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TECHNOLOGICAL INFORMATION

Accumulation of ions in soil fertigated with dilutions of dairy effluents in the Brazilian semi-arid region

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ABSTRACT. Wastewater is an alternative water source with the potential to guarantee agricultural productivity in semi-arid regions, where quantitative and qualitative scarcity is a limiting factor. This study aimed to analyze the effects of the application of dairy effluent dilutions on the alterations of sodium, calcium, magnesium, and nitrogen contents along the profile of an Ultisol cultivated with *Cereus hildmannianus* in the semi-arid region of Brazil. The experimental design used was a 5 x 5 factorial randomized block design with five dilutions of dairy effluent (T1 - only well water (WW); T2 - 0.1 x annual loading rate according to EPA (1981) (LW) plus WW; T3 - 0.2 x LW plus WW; T4 - 0.3 x LW plus WW; and T5 - 0.4 x LW plus WW) and five depths (0 to 0.10 m; 0.10 to 0.20 m; 0.20 to 0.30 m; 0.30 to 0.40 m and 0.40 to 0.50 m), with five replicates. *Cereus hildmannianus* cultivation lasted 240 days, and after this period, soil samples were taken to determine the contents of sodium, calcium, magnesium, and nitrogen. Fertigation using dairy effluent with up to 40% of the annual loading rate in Ultisol poses no risk of water and soil contamination by nitrogen leaching. Fertigation using dairy effluent in proportions of up to 20% of the annual loading rate poses no risk of soil degradation due to excessive accumulation of ions.

Keywords: wastewater; agroindustry; soil quality; crop management.

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Introduction

Water is considered a limited, public-domain natural resource with economic value. However, problems of water scarcity and pollution are increasingly frequent, in contrast with the limitation of freshwater reserves on the planet, combined with uncontrolled population growth, which favors the increase in water demand to meet mainly human, agricultural, and industrial consumption (Arenas-Sánchez, Rico, & Vighi, 2016; Boudiombo, Madden, Cusack, Cronin, & Ryan (2023); Liu, Liu, & Yang, 2016).

Agriculture accounts for 70% of all global water consumption; approximately 19% is destined for the industrial sector and 11% for domestic use (Ungureanu, Vlăduț, & Voicu, 2020; Khan et al., 2021). Among the various uses of water in the industrial sector, it is possible to highlight its utilization for processing needs, such as manufacturing, dilution, incorporation of water into a product, as well as in the process of refrigeration and sanitation needs inside the facilities (Aguiar, Martins, Almeida, Ribeiro, & Marto, 2022).

Food industries require a large amount of water at all stages of the production process and in the operational needs, generating a large amount of effluent, which needs to be treated before discharge into receiving water bodies (Ahmad et al., 2019).

The dairy industry plays a significant role in the food market segment, and water is an essential resource for the satisfactory performance of this sector at all stages of the process (Muniz, Silva, & Borges, 2020). The industrial flow and volume of effluents are directly related to the volume of water consumed by the dairy industry (Pereira, Borges, Heleno, Squillace, & Faroni, 2018). On average, 10 liters of effluent are generated per liter of processed milk (Krishna et al., 2022).

According to Bhuvaneshwari, Majeed, Manoj M., Jose, and Mohan (2022) and Muniz, Borges, Silva, Batista, and Castro (2022), dairy industries are considered one of the largest generators of wastewater. Water is used in processing, heating, cooling, cleaning, and sanitizing operations such as washing floors and cleaning products remaining in the tank, trucks, cans, pipes, tanks, and other equipment, which are routinely carried out.

The main organic contributors present in the wastewater are carbohydrates, proteins, and fats from milk. Its pH varies from neutral to slightly alkaline, tending to acidification due to the fermentation of milk sugar into lactic acid. These effluents cause several negative impacts on the environment when improperly managed due to the concentration of these elements (Bella & Rao, 2021; Ramos-Suarez, Zhang, & Outram, 2021).

Ofori, Puškáčová, Růžičková, and Wanner (2021) points out that the reuse of effluents can significantly reduce, or even eliminate, the impacts caused on the environment, in addition to the great potential for agricultural use, reducing the amount of water extracted from natural sources. However, irrigation with wastewater in agricultural soils can cause changes in the chemical properties, which may have positive effects on their fertility or trigger the accumulation of toxic materials in the soil, leading to environmental degradation (Costa, Alves, Batista, Mendes, & Souza, 2018; Costa, Vale, Batista, Travassos, & Portela, 2019; Costa et al., 2020; Mesquita et al., 2023).

