

Research Article

Impact of the Application of Domestic Wastewater by Subsurface Drip Irrigation on the Soil Solution in Sugarcane Cultivation

Aline Azevedo Nazário ^{1,2}, **Ivo Zution Gonçalves**,³ **Eduardo Augusto Agnellos Barbosa**,⁴ **Leonardo Nazário Silva dos Santos**,⁵ **Daniel Rodrigues Cavalcante Feitosa**,⁶ and **Edson Eiji Matsura**⁷

¹University Adventist Center of São Paulo, Department of Agronomic Engineering, Engenheiro Coelho, Brazil

²State University of Campinas, Faculty of Agricultural Engineering, Campinas, São Paulo, Brazil

³University of Nebraska, Daugherty Water for Food Global Institute, Nebraska, Lincoln, USA

⁴State University of Ponta Grossa, Department of Soil Science and Agricultural Engineering, Ponta Grossa, Paraná, Brazil

⁵Federal Institute of Goiano, Agronomy Department, Rio Verde, Goiás, Brazil

⁶Federal Institute of Education, Science and Technology of Sertão Pernambucano, Pernambuco, Brazil

⁷State University of Campinas, Faculty of Agricultural Engineering, Campinas, São Paulo, Brazil

Correspondence should be addressed to Aline Azevedo Nazário; aline.a.n@hotmail.com

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The agricultural use of domestic sewage is a viable alternative for recycling nutrients; however, there is concern regarding the impact of its use due to the concentration of chemical elements present in this type of effluent. The use of principal component analysis determines the existence or lack of anomalous samples and the relations between measured variables and their relative contribution among samples that help in monitoring the impact of the use of effluents on soil chemical components. Thus, the objective of this work was to identify nutrient ions present in the soil solution during the first ratoon sugarcane irrigated with treated domestic sewage applied by subsurface drip irrigation. The experiment was conducted under a randomized block design with 5 treatments and 5 replicates. The treatments were distributed according to the type of water applied in the irrigation system (water surface reservoir and treated domestic sewage), the installation depth of the drip tapes (0.2 or 0.4 m depth), and the treatment without irrigation. By means of soil solution, it was possible to identify an increase in the concentration of salts in the treatments irrigated with treated domestic sewage, which however did not affect the soil quality in the short term. The principal component analysis selected the variables Ca^{2+} , Mg^{2+} , NO_3^- , K^+ , and EC as soil solution indicators to monitor areas irrigated with treated domestic sewage.

1. Introduction

Soil is a dispersed, polyphase, and heterogeneous system and, due to its physical, chemical and biological attributes, it allows the deposition of wastewater acting as a scrubber through the interception of suspended solids and nutrient removal [1].

The presence of residual water in the soil through the irrigation of plants alters its chemical characteristics [2, 3], which can lead to possible toxicity problems depending on

the concentration of the chemical elements present in the effluent [4]. Accumulation of salts may occur in the soil [5–7], as well as the contamination of surface and underground water sources [8].

In addition, the increase in soil fertility, due to effluent disposal, has been observed by several studies, which report increase in contents of nitrogen [9, 10], phosphorus and potassium [11], calcium, and magnesium in the soil [7, 9, 11]. Fonseca et al. [12] concluded that irrigation with treated domestic sewage (TDS) led to saving from 32 to 81%

in the dose of mineral nitrogen fertilization required for the high productive yield of Tifton 85 grass without causing negative changes in both soil and plant.

Ali et al. [13] showed that irrigation of the soil with waste water from a sewage treatment plant gradually improved the chemical and biological properties of the soil, compared to well water. Duarte et al. [14] found that fertigation with TDS did not affect soil pH in response to high soil buffer capacity. Fonseca et al. [15] in different fertigation treatments with TDS did not observe changes in sulfur availability, phosphorus concentration, and soil carbon and soil pH increase and found only nitrogen increases in maize plants, but without entailing effects on dry matter production.

According to Silva et al. [16], soil solution extractors provided with porous capsules are presented as an alternative to detect the ion concentration of the soil solution and consequently its salinity, as Medeiros et al. [17] found good data accuracy for the use of this methodology to determine the concentration of nitrate, potassium, and electrical conductivity (EC) when evaluating soil solution.

As for soil solution studies, where there is a great diversity of nutrient ions or a large number of variables for evaluation, exploratory analysis tools such as principal component analysis (PCA) allow to demonstrate the existence or not of atypical samples, which ultimately lead to conclusions on data groupings, depending on the relations between different sets of measured samples [18].

By applying the PCA technique to find variables that could be used to monitor areas treated with sewage sludge, Coscione et al. [19] observed that the attributes pH, Mn^{2+} , SO_4^{2-} , NO_3^- , NH_4^+ , and organic carbon dissolved in soil solution, which are trace elements left by soil residue, were useful to identify these areas with regard to applied fertilization sewage and mineral fertilization. In a study by Chen et al. [20], using PCA to verify the influence of irrigation water quality on soil attributes, reported that the ionic components of irrigation water directly influenced soil saline ions and have shown that the ionic effects of irrigation water on soil processes would be more complex than currently understood.

In a study by Visconti et al. [21], by means of PCA for characterizing the calcite equilibrium of soil solutions in irrigated systems interpreted as caused by salinization, collection depth, and soil fertilization state, it was observed that sodium, chloride, magnesium, calcium, and sulfate concentrations were highly correlated with the first main component, which explained the variance of the EC of the soil. In turn, the parameters alkalinity, pH, and nitrite concentration were related to the second main component, whereas potassium, ammonium, and nitrite were related to the third component, with independent variation of the degree of humidity and soil depth.

