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Carbon and nutrient contents in residues of pineapple crops fertigated with treated wasterwater

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ABSTRACT: The use of treated wastewater in agriculture is a viable alternative to produce foods, which can reduce production costs in pineapple crops by substituting partially irrigation and meeting the plants' nutritional demand. This management can increase yield and plant residue and soil nutrient contents for subsequent crops. The objective of this study was to evaluate carbon and nutrient contents in residues of pineapple crops fertigated with treated wastewater. The experiment was conducted using a randomized block design with four replications, in a split-plot arrangement. The plots consisted of five treated wastewater rates: 0, 100, 200, 300, and 400% of the maximum annual limit of Na applied to the soil, which corresponded to irrigation water depths of 0, 117.3, 234.1, 351.4, and 468.3 mm, respectively. The subplots consisted in three pineapple cultivars: Pérola, Smooth Cayenne, and IAC-Fantástico. The treatments with treated wastewater doses had no effect on dry weight accumulation, and content and accumulation of organic carbon, macronutrient, and sodium in pineapple crop residues. Pineapple plants of the cultivar Pérola have lower dry biomass and carbon accumulation than those of the cultivars IAC-Fantástico and Smooth Cayenne.

Key words: *Ananas comosus* var. *comosus*; cultivars; macronutrients; sodium; water reuse

Teor de carbono e nutrientes nos restos culturais do abacaxizeiro fertirrigado com água residuária tratada

RESUMO: O uso de águas residuárias tratadas na agricultura é uma alternativa viável para a produção de alimentos e que pode reduzir os custos de produção na lavoura de abacaxi ao substituir parcialmente a irrigação e atender a demanda nutricional das plantas. Este manejo pode aumentar a produtividade, os restos culturais da lavoura e os teores de nutrientes do solo para as safras subsequentes. O objetivo deste estudo foi avaliar os teores de carbono e nutrientes em restos culturais de abacaxizeiro fertirrigados com água residuária tratada. O experimento foi conduzido em delineamento de blocos casualizados com quatro repetições, em esquema de parcelas subdivididas. As parcelas consistiram em cinco tratamentos de efluente tratado: 0, 100, 200, 300 e 400% do limite máximo anual de Na aplicado ao solo, que corresponderam a lâminas de irrigação de 0, 117,3, 234,1, 351,4 e 468,3 mm, respectivamente. As subparcelas foram constituídas por três cultivares de abacaxi: Pérola, Smooth Cayenne e IAC-Fantástico. Os tratamentos com as doses de água residuária tratadas não afetaram o acúmulo de massa seca e o conteúdo e acúmulo de carbono orgânico, macronutriente e sódio nos restos culturais da cultura do abacaxizeiro. As plantas de abacaxi da cultivar Pérola apresentam menor biomassa seca e acúmulo de carbono do que as cultivares IAC-Fantástico e Smooth Cayenne.

Palavras-chave: *Ananas comosus* var. *comosus*; cultivares; macronutrientes; sódio; reuso de água

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Introduction

Pineapple yield can increase with the use of irrigation and new pineapple cultivars. Fertigation with treated wastewater (TWW) can be a viable alternative for increasing yield and decreasing the use of clear water and fertilizers, and contamination of water resources.

However, the use of TWW in agriculture should be done with criteria. Frequent applications increase soil exchangeable Na contents, possibly causing soil salinization and sodicity, and contaminate the soil and groundwater with other pollutants (Qadir et al., 2010; Xu et al., 2010; Muyen et al., 2011).

The nutritional demand for pineapple plants to obtain a high yield is high; K, N, and Ca are the most required nutrients (Pegoraro et al., 2014b; Souza et al., 2019). This demand varies depending on the cultivar and can be partially met by fertigation with TWW.