In this context, the present study aimed to analyze the effects of the application of dairy effluent dilutions with well water on the alterations of sodium, calcium, magnesium, and nitrogen along the profile of an Ultisol cultivated with *Cereus hildmannianus* in the semi-arid region of Brazil.

Material and methods

This study was carried out in the Water Reuse Experimental Unit (UERA), which is an area of 770 m² (20 x 38.5 m), located at the Federal Rural University of the Semi-Arid Region (UFERSA), campus East, BR 110-Km 47, Presidente Costa e Silva neighborhood, Mossoro, state of Rio Grande do Norte, Brazil (5° 12' 29.32" S; 37° 19' 06.12" W; 18 m altitude).

According to the Köppen-Geiger classification, the climate of the region is BSh', hot and dry, with a rainy season between May and July and intense drought from September to December, with an annual rainfall lower than 650 mm and annual average temperature slightly higher than 26.5°C (Dubreuil, Fante, Planchon, & Sant'anna Neto, 2019).

According to the Brazilian Soil Classification System, the soil in the experimental area is classified as Argissolo Vermelho-Amarelo eutrófico (Ultisol). Table 1 lists its physical and chemical properties before the application of diluted dairy effluent.

Table 1. Physical and chemical properties of the Ultisol before the application of dairy effluent dilutions with well water.

Depth (m)	ρ_s g cm^{-3}	ρ_p g cm^{-3}	Sd	St .... kg kg^{-1}	Cl	Na^+	Ca^{2+} ....cmol$_c$ dm^{-3}.......	Mg^{2+}	N g Kg^{-1}
0.0 a 0.10	1.81	2.64	0.83	0.09	0.08	0.83	4.20	2.60	1.40
0.10 a 0.20	1.70	2.44	0.83	0.09	0.08	0.62	2.80	1.90	1.05
0.20 a 0.30	1.28	2.41	0.81	0.08	0.11	0.32	1.90	3.30	0.70
0.30 a 0.40	1.96	2.38	0.71	0.12	0.17	0.49	2.80	1.50	0.70
0.40 a 0.50	1.86	2.45	0.63	0.07	0.30	0.53	3.20	3.10	0.70

Note: ρ_s - Soil bulk density determined by the volumetric ring method; ρ_p - Soil particle density determined by the volumetric flask method; Sd, St and Cl - Sand, silt and clay determined by the pipette method; Na^+ - Sodium; Ca^{2+} - Calcium; Mg^{2+} - Magnesium; N - Nitrogen, according to the technical recommendations of EMBRAPA (Teixeira, Donagemma, Wenceslau, & Teixeira, 2017).

In the UERA, the experimental area was set up for the production of spineless cactus irrigated with dairy effluent dilutions of public-supply water. The effluent was collected from an aerated facultative pond of a dairy company in Mossoró, where the average daily flow rate is 35 m³, originated from the processing of pasteurized milk, dairy beverage, dulce de leche, cream cheese, curd cheese, Minas Frescal cheese and Sertão butter and the sanitation of the company (Marques, Cunha, Cunha, Silva, & Batista, 2016).

The dairy effluent was transported from the dairy company to the UERA in five 20-L waterproof tanks, always on the day of the fertigation of spineless cactus to minimize the loss fewer changes of its characteristics.

The water used in spineless cactus irrigation came from a deep well managed by the Water and Sewage Company of Rio Grande do Norte (CAERN) and was stored in a 16-m³ waterproof tank.

An experimental area of 49 m² was delimited in the UERA, with 25 plots, each one with dimensions of 1.0 x 1.0 m (1.0 m²) and a 0.50 m spacing between blocks and plots (Figure 1).

Figure 1. Experimental area.

The experiment was conducted in a randomized block design, evaluating the factors dairy effluent dilutions in well water and soil depths, according to the recommendations of Coelho, Batista, Silva, and Mesquita (2015).

For well water application, according to the recommendations of Mesquita, Pedrosa, Batista, and Andrade (2021), the following components were used: a) a 16-m^3 concrete tank; b) a 0.5-hp motor pump set with a screen filter, with 130-µm openings; c) A main line made of PVC with 32 mm diameter; and d) 20 lateral lines with non-pressure compensating emitters with nominal flow rate of 2.0 L h^{-1} spaced by 0.30 m.

The irrigation system was operated with public-supply water along the experimental period, under operating pressure of 100 kPa, using a glycerin manometer graduated from 0 to 400 kPa, accurate to 10 kPa.