Soil solution, with its chemical composition, is an effective indicator of the nutrient supply potential of plants, more specifically along the root system, promoting chemical reactions and redistribution of solutes in the soil. Therefore, understanding the quality of irrigation water and its possible interactions in the soil is essential to provide important information for studying the solute dynamics in the soil.

Therefore, investigating the chemical alterations of the soil solution through use of PCA—while considering the chemical parameters of soil, plant, and environmental conditions in response to the application of TDS and surface reservoir water (SRW) resulting in subsurface irrigation—will allow to determine the soil support ability to receive different qualities of irrigation water, of which the association between these factors can substantiate the technical viability, crop productivity, and sustainability of this management system.

2. Materials and Methods

2.1. Location and Climate. The experiment was carried out in the experimental field of the School of Agricultural Engineering of the State University of Campinas, coordinates 22°53'S and 47°05'W and average altitude of 664 m. The climate, according to the Köppen classification, is a transition between Cwa and Cfa, that is, subtropical altitude, dry in winter and rainy and hot in summer, with annual rainfall around 1425 mm, average annual temperature of 22.4°C, and 62% relative humidity [22].

2.2. Soil Characterization. The soil was classified as oxisol dystroferic [23]. For the physical characterization of the soil (Table 1), deformed and undisturbed soil samples were taken in the layers 0–0.20, 0.20–0.40, and 0.40–0.60, for analyzing soil moisture retention curve [24], granularity, density, macroporosity, microporosity, total soil porosity, and hydraulic conductivity of saturated soil [25] and soil chemical analysis (Table 2).

2.3. Experimental Design. The sugarcane variety used was RB86-7515 in combined spacing, where two lines of sugarcane were planted 0.4 m apart, with an interline spacing of 1.4 m, totaling 1.8 m. The experiment was based on a set of treatments under a randomized complete block design, in a $2 \times 2 + 1$ factorial scheme (two drip tape installation depths, two water qualities, and control group without irrigation) its SI: nonirrigated treatment; E20: wastewater domestic sewage applied to 0.20 m; E40: wastewater domestic sewage applied to 0.40 m, A20: surface reservoir water to 0.20 m, A40: surface reservoir water applied to 0.40 m.

2.4. Irrigation Management and Water Quality. A drip irrigator was used, with a flow rate of $1.6 \text{ L} \cdot \text{h}^{-1}$ and spaced at 0.65 m with irrigation management via soil water balance, using time-domain reflectometry (TDR) [27]. The irrigation was estimated based on the volume of water to reach the field capacity humidity in the layer of 0.00–0.60 m from the soil (Figure 1).

All of the irrigated treatments were fertigated with mineral chemical fertilizer, subtracting the nutrient contribution of each water source following the nutrient absorption rate of sugarcane described by Haag et al. [28]. Therefore, 120, 40, and $60 \text{ kg} \cdot \text{ha}^{-1}$ of nitrogen (calcium nitrate), phosphorous (monoammonium phosphate), and

TABLE 1: Physical characterization of the soil from the experimental area in the layer 0–0.20 m before conducting the experiment.

Layer	SD ¹	Porosity			Texture ⁵			Soil moisture		Ks ⁸
		Total ²	Macro ³	Micro ⁴	Clay	Silt	Sand	θ_{CC} ⁶	θ_{PWP} ⁷	
0–0.20	1.38	52	0.11	0.41	572	178	250	0.34	0.25	3.29
0.20–0.40	1.49	50	0.07	0.43	611	161	228	0.36	0.28	0.83
0.40–0.60	1.36	49	0.08	0.41	652	141	207	0.34	0.27	2.60
0.60–0.80	1.20	50	0.11	0.39	650	145	205	0.36	0.27	1.38

¹Soil density (g·cm⁻³); ²total porosity (cm³·cm⁻³); ³macroporosity (cm³·cm⁻³); ⁴microporosity (cm³·cm⁻³); ⁵texture (g·kg⁻¹); ⁶soil moisture in the field capacity: 10 kPa; ⁷soil moisture at the permanent wilting point: 1500 kPa; ⁸saturated soil hydraulic conductivity (cm·h⁻¹).

TABLE 2: Chemical analysis of the soil from the experimental area in the layer 0–0.20 m before conducting the experiment.

Parameter	Unit	Average	CV ¹	Level [26]
pH (H ₂ O)	—	5.62	4.77	Medium
Phosphorus	mg·dm ⁻³	19.33	24.12	High
Sulfur	mg·dm ⁻³	15.56	18.81	High
Sodium	mg·dm ⁻³	1.90	30.23	Low
Potassium	cmol _c ·dm ⁻³	0.570	24.66	High
Calcium	cmol _c ·dm ⁻³	5.10	23.69	High
Magnesium	cmol _c ·dm ⁻³	0.94	16.83	Medium
Aluminum	cmol _c ·dm ⁻³	0.00	—	Low
H + Al ²	cmol _c ·dm ⁻³	3.25	20.50	Medium
CEC ³	cmol _c ·dm ⁻³	9.87	9.79	Medium
SAR ⁴	cmol _c ·dm ⁻³	0.0047	19.32	Low
OM ⁵	g·kg ⁻¹	37.5	10.41	High
EC ⁶	dS·m ⁻¹	0.096	17.78	Low
PST ⁷	%	0.083	21.62	Low
BS ⁸	%	66.40	13.22	Medium

¹Coefficient of variation (%); ²potential acidity; ³cation exchange capacity; ⁴sodium absorption ratio; ⁵organic matter; ⁶electrical conductivity; ⁷exchangeable sodium (%); ⁸base saturation.