Approximately 70% of all nutrients in pineapple plants can return to the soil through crop residues. These nutrients are mineralized and can be used by subsequent crops (Pegoraro et al., 2014b). Nahrawi et al. (2011) incubated crop residues (leaves and roots on the soil surface) and found a decomposition of 90% of the leaves and 50% of the roots after 14 months, and decomposition of more than 80% of the leaves after 210 days. This indicates the potential of nutrient supply by mineralization of crop residues, especially leaves, which represent approximately 40% of the total dry weight of the plant (Pegoraro et al., 2014a; Maia et al., 2016).

Thus, objective of this work was to evaluate carbon and nutrient contents in residues of pineapple crops of different cultivars fertigated with different doses of treated wastewater.

Materials and Methods

The experiment was conducted between July 2015 and March 2017 in an experimental area at 15º46’14.5’’S, 43º19’14.31’’W, and 534 m altitude, near an urban TWW plant, where the effluent was obtained via a direct pipeline. Cotton, maize, cotton, and dry edible bean/common bean had been previous cultivated in the same plots in this area with the use of TWW treatments. The Köppen classification of the climate in the region was Aw (tropical with dry winter). The climate data used for the irrigation management were obtained from an automatic meteorological station installed in the experiment site.

The soil at the site was a Latossolo Vermelho Eutrófico of medium/clayey texture, and its physical and chemical attributes in the 0-20 cm layer were: pH (H_2O) = 6.4, OM = 1.17 dag kg^{-1}, P = 25.5 mg dm^{-3}, K = 111.88 mg dm^{-3}, Fe = 18,75 mg dm^{-3}, and Na = 0.18 $cmol_c$ dm^{-3} (Mehlich^{-1}); Ca = 3.53 $cmol_c$ dm^{-3} and Mg = 1.41 $cmol_c$ dm^{-3} (1 mol L^{-1} KCl); base saturation (V) = 72.75%; electrical conductivity (EC) = 0.57 dS m^{-1}; sand = 517 g kg^{-1}; silt = 222 g kg^{-1}; and, clay = 261 g kg^{-1}.

The experiment was conducted in a randomized block design, with a split-plot arrangement and four replications. The plots consisted of five dose levels of tertiary TWW, namely, 0, 100, 200, 300, and 400% of the annual maximum application limit of Na in the soil (150 kg ha^{-1}), which resulted, respectively, in the following depths: 0, 117.3, 234.1, 351.4, and 468.3 mm. The depths values were calculated based on Na concentration in TWW (analysis results ahead) and the times of application in each plot (Table 1). The applied volume was measured using a hydrometer.

The split-plots consisted in three pineapple cultivars: Pérola, Smooth Cayenne, and IAC-Fantástico. The TWW application started at 83 days after planting (DAP) via drip irrigation; after the TWW application, the plants were irrigated with clear water, also via drip irrigation, to supply the crop water demand.

The pineapple was planted in a doublerow spacing of 0.60 × 0.30 × 0.20 m (corresponding to 111,111 plants ha^{-1}), using slips propagules of the same age and with 30 cm length. The experimental units consisted of three double rows for each cultivar, with a total of 60 plants per split-plot.

At planting, 1.75 g of P (monoammonium phosphate) and 8 g FTE BR12 (micronutrients source: 1.8 g kg^{-1} B; 0.8 g kg^{-1} Cu; 3.0 g kg^{-1} Fe; 2.0 g kg^{-1} Mn; 0.1 g kg^{-1} Mo; 9.0 g kg^{-1} Zn) were applied per plant. During the vegetative stage (beginning at 218 DAP), fertilization was complemented with N and K through fertigation, with application every two weeks, for a total of 20 g $plant^{-1}$ of N (urea) and 12.45 g $plant^{-1}$ of K (KNO_3) (Table 1) until forcing date (Cardoso et al., 2013). This fertilization schedule was followed to provide a balanced supply to all of the plants of the nutrients that most affect growth and production.