Dairy effluent was applied as proposed by Coelho et al. (2015): a) Mixture of the effluent in a tank to homogenize the fluid, minimizing the effect of sedimentation; b) Measurement of the specific quantity with a 1-L graduated cylinder; c) Transfer of the quantity measured to a watering can; and d) Application of the effluent with a watering can directly in the soil, within each plot, minimizing the direct contact between the liquid and the spineless cactus plants.

The spineless cactus was planted on April 18, 2015 (Figure 2), using four 0.25-m-long seedlings per plot, buried at 0.15 m in the soil and spaced by 0.50 m. Along the crop cycle, no liming or mineral basal or top-dressing fertilization was performed.

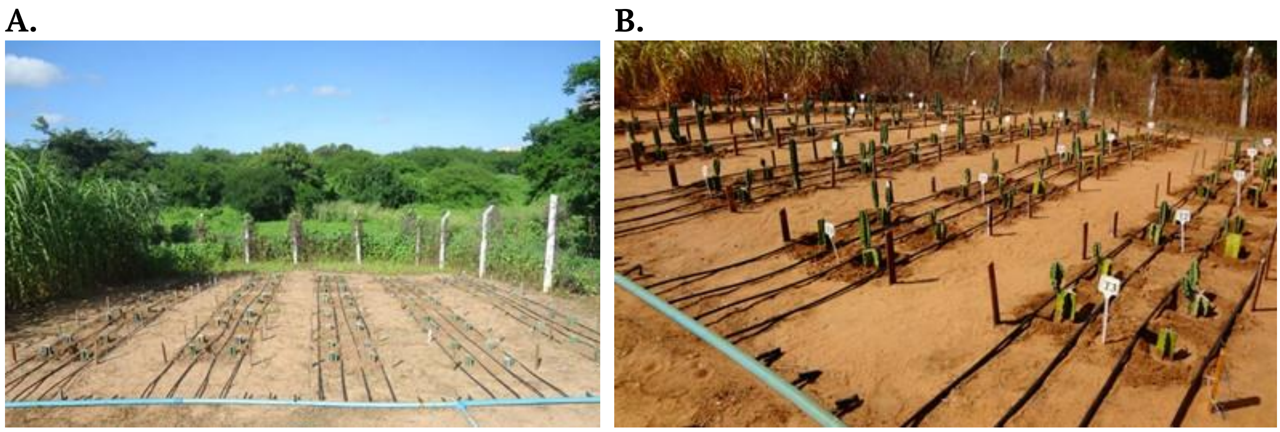

Figure 2. *Cereus hildmannianus* at the beginning (A) and in the intermediate phase (B) of the experiment.

The treatments applied, based on the criteria of the Environmental Protection Agency (EPA), presented in Equation 1, and on the water requirements of the crop, were: T1 - only well water (WW); T2 - 0.1 x annual loading rate (LW) plus WW; T3 - 0.2 x LW plus WW; T4 - 0.3 x LW plus WW; and T5 – 0.4 x LW plus WW.

$$Lw = \frac{Cp.(PR - ET) + 10U}{(1 - f)Cn - Cp} \tag{1}$$

Where:

L_W - annual loading rate, cm year^{-1};

Cp - nitrogen concentration in percolating water, mg L^{-1};

PR - local precipitation rate, cm year^{-1};

ET - crop evapotranspiration rate at the site, cm year^{-1};

U - nitrogen uptake by the crop, kg ha^{-1} year^{-1};

Cn - nitrogen concentration in the wastewater, mg L^{-1}; and

f - fraction of nitrogen removed by denitrification and volatilization.

During the experimental period, the dairy effluent and well water were chemically characterized every month, using three composite samples collected from April to December 2015. Table 2 presents the mean values of chemical characteristics of both dairy effluent and well water.

Table 2. Mean values of the chemical characteristics of the dairy effluent and well water along the experimental period.

	Na^+	Ca^{2+}	Mg^{2+}	N
	....mg L^{-1}.............................			
Dairy effluent	32.19	15.43	21.87	49.33
Well water	6.55	1.60	1.07	ND

Note: ND – Not determined.

In the treatments T1 to T5, well water was applied every 15 days from the planting of spineless cactus (*Cereus hildmannianus*) on April 18, 2015, until the end of the experiment, on December 18, 2015. However, the dairy effluent applications began on June 1, 2015. At the end of 240 days, all treatments received a gross depth of 227.14 mm of dairy effluent diluted with well water.