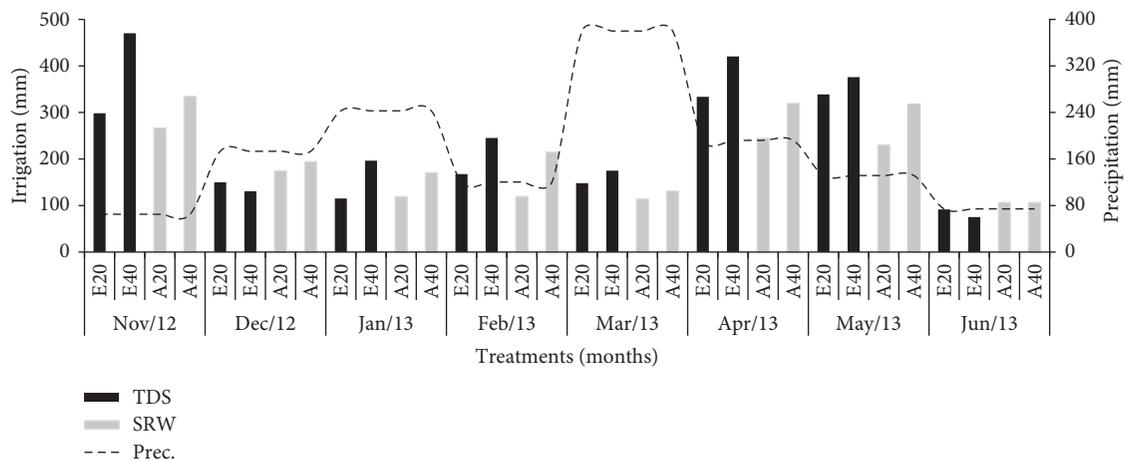


FIGURE 1: Effective precipitation (mm) and irrigation (mm) applied in each treatment by the time of the first sugarcane ratoon.

potassium (potassium sulfate) were applied, respectively. For the nonirrigated treatment, topdressing was done, with nutrients arranged between planting rows according to the recommendation of Rossetto et al. [29] for high yields.

To characterize TDS and SRW, a chemical analysis was performed (Table 3), with the samples being collected after the filtration system of the irrigation equipment. The TDS was treated at the research institution’s own treatment station, and SRW was obtained from a reservoir near the experimental area.

2.5. Soil Solution. For the extraction of soil solution, five extractors of porous capsule solution were installed in the depths of 0.10, 0.30, 0.50, 0.70, and 0.90 m, representing the soil layers of 0.0–0.20, 0.20–0.40, 0.40–0.60, 0.60–0.80, and 0.80–1.00 m, respectively. The extraction procedure of the soil solution was carried out by means of a vacuum in each extractor with the aid of a disposable syringe, in order to remove all air present in the porous capsules and establish the negative gradient for entering the soil solution after 48 h of vacuum application. For the chemical analysis of the

TABLE 3: Average concentration of the water quality parameters used in irrigation during the rainy and dry periods for the first crop.

Attribute	Rainy season				Dry season			
	TDS ⁷	CV ⁹ (%)	SRW ⁸	CV (%)	TDS	CV (%)	SRW	CV (%)
Total nitrogen (mg·L ⁻¹)	59.23	19.67	1.06	61.45	98.05	31.66	0.68	51.61
Total phosphorus (mg·L ⁻¹)	8.57	15.53	0.04	31.49	20.50	67.57	0.04	106.06
Potassium (mg·L ⁻¹)	25.00	13.67	1.35	30.76	26.70	55.08	0.81	16.07
Calcium (mg·L ⁻¹)	18.56	10.69	3.70	33.40	21.60	17.67	4.40	11.89
Magnesium (mg·L ⁻¹)	3.30	15.74	2.48	19.68	3.80	7.44	3.18	8.21
Sulfur (mg·L ⁻¹)	14.60	21.95	<5	n.d.	6.15	42.54	<5	n.d.
Sodium (mg·L ⁻¹)	56.36	14.32	2.20	26.59	76.70	4.79	2.20	7.07
Boron (mg·L ⁻¹)	0.31	44.34	<0.001	n.d.	0.20	85.99	<0.001	n.d.
Iron (mg·L ⁻¹)	0.84	41.13	0.20	72.61	0.93	41.84	0.25	37.09
Manganese (mg·L ⁻¹)	0.08	16.16	0.03	48.66	0.06	7.67	0.02	2.55
Zinc (mg·L ⁻¹)	0.08	28.75	0.08	38.82	0.05	20.20	0.05	732.61
Total chlorine (mg·L ⁻¹)	0.02	33.33	0.03	57.28	<0.01	n.d.	<0.01	n.d.
BOD ¹ (mg·L ⁻¹)	5.00	52.91	<5	n.d.	14.70	79.85	<5	n.d.
EC ² (dS·m ⁻¹)	0.99	15.54	0.07	14.70	1.24	8.88	0.06	5.94
SAR ³ (mmol·L ⁻¹)	4.46	8.70	0.30	15.26	5.66	12.31	0.27	4.02
pH	7.70	2.87	7.33	5.20	7.21	12.35	7.23	1.37
FC ⁴ (MPN 100 ml ⁻¹)	72167	27.97	n.d. ⁶	n.d.	23215380	141.16	59.00	n.d.
<i>E. coli</i> ⁵ (MPN 100 ml ⁻¹)	66827	36.42	n.d.	n.d.	203910	124.90	66.00	n.d.

¹Biochemical oxygen demand; ²electrical conductivity; ³sodium adsorption ratio; ⁴fecal coliforms; ⁵*Escherichia coli*; ⁶not determined; ⁷treated domestic sewage; ⁸surface reservoir water; ⁹coefficient of variation.

samples, the methodology described by Embrapa [25] was used, obtaining the results used for the analysis of main components.