Simple samples of TWW were collected monthly during the plant growth, at the end of the lateral lines and at the time of application, placed in identified containers, and sent to a laboratory for analyses, according to the methodologies described by Baird et al. (2017). The analysis of the samples (n =11) showed the following means (mg L^{-1}): 90.5 of N, 4.1 of P, 47.2 of K, 125.2 of Na, 38.1 of Ca, 6.6 of Mg, 0.18 of B, 0.92 of Fe, 0.17 of Mn, 184.8 of Cl, and chemical oxygen demand of 163.1. The samples presented pH of 7.5 and electrical conductivity of 1.7 dS m^{-1}.

The TWW doses (mm), main constituents of the TWW, and nutrients applied to the soil via fertigation during the experiment are described in Table 1.

The fruits were harvested between 18 and 20 months after planting, when the irrigation was suspended. The crop residues were collected after the fruit and sucker harvest; three plants of each subplot were harvested and separated into roots, stem, leaves, and peduncle. These parts were weighed to determine their fresh weight, and then dried in a forced-air circulation oven at 65 °C until constant weight to determine their dry wight. The total dry weight was calculated by summing the dry weights of the parts. The total dry weight was converted into Mg ha^{-1}, according to the plant population (111,111 plants ha^{-1}) and used to calculate the total contents (Mg ha^{-1}) of the nutrients evaluated.

The dry weight of each plant part of each plant was used to determine the content (dag kg^{-1}) and accumulation (g) of

Table 1. Nitrogen (N), potassium (K_2O), and sodium (Na) applied to the soil via treated wastewater (TWW, mm) and mineral fertilization (MF, kg ha^{-1}) in each treatment for pineapple crops.

Treatment (mm)*	N			K_2O			Na	
	MF	TWW	Total	MF	TWW	Total	TWW	Total
0.0	2200	0.0	2200	1667	0	1667	0	0
117.3	2094	106.0	2200	1600	66.9	1667	150.9	150.9
234.1	2016	184.1	2200	1533	133.7	1667	301.4	301.4
351.4	1938	262.3	2200	1466	200.5	1667	452.4	452.4
468.3	1860	340.0	2200	1400	267	1667	602.8	602.8

*Doses of TWW (mm) applied representing 0%, 100%, 200%, 300%, and 400% of the maximum annual limit of Na applied to the soil (150 kg ha^{-1}).

organic carbon, macronutrients (N, P, K, Ca, Mg, and S) and sodium, according to the methodology proposed by Tedesco et al. (1995). The mean organic carbon, macronutrient, and sodium contents in the dry biomass of crop residues and total biomass were also evaluated.

The data were subjected to analysis of variance. Regression analysis was used for the quantitative factor with significant effect in the analysis of variance. The qualitative factors were compared by the Tukey test ($p \leq 0.05$).

Results and Discussion

The variables evaluated were not affected by the treated wastewater (TWW) doses used. Therefore, the use of TWW does not affect the dry weight accumulation, and contents and accumulations of organic carbon, macronutrients, and sodium in pineapple crop residues.

Significant differences between the cultivars studied were found for total dry weight accumulation for most plant parts (Table 2). Organic carbon accumulation was also different, but without differences in contents. The cultivars had significant effect on content of phosphorus (P) in the peduncle, potassium (K) in the peduncle and roots, calcium (Ca) in the leaves, stem and peduncle, magnesium (Mg) in the leaves, stem, and peduncle, and sulfur (S) in the stem and roots (Tables 3, 4, and 5).

The cultivars had significant effect on N, P, K, and Mg accumulation in leaves, stem, roots, and total biomass. In addition, the cultivars affected calcium accumulation in leaves, stem, and total biomass, sulfur accumulation in the stem and total biomass, and sodium accumulation in leaves, roots, and total biomass (Tables 3, 4, and 5).

The cultivars IAC-Fantástico and Smooth Cayenne were similar regarding crop residue production, and had higher dry weight accumulation in the leaves, stem, and total biomass than the cultivar Pérola (Table 2). These differences are explained by differences between cultivars in morphology and dry weight distribution to plant parts, which results in different harvest indexes, and other differences, as found by Pegoraro et al. (2014a) and Maia et al. (2016).