To evaluate soil quality, samples were taken in the layers from 0 to 0.10 m, 0.10 to 0.20 m, 0.20 to 0.30 m, 0.30 to 0.40 m, and 0.40 to 0.50 m, using a Dutch auger before and after 240 days of application of the dairy effluent dilutions with well water.

Four individual samples were collected within the wet strip formed by the drip irrigation system in each layer, obtaining one composite sample per depth in each of the 25 experimental plots.

In the Water, Soil and Plant Analysis Laboratory (LASAP) of UFERSA, the following soil chemical properties were determined: sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), and nitrogen (N), according to the technical criteria of EMBRAPA (Teixeira, et al., 2017).

The experiment was a 5 x 5 factorial randomized block design with five repetitions. The first factor was the five dairy effluent dilutions (T1 - only well water (WW); T2 - 0.1 x annual loading rate (LW) plus WW; T3 - 0.2 x LW plus WW; T4 - 0.3 x LW plus WW; and T5 – 0.4 x LW plus WW). The second factor was represented by the five soil depths 0 to 0.10 m, 0.10 to 0.20 m, 0.20 to 0.30 m, 0.30 to 0.40 m, and 0.40 to 0.50 m).

Data referring to soil properties were subjected to analysis of variance using the program SISVAR (System for Analysis of Variance), developed by Ferreira (2019). In cases of significance, Tukey test was applied for the single factors and the interaction.

Results

Sodium (Na^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}) contents were significantly ($p < 0.01$) affected by the single factors dairy effluent dilutions applied through fertigation and soil depths (Table 3). There was no significant interaction between dairy effluent dilutions and soil depths for Na^+, Ca^{2+}, and Mg^{2+} contents. N contents were not influenced by fertigation with dairy effluent at the different soil depths studied (Table 3).

Higher Na^+ contents were found in soil fertigated with T5 (913.65 cmol$_c$ dm^{-3}), in which the accumulation was 182.6% higher than in the T1 treatment (control). There was no significant difference in Na^+ accumulation in soil in the dairy effluent fertigation treatments T2 and T3, compared to the treatment irrigated only with well water (T1) in the first 240 days of *Cereus hildmannianus* cultivation (Table 3). As for the soil depth, Na^+ accumulation was higher on the surface, mainly in the 0.0 to 0.30 m layer (D1, D2, and D3). At depth from 0.0 to 0.1 m, Na^+ accumulation was 383.9% higher than that found from 0.4 to 0.5 m (Table 3).

Higher Ca^{2+} contents were observed under fertigation with T5 (3.44 cmol$_c$ dm^{-3}), where the accumulation was 47.6% higher than verified in the T1 treatment (control). The dairy effluent fertigation treatments T2, T3, and T4 did not differ statistically from T1 (Table 3). Ca^{2+} contents increased in the subsurface as a function of fertigation with dairy effluent, and the highest Ca^{2+} accumulation (3.11 cmol$_c$

dm^{-3}) was found at depths from 0.3 to 0.5 m (D4 and D5). There was no statistical difference between Ca^{2+} contents at depths D1, D2, and D3 (0.0 to 0.3 m) (Table 3).

Table 3. Sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), and nitrogen (N) contents at different depths of an Ultisol as a function of the diluted dairy effluent application in *Cereus hildmannianus* cultivation for 240 days in the semi-arid region of Brazil.

Sources of Variation	Degrees of freedom	[1]Pr>Fc			
		[2]Na^+	[2]Ca^{2+}	[2]Mg^{2+}	[2]N
Block	4	0.813	0.047	0.051	0.011
Treatments (T)	4	0.000**	0.000**	0.008**	0.095^{NS}
Depth (D)	4	0.000**	0.000**	0.000**	0.185^{NS}
T x D	16	0.332^{NS}	0.947^{NS}	0.932^{NS}	0.426^{NS}
Error	96	---	---	---	---
Coefficient of variation (%)		30.38	15.04	24.02	17.65
[3] Tukey Test ($p < 0.05$)					
Sources of Variation		Na^+ (cmol$_c$ dm^{-3})	Ca^{2+} (cmol$_c$ dm^{-3})	Mg^{2+} (cmol$_c$ dm^{-3})	N (mg L^{-1})
T1 - Water Supply (WS)		4.83 C	2.33 B	1.47 A	0.75 A
T2 - 0.1 (LW) + AA		6.57 C	2.70 B	1.78 A	0.92 A
T3 - 0.2 (LW) + AA		7.56 BC	2.96 AB	1.90 A	0.93 A
T4 - 0.3 (LW) + AA		11.64 AB	2.97 AB	2.07 A	0.96 A
T5 - 0.4 (LW) + AA		13.65 A	3.44 A	2.10 A	1.01 A
D1 – 0.0 a 0.1 m		15.29 A	2.68 AB	1. 18 B	1.06 A
D2 – 0.1 a 0.2 m		10.98 AB	2.41 B	1.25 B	0.89 A
D3 – 0.2 a 0.3 m		8.57 B	2.89 AB	1.61 B	0.89 A
D4 – 0.3 a 0.4 m		6.25 BC	3.11 A	2.47 A	0.91 A
D5 – 0.4 a 0.5 m		3.16 C	3.31 A	2.81 A	0.82 A
DMS		4.97	0.70	0.64	0.27