Among the attributes of soil solution collected in the first sugarcane bagasse, only potassium (K), sodium (Na), calcium (Ca), magnesium (Mg), sulfur (S), pH, EC, and nitrate (NO₃⁻) reached sufficient average concentration for reading and the remaining elements were below the limits of instrumental quantification for the methodology adopted.

The data collected were studied for each depth of collection together and for each treatment, that is, regardless of the soil solution collection period, since the focus was on studying and identifying possible differences in soil solution attributes as a result of the treatment in opposition to it being a result of the soil solution. Although the chemical composition of the effluent can be relatively stable, the concentration of dissolved nutrients in the soil solution presents great variability in time and space, given the dynamic nature of the solution influenced by local soil. Thus, the results obtained from a soil solution are of a short-term nature, whereas soil chemistry can provide long-term information [30, 31].

2.6. Productivity and Technological Quality of Culture. At the end of the sugarcane cultivation cycle, a technological analysis was carried out and an estimate of the shoot production by means of average fresh stalk mass was determined using an area of 1 m linear per treatment and hectare. These analyses were performed according to the methodology described by Consecana [32].

2.7. Statistical Analysis. The statistical analysis for the technological attributes of culture and productivity was subjected to analysis of variance at 5% of probability, and the

means of each treatment were compared using the Tukey test, with 5% of error probability, and the attributes of solution were subjected to the PCA.

3. Results and Discussion

The concentration of nitrate in the soil solution showed higher values for all treatments in the superficial layer (0.0–0.10 m), with reduction in depth for this anion (Table 4), except for treatments irrigated at 0.40 m depth of the drip tape; in these treatments, it was possible to observe a slight increase in the deeper layers of the soil, which reinforces the need for monitoring irrigated crops, since, regardless of water source and fertilization, irrigation depth may cause nitrate leaching to deeper layers of the soil in cases of high precipitation.

According to the results, there was increase in nitrogen in the soil solution by means of TDS. Studies conducted by Santos et al. [9], Fonseca et al. [12] and Gloaguen et al. [33] report better conditions of soil fertility from irrigation with TDS. It is noteworthy that this nutrient is required in large quantities and acts in various metabolic processes of the plant and the use of TDS becomes an additional source of this nutrient for agricultural production.

By means of Ca²⁺ and Mg²⁺ results for each soil solution extraction depth (Table 4), higher concentrations of nutrients were observed in treatments A20 and SI in the upper layers, whereas for treatments E20, E40, and A40, high concentrations can be observed in the lower layers (0.70 and 0.90 m), indicating that there was no depth movement of these elements in the soil. It is worth mentioning that the TDS used exceeded by five times the concentration of Ca²⁺ found in the SRW (Table 3). However, the increase or decrease in Ca²⁺ and Mg²⁺ is directly related to the concentration of applied wastewater, the concentration absorbed by

TABLE 4: Average anion and cation concentrations and values of electrical conductivity and pH in soil solution by the time of the first sugarcane sack.

Depth ¹ (m)	Treat ²	NO ₃ ⁻	Ca ²⁺	Mg ²⁺ (mg·L ⁻¹)	K ⁺	SO ₄ ⁻²	Na ⁺	EC (dS·m ⁻¹)	pH
0.10	A20	8.0	17.9	2.3	3.6	2.8	0.8	177.5	7.5
	A40	3.7	13.9	1.6	5.4	3.9	0.5	144.0	7.6
	E20	5.0	18.8	2.8	6.3	4.3	0.5	210.0	7.4
	E40	4.4	16.5	2.3	15.8	5.3	0.5	251.5	7.4
	SI	5.5	16.4	2.4	4.6	3.3	0.5	158.2	7.4
0.30	A20	5.5	17.8	3.3	4.9	2.3	1.5	155.9	7.6
	A40	2.3	15.0	1.4	4.3	2.5	0.5	146.0	7.6
	E20	4.7	17.6	1.3	1.8	3.0	2.1	133.0	7.4
	E40	2.6	14.9	1.9	1.8	2.1	1.0	149.3	7.5
	SI	2.6	15.4	2.0	2.9	2.9	0.6	140.1	7.4
0.50	A20	2.5	16.5	1.3	3.8	2.9	1.0	150.0	7.6
	A40	1.9	10.5	1.0	1.5	2.3	0.9	122.5	7.3
	E20	1.7	8.4	1.0	2.4	2.0	1.4	114.3	7.4
	E40	2.4	16.3	2.6	0.5	3.0	6.9	200.0	7.4
	SI	2.5	24.0	2.0	1.9	2.6	0.8	175.5	7.3
0.70	A20	2.8	12.0	1.5	2.8	3.0	1.0	130.5	7.6
	A40	1.8	9.0	1.0	2.5	2.4	1.0	112.3	7.6
	E20	1.2	10.5	1.3	2.3	2.6	1.8	112.5	7.5
	E40	3.1	15.8	2.9	2.0	2.8	7.3	223.8	7.3
	SI	2.2	17.0	1.5	2.0	3.3	0.5	139.5	7.3
0.90	A20	1.8	9.8	1.6	2.1	3.5	1.0	117.5	7.5
	A40	2.7	11.3	2.0	3.5	3.4	1.3	178.3	7.5
	E20	2.2	19.6	2.6	3.0	2.6	3.4	212.3	7.4
	E40	4.0	23.3	3.5	1.8	2.0	8.3	281.5	7.3
	SI	1.3	9.2	1.6	4.1	3.5	0.8	183.5	7.3

¹Depth of soil solution collection; ²treatments evaluated: SI: no irrigation; E20: treated domestic sewage applied at 0.20 m; E40: treated domestic sewage applied at 0.40 m; A20: surface reservoir water applied at 0.20 m; A40: surface reservoir water applied at 0.40 m. ³Coefficient of variation.

the plants, and the leaching in the soil profile. Santos et al. [9], Heidarpour et al. [11], and Pereira et al. [34] also observed an increase in Ca²⁺ and Mg²⁺ caused by the TDS in the soil.