High values of dry weight per hectare were found, confirming that pineapple plants have high carbon fixation capacity, despite their CAM metabolism and, consequently, present high dry biomass yield even when compared to plants of C_3 and C_4 metabolisms (Nobel, 1991). The acidic metabolism of crassulacean plants is a survival strategy for droughts, and not necessarily for yield. However, irrigation causes an expressive response in dry biomass yield of plants

Table 2. Dry weight accumulation in plant parts and total biomass of pineapple plants of the cultivars IAC-Fantástico, Pérola, and Smooth Cayenne grown under fertigation with different doses of treated wastewater.

Cultivar	Dry weight (g plant^{-1})					
	Leaves	Stem	Peduncle	Root	Total dry weight	Total (Mg ha^{-1})
IAC-Fantástico	760.6a	173.1a	8.8a	27.9a	970.4a	107.82
Pérola	467.1b	98.0b	16.0a	14.0b	595.1b	66.12
Smooth Cayenne	899.6a	153.5a	17.0a	20.1ab	1090.2a	121.13
Mean	709.1	141.5	13.9	20.6	885.2	98.3

Means followed by the same letter in the column are not different by the Tukey test at 5% significance.

Table 3. Organic carbon content and accumulation in plant parts and total biomass of pineapple plants of the cultivars IAC-Fantástico, Pérola, and Smooth Cayenne grown under fertigation with different doses of treated wastewater.

Cultivar	Organic carbon										
	Content (dag kg^{-1})					Accumulation (g plant^{-1})					
	Leaves	Stem	Peduncle	Root	Mean content	Leaves	Stem	Peduncle	Root	Total accumulation	Total accumulation (Mg ha^{-1})
IAC-Fantástico	50.4a	46.2a	45.8a	45.9a	49.5a	381.44a	80.92a	3.98a	12.74a	479.1a	53.23
Pérola	48.2a	46.6a	45.9a	45.7a	47.5a	221.84b	45.25b	7.41a	6.44b	280.9b	31.21
Smooth Cayenne	48.7a	46.5a	45.8a	46.8a	48.1a	433.16a	71.97a	7.76a	9.42ab	522.3a	58.03
Mean	49.1	46.4	45.9	46.1	48.4	301.6	66.1	6.4	9.5	427.4	47.5

Means followed by the same letter in the column are not different by the Tukey test at 5% significance.

Table 4. Macronutrient content and accumulation in plant parts and total biomass of pineapple plants of the cultivars IAC-Fantástico, Pérola, and Smooth Cayenne grown under fertigation with different doses of treated wastewater.