[1] ** and NS = significant at 1% probability level ($p < 0.01$) and non-significant, respectively. [2] Data transformed to $\sqrt{x}$. [3] Different letters in the same column indicate differences by Tukey test at 5% probability level. [4] LW = Annual loading rate of dairy effluent according to EPA.

There was no significant difference in Mg^{2+} contents as a function of the fertigation with dairy effluent, and the contents varied from 1.47 to 2.10 cmol$_c$ dm^{-3} in treatments T1 and T5, respectively (Table 3). Mg^{2+} contents in the soil increased with the increment of depth as a function of the fertigation with dairy effluent, and depths D4 and D5 (0.3 to 0.5 m) showed Mg^{2+} contents of 2.47 and 2.81 cmol$_c$ dm^{-3}, respectively. There was no statistical difference in Mg^{2+} contents at depths D1, D2, and D3 (0.0 to 0.3 m), ranging from 1.18 to 1.61 cmol$_c$ dm^{-3} (Table 3).

The N contents were not influenced by the depths and fertigation with dairy effluent (Table 3). However, the N contents ranged from 0.75 to 1.01 mg L^{-1} in treatments from T1 to T5 and from 1.06 to 0.82 mg L^{-1} at depths from D1 to D5 (0.0 to 0.5 m), respectively (Table 3).

Figure 1 illustrates the behavior of Na^+, Ca^{2+}, Mg^{2+}, and N along the soil profile at 240 days after planting *Cereus hildmannianus* fertigated with dilutions of dairy effluent and well water. Na^+, Ca^{2+}, Mg^{2+}, and N contents were higher in treatments T4 and T5 at all depths studied (0.0 to 0.5 m) (Figure 1A, B, C, and D).

In these treatments (T4 and T5), Na^+, Ca^{2+}, and Mg^{2+} contents were accumulated mainly on the surface, at depths from 0.0 to 0.2 m (D1 and D2) (Figure 1A, B, and C). The N contents in these treatments (T4 and T5) were accumulated mainly from 0.2 to 0.3 m (D3) (Figure 1D).

Na^+contents in T1 (control), T2, and T3 had similar increments at depths from 0.0 to 0.5 m (Figure 1A). Ca^{2+} contents in treatments T2 and T3, at depths from 0.1 to 0.3 m (D2 and D3), increased compared to T1 (control) and showed similar behavior at depths D1, D4, and D5 (Figure 1B). The Mg^{2+} contents in treatments T2 and T3 increased at depths from 0.1 to 0.4 m (D2 and D3), compared to the T1 treatment (control), and showed similar behavior at depths D1 and D5 (Figure 1C). The N contents of treatments T2 and T3 were higher than those found in T1 (control) at depths D2, D3, D4, and D5 (0.1 to 0.5 m), and only at D1, the results for N contents were similar (Figure 1D).

Discussion

Lima et al. (2013) observed a higher increase in Na^+ contents in the layer with higher organic matter content. This result is similar to that obtained in the present study because, as shown in the initial characteristics of the soil, the OM content was higher in the layers from 0.10 to 0.20 m, a region in which there was higher Na^+ accumulation. Oliveira, Alves, Batista, Lima, and Di Souza (2014) evaluated a milk treatment system and the effect of the generated effluent on soil and reported the highest Na^+ content in the 0.0 to 0.10 m layer, a value of 1.373,6 $cmol_c$ dm^{-3}, which decreased in the subsequent layers.