The K⁺ did not present a behavior pattern for the deep extraction of the solution or between treatments (Table 4), that is, neither water quality nor irrigation management promoted changes in the exchangeable contents of K⁺. In some studies, there are reports of decrease in its concentration in the soil due to the substitution of K⁺ by the Na⁺ of the effluent [34]. According to Feigin et al. [2], even though there is an increase in the K⁺ concentration available due to disposal of wastewater onto the soil, the amount of that nutrient as required by the plants is so high that effluent irrigation alone is rarely able to adequately supply plants.

As for the concentration of SO₄⁻² (Table 4) and potassium, it was not possible to define a standard between treatments or solution collection depths; however, the TDS provided a higher concentration of this nutrient compared to SRW, regardless of rainy or dry season (Table 3).

The concentration of Na⁺ (Table 4) increased according to depth of soil solution collection, with significant changes for the treatments irrigated with TDS. This result is justified by the concentration of this element in the irrigation water (Table 2). In a study by Andrade et al. [35], the authors sought to evaluate the behavior of salts in the soil and the effect of rains on leaching in an irrigated area of Ceará, the results demonstrating accumulation of Cl⁻ and Na⁺ salts in

irrigated areas, noting that the rains of the region were sufficient to return the concentration of these salts as in conditions of nonirrigated areas, so it is important to monitor the increase of ions in the soil solution so that soil salinization does not occur in the long term.

Regarding EC (Table 4), only the E20 treatment had a decrease along the solution collection depth, whereas for the other treatments, the opposite occurred, with salinity increasing proportionally with the layers of the soil. This increase in salinity is due to the Na⁺ concentrations provided by the TDS in depth and the SRW by the severe degree of use restriction, according to the Ayers and Westcot [36] classification.

Soil pH is one of the factors that most influence the availability of nutrients for plants. The pH of soil solution (Table 4), regardless of treatment and depth, showed similarity, without significant changes in irrigation water quality (TDS and SRW). The results found follow the reports by Fonseca et al. [15] and Duarte et al. [14].

The PCA allowed to distinguish possible relationships between measured variables and their relationships with treatments evaluated at different depths. For the depth of 0.10 m (Figure 2(a)), the variance explained by the first two principal components (PCs) was 60.68% and the variables that contributed most were Ca, Mg, Na, and EC. In CP2, the variables that contributed most were NO₃⁻, K, S, Na, and pH, corresponding to those with higher modulus in the respective axes of the graph of Figure 3(a).