Cultivar	Content (dag kg^{-1})					Accumulation (g plant^{-1})					
	Leaves	Stem	Peduncle	Root	Mean content	Leaves	Stem	Peduncle	Root	Total accumulation	Total accumulation (Mg ha^{-1})
						Nitrogen					
IAC-Fantástico	2.1a	1.6a	1.1a	1.1a	1.9a	15.945a	2.76a	0.10a	0.32a	19.1a	2.12
Pérola	2.1a	1.7a	1.1a	1.3a	1.9a	9.161b	1.62b	0.16a	0.17b	11.1b	1.23
Smooth Cayenne	2.2a	1.6a	1.1a	1.2a	2.0a	19.188a	2.46a	0.19a	0.26ab	22.1a	2.46
Mean	2.1	1.6	1.1	1.2	1.9	14.8	2.3	0.1	0.2	17.4	1.9
						Phosphorus					
IAC-Fantástico	0.05a	0.06a	0.02b	0.05a	0.05a	0.36ab	0.10a	0.002a	0.015a	0.48ab	0.05
Pérola	0.05a	0.06a	0.03ab	0.06a	0.05a	0.23b	0.06b	0.005a	0.008b	0.31b	0.03
Smooth Cayenne	0.06a	0.07a	0.04a	0.05a	0.06a	0.52a	0.11a	0.007a	0.009b	0.64a	0.07
Mean	0.05	0.06	0.03	0.05	0.05	0.37	0.09	0.004	0.01	0.47	0.05
						Potassium					
IAC-Fantástico	1.76a	0.91a	1.06b	0.89a	1.53a	12.84ab	1.63a	0.10a	0.25a	14.82ab	1.65
Pérola	1.96a	0.90a	1.72a	0.69b	1.70a	9.24b	0.87b	0.27a	0.09b	10.47b	1.16
Smooth Cayenne	1.71a	0.77a	1.58a	0.69b	1.51a	15.15a	1.20ab	0.30a	0.14b	16.78a	1.86
Mean	1.81	0.86	1.45	0.75	1.58	12.41	1.23	0.22	0.16	14.02	1.55
						Calcium					
IAC-Fantástico	0.46b	0.51b	0.38ab	0.26a	0.47a	3.45ab	0.91a	0.03a	0.07a	4.46ab	0.50
Pérola	0.56a	0.47b	0.33ab	0.39a	0.53a	2.53b	0.48b	0.05a	0.05a	3.12b	0.35
Smooth Cayenne	0.43b	0.74a	0.29ab	0.29a	0.48a	4.03a	1.12a	0.04a	0.06a	5.25a	0.58
Mean	0.48	0.57	0.33	0.31	0.49	3.33	0.83	0.04	0.06	4.28	0.47
						Magnesium					
IAC-Fantástico	0.19b	0.09a	0.11a	0.07a	0.16a	1.43a	0.15a	0.01a	0.02a	1.60a	0.18
Pérola	0.16ab	0.07b	0.06c	0.10a	0.14b	0.72b	0.08b	0.01a	0.01b	0.82b	0.09
Smooth Cayenne	0.21a	0.06c	0.08b	0.07a	0.17a	1.89a	0.09b	0.01a	0.01b	2.00a	0.22
Mean	0.19	0.07	0.08	0.08	0.15	1.35	0.10	0.01	0.01	1.21	0.16
						Sulfur					
IAC-Fantástico	0.06a	0.07b	0.04a	0.07b	0.07a	0.50a	0.13ab	0.003a	0.020a	0.65ab	0.07
Pérola	0.06a	0.08ab	0.03a	0.10a	0.07a	0.31a	0.08b	0.005a	0.014a	0.41b	0.05
Smooth Cayenne	0.05a	0.10a	0.04a	0.07b	0.06a	0.52a	0.15a	0.006a	0.014a	0.69a	0.08
Mean	0.06	0.08	0.04	0.08	0.07	0.44	0.12	0.005	0.016	0.58	0.07

Means followed by the same letter in the column are not different by the Tukey test at 5% significance.

Table 5. Sodium content and accumulation in plant parts and total biomass of pineapple plants of the cultivars IAC-Fantástico, Pérola, and Smooth Cayenne grown under fertigation with different doses of treated wastewater.

Cultivar	Sodium										
	Content (dag kg^{-1})					Accumulation (g plant^{-1})					
	Leaves	Stem	Peduncle	Root	Mean content	Leaves	Stem	Peduncle	Root	Total accumulation	Total accumulation (Mg ha^{-1})
IAC-Fantástico	40.2a	35.7a	38.0a	83.5a	39.4a	26.40a	6.25a	0.35a	2.40a	35.4a	0.0039
Pérola	34.2a	54.2a	32.3a	78.7a	38.2a	14.77b	5.56a	0.54a	1.12b	22.0b	0.0024
Smooth Cayenne	34.3a	67.2a	37.7a	112.1a	43.1a	26.32a	8.87a	0.62a	2.25a	38.1a	0.0042
Mean	36.2	52.4	36.0	91.4	40.2	22.50	6.90	0.51	1.92	31.8	0.003

Means followed by the same letter in the column are not different by the Tukey test at 5% significance.

with this type of metabolism of carbon fixation (Nobel, 1991; Stewart, 2015).

Considering the distribution of dry weight of plant parts in the crop residues, the cultivars IAC-Fantástico, Pérola, and Smooth Cayenne had similar values: 78.4, 78.5, and 82.5% of leaves; 17.8, 16.5, and 14.1% of stem; 0.9, 2.6, and 1.6% of peduncle; and 2.9, 2.4, and 1.8% of roots, respectively.

