielorai et al. (1984) and Feigin et al. (1984), which reported excess N content in tissues of N-fertilized and effluent irrigated plants.

Maize plants that were not fertilized but did receive STSE irrigation (T3) presented higher leaf N and chlorophyll concentrations than the plants that received distilled water irrigation and mineral fertilizer without N (T1) (Table 4). This fact might be due to a concentration/dilution effect, because plants from both treatments (T1 and T3) accumulated similar N amounts (Figure 1A), but T3 plants showed lower dry matter yields (Figure 2). It is pointed out that the leaf N concentration indeed affected the chlorophyll concentration, and a highly significant positive correlation was obtained for these two variables ($r = 0.93^{**}$), which was expected and has been corroborated in the literature for maize crop (Waskom et al. 1996).

Table 4. Effects of water sources for irrigation (effluent and deionized water) and fertilization in nitrogen and chlorophyll (measured indirectly) concentration in leaves of corn

Treatment	N ($g\,kg^{-1}$)	Chlorophyll meter readings
T1[a]	8.0 d[g]	17.2 c
T2[b]	20.6 a	39.5 a
T3[c]	16.3 b	26.4 b
T4[d]	11.4 c	24.2 b
T5[e]	19.7 a	40.4 a
C.V. (%)[f]	8.7	7.3

[a]T1, irrigation with deionized water and complete mineral fertilization, except N.
[b]T2, irrigation with deionized water and complete mineral fertilization.
[c]T3, only irrigation with effluent, without (addition of) mineral fertilizer.
[d]T4, irrigation with effluent and complete mineral fertilization, except N.
[e]T5, irrigation with effluent and complete mineral fertilization.
[f]C.V., coefficient of variation.
[g]Data in a column followed by the same letter do not differ significantly by Tukey test ($p < 0.05$).

Comparing plants from treatments T1 and T4 that received mineral fertilizer, except N, it was observed that T4 plants (STSE treated) showed higher P and N acquisition, which was inferred from their higher plant part nutrient contents (Figures 1A and 1B), higher leaf and chlorophyll concentrations (Table 4), and higher plant part dry matter yields (Figure 2). In this case, although the STSE irrigation has caused N apposition to the experimental units, the plant dry matter yield was significantly lower than that observed in treatments T2 and T5, which received complete mineral fertilization. These results corroborated the data obtained by Feigin et al. (1981), comparing the effects of sewage effluent, similar effluent composition nutrient mineral solution, and deionized water on maize nutrient concentration. These authors observed no influence of the irrigation water quality on N accumulation by maize plants; however, the N plant acquisition from the effluent was lower than that obtained with mineral N fertilizers added to the soil.

The lower effluent efficiency as an N fertilizer might be due, first, by the different plant demands for water and N, once N is required by most plants, in higher rates during the growing period and in lower rates during the reproductive stages near harvesting, but the inverse occurs for the plant water demand (Bouwer and Idelovitch 1987). Second, the N losses in effluent-irrigated soils has been considered relatively high (Polglase et al. 1995), by 1) NH_3–N volatilization (Smith et al. 1996); 2) NO_3^-–N lixiviation (Hook and Kardos 1978; Polglase et al. 1995); and 3) denitrification, once this process has increased in

STSE-irrigated soils (Friedel et al. 2000). There are reports in the literature showing that the N losses can be significant in high pH organic residues, due to the NH_3-N volatilization, mainly in low CEC soils (Stevenson 1986). This certainly occurred in this research study, once the effluent is considered an alkaline organic residue (Table 2) and the soil used presented low clay ($160\,g\,kg^{-1}$, mainly kaolinite) and low CEC ($38.8\,mmol_c\,dm^{-3}$) (Table 1). In addition, the experimental conditions probably favored denitrification, for several reasons: 1) the effluent addition to the soil samples probably caused apposition of soluble C, readily decomposable (Bouwer and Chaney 1974); 2) the effluent infiltration rate started decreasing 21 days after seedling emergence in the higher irrigation rate treatments, suggesting lower soil aeration; 3) the average temperature in the greenhouse was higher than 25°C, favoring denitrification; 4) the soil sample pH was above 5.0 in the beginning of the experiment, favoring denitrification, and after STSE irrigation the pH value increased up to 0.9 unity. All the above conditions usually induce gaseous N losses due to biological denitrification, according to Stevenson (1986).

In this research work, the STSE was effective only as a partial N source, in the absence of N mineral fertilizer and provided adequate irrigation water in the pots that received complete mineral fertilization. The effective substitution of conventional water irrigation by STSE irrigation has been well documented, particularly for the maize crop (Karlen et al. 1976; Al-Jaloud et al. 1995; Overman et al. 1995; Mohammad and Mazahreh 2003). Despite the high Na apposition occurred by STSE irrigation, resulting in 15 and 100 times increases in Na concentrations in soil and plants, respectively, no Na effect on dry matter yield of plants adequately fertilized (T5) was observed (Figure 2). Certainly, other nutrients, mainly K, present in this treatment avoided the toxic effect of high Na concentration (Al-Jaloud et al. 1995). Undoubtedly, P was the major limiting nutrient for plant production, because in the absence of P fertilizer (T3), the plants showed P deficiency symptoms 11 days after emergence, resulting in lower dry matter yield of maize plant parts (Figure 2). Nevertheless, several papers in the literature have reported adequately plant P nutrition when treated with effluent (Day et al. 1974; 1975), probably because those were not low fertility tropical acid soils, with low CEC and low available P, as was the soil used in the present experiment (Table 1). Evidently, the effluent was not expected to provide all the mineral nutrients and substitute for the mineral fertilization, especially in a low available P soil, which mineralogical composition is predominantly quartz, kaolinite, hematite, and goethite. Besides the low natural available P concentration of the soil used in this experiment, the presence of iron oxides might have contributed to higher P fixation, decreasing its availability to the plants. Although the effluent is considered a mineral enriched wastewater, it cannot be the only source of nutrients to the plants, making necessary a fertilizer application to provide an adequate plant nutritional balance (Inglés et al. 1992), especially for maize crop (Overman et al. 1995).

CONCLUSIONS

The secondary-treated sewage effluent applied to irrigate maize plants, completely substituted for the irrigation water, partially provided N fertilization, but it did not provide adequate nutrition to maize plants in the absence of mineral fertilizers.

The STSE application caused a little increase in the soil total nitrogen, but it did not change the total carbon and available P concentrations and did not increase the plant dry matter yields in the complete mineral fertilization treatments, despite the higher plant part N and P contents.

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