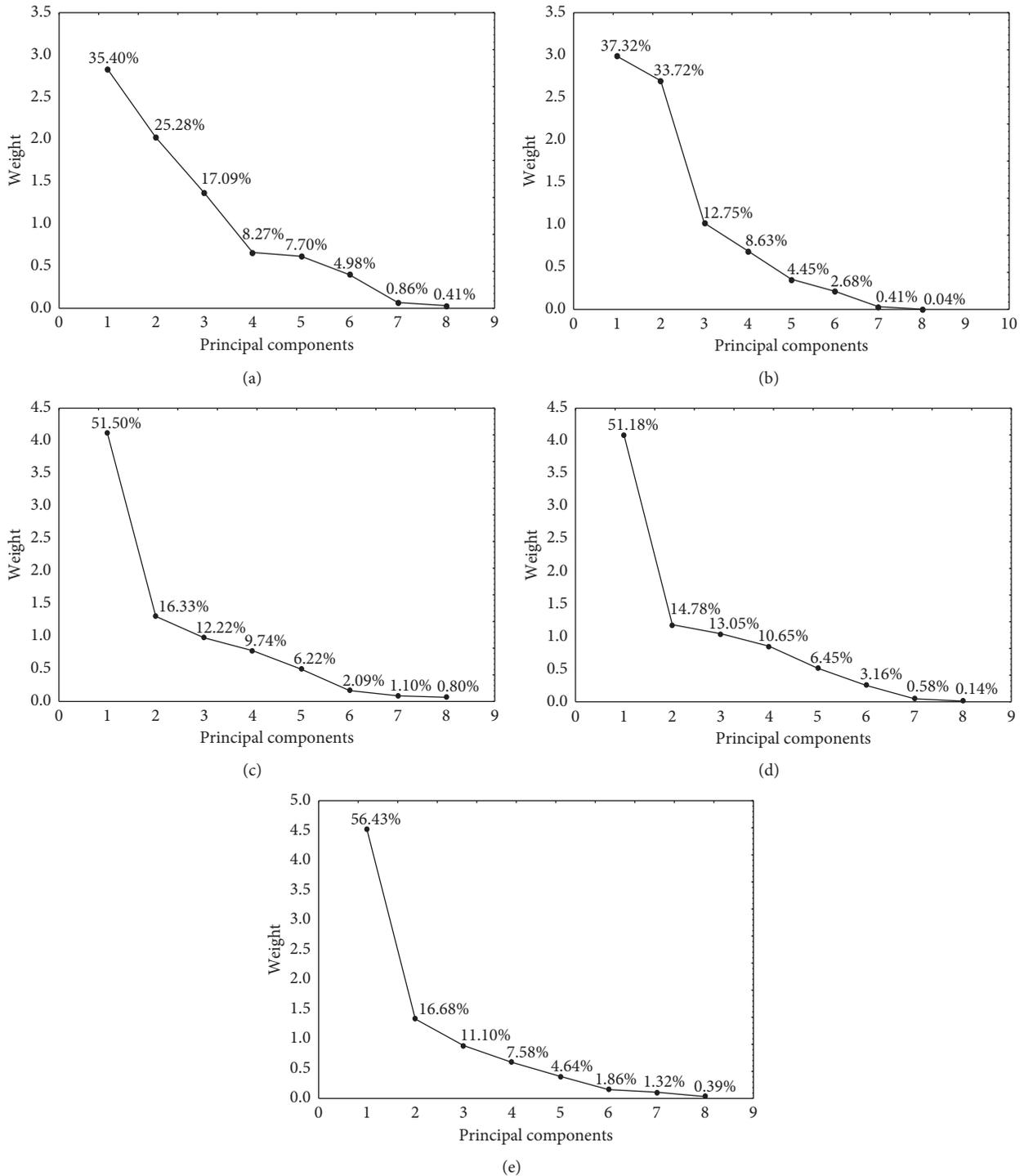


FIGURE 2: Explained variance of the set of variables for each main component for each collection depth. (a) Extractor depth 0.10 m; (b) extractor depth 0.30 m; (c) extractor depth 0.50 m; (d) extractor depth 0.70 m; (e) extractor depth 0.90 m.

Separation of the samples in the CPs can be explained by the relative contribution of the original variables in the calculation of each CP, and by the loadings graph (Figure 3(b)), it can be seen that the separation in this evaluation is divided by the average concentration of anions and cations present in the solution at the time of each collection for this depth.

When the loadings and scores are overlapped (Figures 3(a) and 3(b)), the contribution of the CP1 variables is a function of the treatments irrigated with TDS, where the contribution of each variable was well balanced, with Mg (33%), Ca (23%), EC (21%), and Na (17%); this result evidences the high concentration of these elements present in the TDS (Table 3) used in crop irrigation. For CP2, the

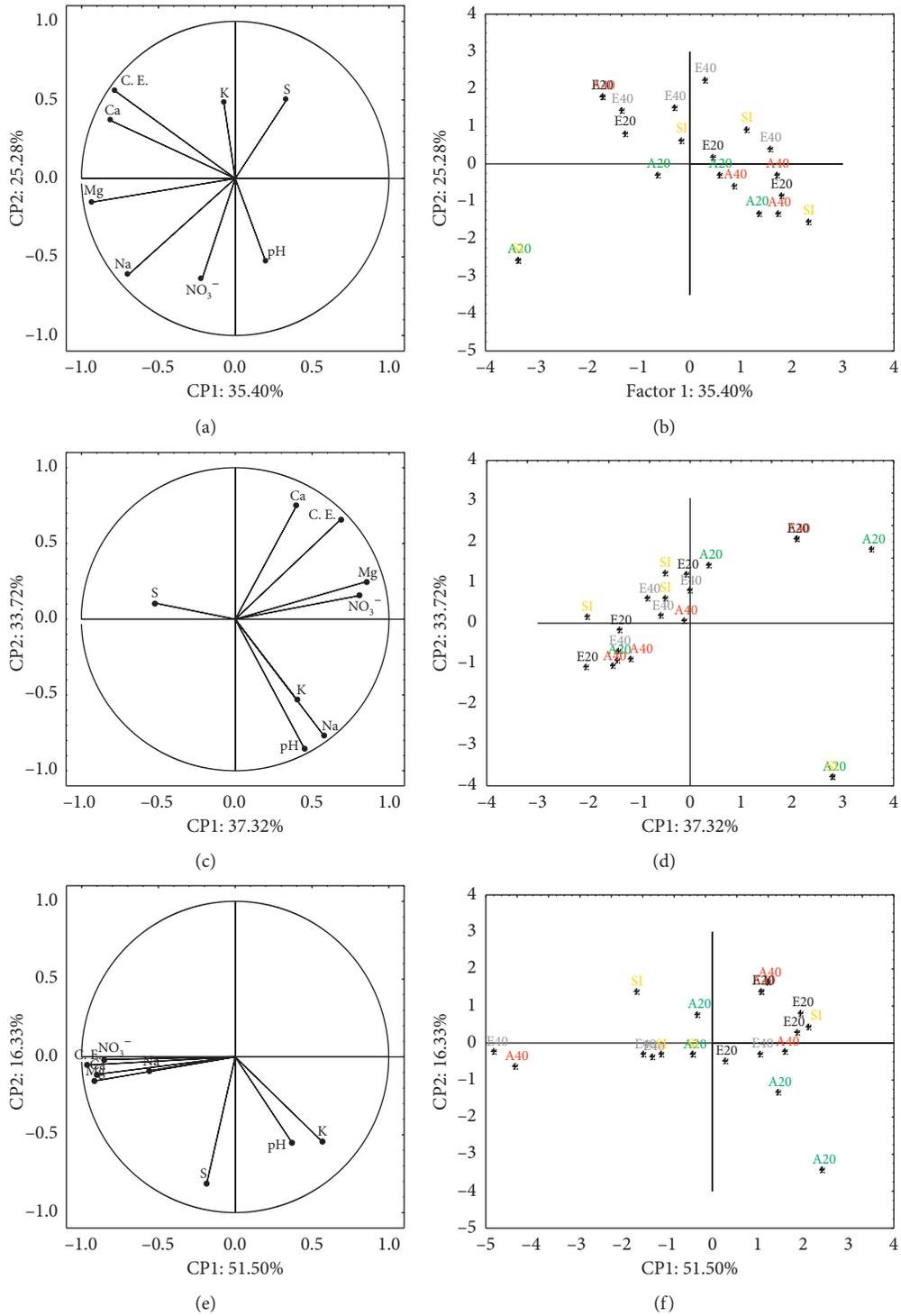


FIGURE 3: Continued.