The treatments (TWW doses and cultivars) had no effect on carbon content in the plant parts and mean content in the dry biomass; however, the cultivar Pérola had lower organic carbon and total dry weight accumulation in the plant parts, except the peduncle (Table 3).

All organic carbon comes from the atmosphere and is fixed by photosynthesis as the plant grows. As the crop residues decompose on the soil, part of this carbon is converted into organic matter, and other part is released to the atmosphere as CO_2 due to the action of microorganisms. The higher the crop capacity in fixing and accumulating carbon, the lower the carbon footprint of the crop, and the higher the benefits to the environment, since CO_2 is one of the gases responsible for the greenhouse effect and climate changes.

According to the results, approximately 1,900 kg ha^{-1} of the 2,200 kg ha^{-1} of N applied to the soil were accumulated in the plants; and 1,550 kg ha^{-1} of the 1,666.7 kg ha^{-1} of K applied to the soil were accumulated in the plants (Table 1). These results correspond to approximately 86.4% of the N and 93% of the K applied to the soil. Therefore, a high proportion of the nutrients applied to the soil returns to the soil and can be used by subsequent crops, and this should be considered for soil fertilization managements, as found by Pegoraro et al. (2014a).

The cultivars had no significant difference in N contents in the plant parts, with means of 2.1, 1.6, 1.1, and 1.2 dag kg^{-1} for leaves, stem, peduncle, and roots, respectively (Table 4). Considering the crop residues, the pineapple plants presented higher N contents and accumulations in the leaves, indicating that this is a preferential plant part for this nutrient to be translocated in the plant. The mean N content in the crop residues was 1.9 dag kg^{-1}.

Regarding the C to N ratio (C:N) of the crop residues, the leaves, stem, peduncle, and roots had C:N of 23.3, 29, 41.7, and 38.42, respectively, with mean of 25.5. Crop residues with low C:N (<25), in general, favor mineralization, whereas a higher C:N (>35) immobilizes carbon with less losses to the atmosphere. According to the results, the peduncle and roots have slower decomposition than the other plant parts, contributing to carbon sequestration (immobilization).

The cultivars IAC-Fantástico and Smooth Cayenne had higher N accumulation in leaves, stem, and total biomass. N is the most absorbed nutrient by the plant (Pegoraro et al., 2014b), as confirmed in the present work (Table 4). The N demand is high, reaching up to 20 g $plant^{-1}$ for maximum yield and fruit size (Cardoso et al., 2013). This explains the large amount of N accumulated in the total biomass and the high nitrogen content in the area (1.23 to 2.46 M ha^{-1}), which requires attention regarding the use and disposal of crop residues.

The lower N accumulation found for the crop residues of the cultivar Pérola does not necessarily mean that this cultivar demands less N. The harvest indexes of the cultivars studied are different (Vilela et al., 2015) and higher for Pérola (49%) (Maia et al., 2016), indicating that this cultivar exports, proportionally, half of its dry weight and consequently large part of absorbed nutrients. This also explains the differences between cultivars for other nutrients.

The cultivars had significantly different P content in the peduncle (Table 4). In this plant part, the cultivar Smooth Cayenne had had higher P content than the IAC-Fantástico. The cultivar Pérola had lower P accumulation in the stem than the other cultivars, which also does not mean lower demand of P by this cultivar. The peduncle, which presented no differences in P for the cultivars evaluated, had mean P accumulation of 0.004 dag kg^{-1}.

P is the least required nutrient by pineapple crops (Maia et al., 2020), as confirmed by the results for the crop residues (Table 4). However, P is important in the plant's floral differentiation stage (Vásquez-Jiménez & Bartholomew, 2018).

K content was higher in the leaves (1.81 dag kg^{-1}) than in the other plant parts (Table 4). This high content, combined with the higher dry weight accumulation in the leaves, resulted in approximately 90% of the K in the pineapple plant crop residues to be in the leaves.