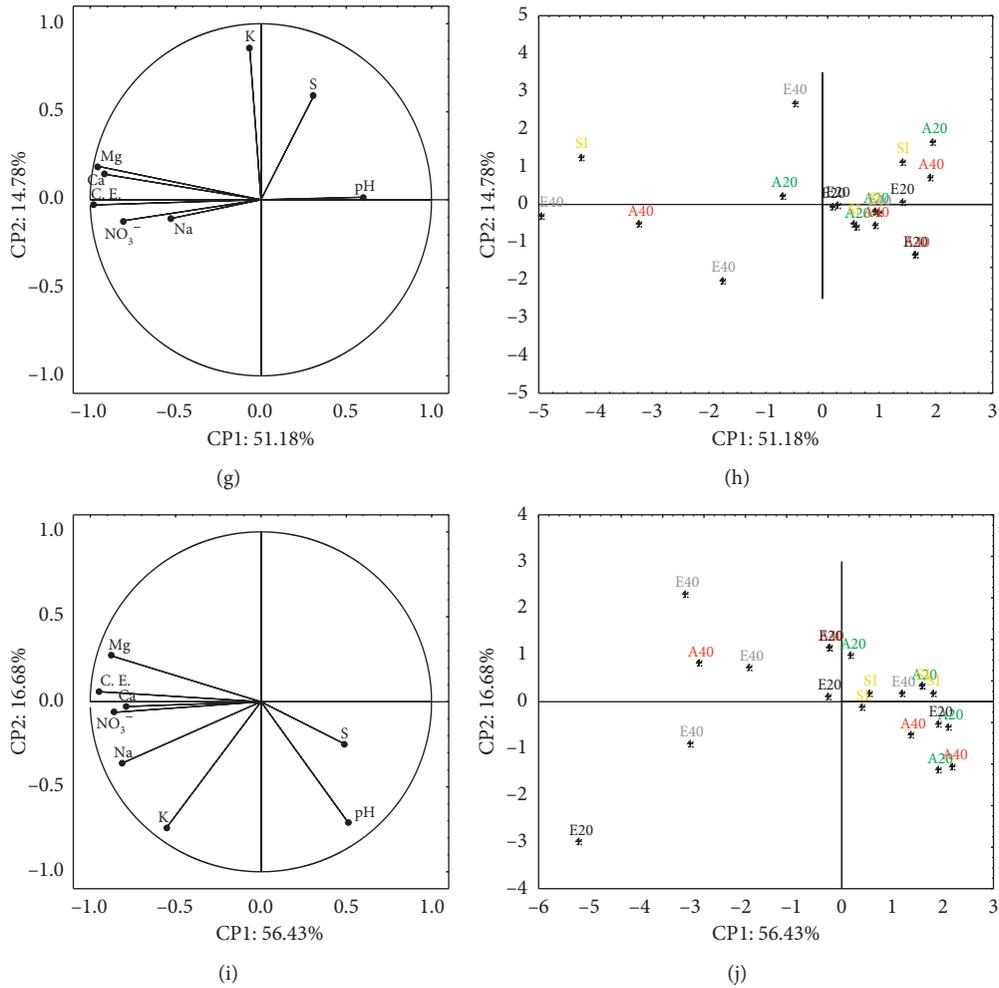


FIGURE 3: Two-dimensional representation (loadings-scores) of the principal component analysis for soil solution of each depth. (a, b) Extraction depth 0.10 m; (c, d) draw depth 0.30 m; (e, f) extraction depth 0.50 m; (g, h) draw depth 0.70 m; (i, j) draw depth 0.90.

variables that influenced the separation of this component were NO₃⁻ (20%), Na (18%), S (12%), K (11%), and pH (13%). The treatments irrigated with SRW and the SI suffered more interference from CP2 variables, emphasizing the treatment with SRW (0.20 m); in this case, the chemical fertilization of fertigation (Nitrocálcio, MAP) and soil moisture conditions close to the capacity of (0.35 cm³·cm⁻³) may have influenced the availability of these elements in the soil solution.

At the 0.30 m soil solution depth (Figure 2(b)), the variance explained by the first two components was 71.04%. The variables that contributed most to CP1 were Mg (24%), NO₃ (22%) and CP2 (26%), Na (21%), Ca (20%), and K in the respective axes of the graph in Figure 3(c), and the EC (16%) had similar weight for both COP. The overlap of the graphs for loadings and scores (Figures 3(c) and 3(d)) did not allow to observe the influence of each variable in the samples, without the clear separation of the treatments for each CP; this result may be due to the homogeneity of the soil solution between treatments, this depth also being a zone equidistant in relation to the depth of the dripping

tapes, that is, a region with higher concentration of elements from irrigation and fertilization water.

When analyzing the depth of 0.50 m in the PCA (Figure 2(c)), it was possible to evidence that 67.83% of the total variance verified was explained by the first two components. The most important variables were CP, Mg, Ca, and NO₃⁻, and for CP2, the most important variables were S, pH, and K, in these specific orders of importance for both CPs (Figure 2(e)). As shown in the score graph of Figure 3(f), treatments with irrigation at 0.40 m depth with TDS presented smaller projections of the samples for each treatment compared to CP1; another relevant observation is that all E20 treatments were displaced towards the positive side, evidencing the weight of the variables EC, Mg, Ca, and NO₃⁻ in the separation of CP1.

For the soil solution depth of 0.70 m, the PCA (Figure 2(d)) showed that 65.96% of the total variance verified was explained by the first two components. The variables with the highest influence on CP1 were EC, Mg, Ca, and NO₃⁻; in CP2, the most important variables were K and S in these specific orders of importance for both CPs

(Figure 3(g)). In the score chart of Figure 3(h), it can be seen that treatments with irrigation at 0.20 m depth and SI treatment were shifted to the positive side, evidencing the weight of the variables EC, Mg, Ca, and NO_3^- in the separation of CP1.

At the depth of 0.90 m soil solution extraction (Figure 2(e)), the variance explained by the first two principal components was of 73.11%. The variables that contributed most to CP1 were EC (19%), Mg (17%), NO_3^- (16%), Ca (14%) and Na (14%) and the CP2 variables were K (41%) and pH (38%), in the respective axes of the graph as presented in Figure 3(i). The overlap of loadings and score graphs (Figures 3(i) and 3(j)) did not allow for the grouping of irrigated treatments; however, SI treatment samples were grouped on the positive side of the score chart, which shows an influence of the variables in CP1 in the deeper layers of soil for SI treatment.

In the first two principal components, for all the depths of soil solution sampling in the first sugar cane smear, it was possible to observe that some variables were repeated with higher influence on the CPs, such as Ca, Mg, NO_3^- and CE, which express and better describe the different management adopted. Wang et al. [37] applying the principal components to assessing the soil quality irrigated with wastewater by long-term, observed that the Mg and CE were attributes able to distinguishing the treatments. However, it was not possible to determine the differences between treatments, which shows the complexity of quantifying significant changes in relation to the evaluated treatments. It is also worth mentioning that the number of samples collected may have been lower than necessary to distinguish groups and the expression of these parameters can also be justified by the mobility of these nutrients in the soil solution.

The results of the estimation of sugarcane production are presented in Table 5. The difference in EPC of the irrigated treatments in relation to the treatment without irrigation may have been influenced mainly by the greater availability of water in the soil as well as by the nutrient supply provided by the treatments, where the demand for N, P and K required for its development was complemented by fertigation when insufficient with regard to water quality, mainly in the case of treatments irrigated with water, since the concentration of these nutrients present in SRW was lower than the concentration of nutrients in TDS. These results are much higher than the national average ($70 \text{ t}\cdot\text{ha}^{-1}$) and the state of São Paulo ($78.2 \text{ t}\cdot\text{ha}^{-1}$) - Safra 2014/2015, according to CONAB [38], for sugarcane without irrigation.

As can be observed in the results (Table 6), it is possible to assume that the nutrients from the irrigation water with TDS can replace mineral fertilization without causing damage to the plant, with good gains in the production of the crop, allowing to save fertilizers without interfering in the technological quality of sugarcane, provided that the quality of water use was monitored, as the results obtained for the technological quality of the sugarcane did not present significant differences (Tukey's test) between treatments, and when compared to market/industry standards, these were satisfactory.

TABLE 5: Estimation of sugarcane yield (EPC, $\text{Mg}\cdot\text{ha}^{-1}$) in the first ratoon.

Estimated production	Treatments				
	A20	A40	E20	E40	SI
	218.74	203.84	230.41	229.98	166.66
	A	A	A	A	B
CV ¹ (%)	5.17	22.70	7.97	6.12	13.32

¹Coefficient of variation. Averages followed by the same letter do not differ from each other at the 5% probability level.

TABLE 6: Technological analysis compared to the standard [32] in the first ratoon sugarcane.

Attribute (%)	Treatments					Pattern	CV ⁷ (%)
	A20	A40	E20	E40	SI		
SSC ¹	19	19	19	19	19	>18	1.27
POL ²	17	18	17	17	17	>14	4.15
Purity ³	88	90	90	90	88	>85	1.49
Fiber ⁴	11	12	11	11	11	11 to 13	3.40
RS ⁵	0.6	0.5	0.5	0.6	0.6	<0.80	8.50
TRS ⁶	15	15	16	14	14	>15	1.16

¹SSC: soluble solids content of the juice; ²Pol: apparent sucrose of the juice; ³Purity: purity apparent of the juice; ⁴Fiber: content of fiber; ⁵RS: reducing sugars; ⁶TRS: total recoverable sugar. ⁷Coefficient of variation. The values shown in italics are within range, and the values shown in bold are outside range.

It is worth noting that the use of TDS did not negatively alter the technological quality and productivity of the crop, demonstrating potential use for sugarcane. For the reuse of TDS in sugarcane, there are positive responses of this management practice, in an experiment conducted in Lins, SP [39], where the increase in productivity was expected both by the response to higher N supply and for meeting the water needs of the crop [40]. In a study by Ali et al. [13], the application of wastewater effluents stimulated the yield characteristics of cereal winter crops compared to well water. Gonçalves et al. [41] demonstrated the efficiency in the export of nutrients and the economics of mineral fertilization when using TDS for irrigation of the sugarcane crop.

4. Conclusion

The present study is considered as a short-term study, so the selected variables are indicative for future long-term studies, which will allow technical definitions to create specific legislation for the use of this effluent in agricultural production.

The analytical determinations performed on soil solution samples and the use of CPA allow to distinguish in the soil layers which variables best express the use of TDS irrigation.

The variables Ca^{2+} , Mg^{2+} , NO_3^- , K^+ , and EC express and better describe the different managements adopted and can be used to monitor soil irrigation with TDS.

Quality of irrigation water did not interfere in technological quality, and the crop presented high productivity indexes when irrigated with TDS, with mean values of $230 \text{ ton}\cdot\text{ha}^{-1}$.

The results obtained regarding the parameters analyzed show the potential for reuse of good quality TDS as a valid alternative for the irrigation of sugarcane crops.

Data Availability

The quantitative data (measured/measured) used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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