The cultivars had differences in K content for the peduncle and roots. IAC-Fantástico had lower K in the peduncle and higher K in the roots than the other cultivars. The cultivar Smooth Cayenne had higher K accumulation in the leaves than the cultivar Pérola. The cultivar IAC-Fantástico had higher K accumulation in the stem than the cultivar Pérola, and higher K accumulation in roots than the other cultivars, which were significantly different from each other. The cultivars had similar K accumulation in the peduncle. The lower K accumulation in the crop residues of Pérola plants does not necessarily mean that this cultivar demands lower amounts of K.

The total accumulated K found was close to the amount applied per plant (15 g of K_2O), indicating that a large part of the K applied was absorbed by the plants. This is explained by the high frequency and small amounts of K_2O applied during the plant growth and use of drip irrigation.

The accumulated K in crop residues per hectare was 1.55 Mg. This confirms that K is the most required macronutrient by pineapple plants (Pegoraro et al., 2014b; Souza et al., 2019) and denotes the need for a correct management of this residue to avoid high nutrient losses in the area, which affects soil fertility, resulting in economic and environmental losses.

Ca content in the leaves was higher in plants of the cultivar Pérola than in those of the cultivars IAC-Fantástico and Smooth Cayenne, which were similar to each other (Table 4). Smooth Cayenne presented the highest Ca content in the stem, and the other cultivars were similar for this plant part. The cultivar IAC-Fantástico had higher Ca content in the peduncle than the Smooth Cayenne. The cultivars had similar Ca content in the roots, with mean of 0.31 g $plant^{-1}$, which was similar to the mean content of the plant.

The Ca contents in leaves and stem were similar, in some cases, the Ca contents in the stem were higher than those found for leaves. Ca is usually described as a little mobile element in the plant that follow the flux of the transpiration chain. Therefore, a higher Ca content in leaves than in other plant parts was expected. This can also be explained by the low number of stomata in the pineapple leaves, which results in lower respiration rates when compared to other species, besides the characteristic acidic metabolism of crassulacean species (Bartholomew, 2018).

The cultivar Smooth Cayenne had higher Ca accumulation in leaves than the Pérola, which was also found for total accumulation. The cultivar Pérola had lower Ca accumulation in the stem than the other cultivars. The cultivars had similar Ca accumulation in the peduncle and roots.

Considering the soil fertilization, if the subsequent crop that will use the crop residues is pineapple, which has low Ca demand (Vásquez-Jiménez & Bartholomew, 2018) and Ca losses in the soil, the Ca contents in the total biomass (0.47 Mg ha^{-1}) are enough to meet the Ca demand, decreasing soil fertilization costs.

The cultivar Smooth Cayenne had higher Mg content in the leaves than the IAC-Fantástico (Table 4). The cultivar IAC-Fantástico had higher Mg content in the stem than the other cultivars; Smooth Cayenne presented the lowest Mg content. The cultivar IAC-Fantástico had higher Mg content in the peduncle than the other cultivars; and the cultivar Pérola presented the lowest content. The cultivars had similar Mg content in the roots. The cultivar Pérola presented the lowest mean content.

The cultivar Pérola had lower Mg accumulation in the leaves than the other cultivars, which was also found for total accumulation. The cultivar IAC-Fantástico had higher Mg accumulation in the stem and roots than the other cultivars. The cultivars had similar Mg accumulation in the peduncle.

The cultivars had no significant difference in S content and accumulation in the leaves and peduncle (Table 4), which was also found for mean content. The cultivar Smooth Cayenne had higher S content in the stem than the cultivar IAC-Fantástico, and the cultivar Pérola had higher S content in the roots than the other cultivars. The cultivars had similar S accumulation in the roots but presented significant difference for S accumulation in the stem; 'Smooth Cayenne' had higher S accumulation than the cultivar Pérola, which was also found for total accumulation.

Macronutrient accumulation in the crop residues of the cultivars IAC-Fantástico, Pérola, and Smooth Cayenne was, in decreasing order: N > K > Ca > Mg > S > P. The largest part of absorbed and accumulated nutrients is found in the leaves, and the lowest in the roots. The quantity of exported nutrients by pineapple plants is relatively high (Souza et al., 2019), which are those immobilized by fruits and propagative organs, and is even higher in cultivars that present higher harvest index.

Information on the amount of nutrients that returns to the soil through crop residues is important for the nutritional management of the subsequent pineapple crop. Considering that the decomposition of leaves is fast because of the low C:N, the nutrients will be released faster by the mineralization of the organic material.

The mean accumulations of nutrients in the crop residues of the cultivars were (mg ha^{-1}): 1.9 of N, 0.05 of P, 1.55 of K, 0.47 of Ca, 0.16 of Mg, and 0.07 of S. These high results explained the absence of response of the subsequent passion fruit crops to N and K fertilization found by Dias et al. (2017). Pineapple plants can accumulate (kg ha^{-1}): 898.32 of K, 451.71 of N, 134.27 of S, 129.17 of Ca, 126.41 of Mg, and 107.26 of P (Pegoraro et al., 2014b). The amount of these nutrients in the crop residues (Table 4) would be enough to meet the crop demand, except for P and S. Studies evaluating the dynamics of these nutrients in organic matter can indicate if, and how much the maintenance of crop residues in the area decreases the demand for fertilizations.

Several managements can be proposed for pineapple crop residues; the most common are burning and incorporation to the soil. The least recommended management, economically and environmentally, is the burning. Other managements include the use of these residues in biofuel production and animal feed, due to the large amount produced per hectare - the mean of the cultivars was 98.3 mg ha^{-1}, and the use as soil cover for no-till system.

The use of these residues for animal feed can be recommended for regions with low forage options; in this management, the manure produced should be returned to the soil to reduce nutrient losses and improve soil fertility. Considering agronomical, economic, and environmental aspects of the results of the present study, the most indicated options are the maintenance of crop residues as soil cover and the incorporation of crop residues to the soil.

The cultivars had no difference in Na contents in leaves, stem, peduncle, and roots (Table 5). The Na contents in roots, differently than those of other nutrients, were higher than those of other plant parts, approximately 2-fold the mean content. This indicates that the plant is restricting or compartmentalizing Na in roots, not allowing or decreasing its distribution and, consequently, its accumulation in the shoot, where it can have negative effects.

The cultivars IAC-Fantástico and Smooth Cayenne had higher Na accumulation in the leaves and roots than the Pérola, which was also found for the total accumulation, but with no differences from the other plant parts.

Approximately 602.8 kg ha^{-1} of Na was applied via TWW (Table 1), and there was a total mean accumulation of 3 kg ha^{-1} (Table 5), 0.5% of the total applied. Na can have negative effects on the environment, and change soil physical and chemical attributes, mainly clay dispersion.

Na is not an essential nutrient for most plant species (Marschner, 2012; Maathuis, 2014). However, the most C_4 and CAM species require Na ions for phosphoenolpyruvate regeneration, which is a substrate of the first carboxylation in the CO_2 fixation metabolic route for these types of metabolism (Marschner, 2012).

Na can be a beneficial or even an essential element for pineapple plants, although there are no studies proving this effect. Na promotes plant growth in some species by compensating some K functions, such as activation of ATPase enzymes, osmotic regulation, macronutrient absorption, carbohydrate synthesis, and stomatal opening and closure (Marschner, 2012; Maathuis, 2014).

Conclusions

The treated wastewater used does not affect the dry biomass accumulation, and content and accumulation of organic carbon, macronutrients, and sodium in the pineapple crop residues.

Pineapple plants of the cultivar Pérola have lower dry biomass and carbon accumulations in the crop residues than the cultivars IAC-Fantástico and Smooth Cayenne, with similar results for most macronutrients and sodium.

Macronutrient accumulation in pineapple crop residues has the following decreasing order: N > K > Ca > Mg > S > P.

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Compliance with Ethical Standards

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