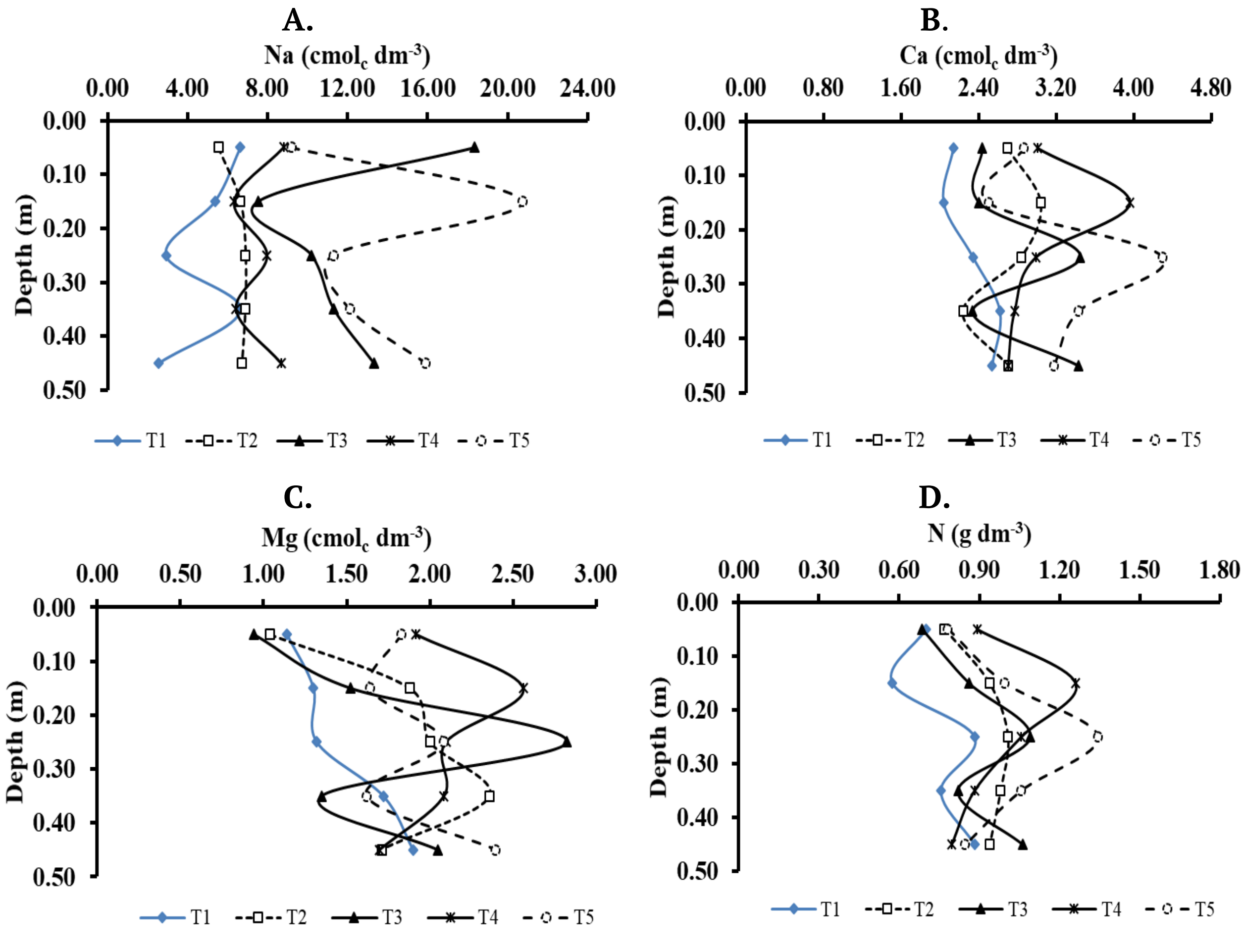

Figure 1. Sodium (A), calcium (B), magnesium (C), and nitrogen (D) in soil cultivated with *Cereus hildmannianus* irrigated with proportions of dairy effluent diluted with public-supply water at five depths at 240 days after planting.

The application of treated domestic sewage in the fertigation of cactus pear, for 2 years, resulted in an increase in Na^+ levels and the percentage of sodium saturation depending on the Na^+ in the wastewater (Mesquita et al., 2023). However, in another study with forage cactus, the greater proportion of treated oil produced water resulted in lower Na^+ accumulation in the soil, due to the lower Na^+ input from this wastewater compared to the groundwater used as control (Costa, Vale, Batista, Travassos, & Portela, 2019).

According to Miranda et al. (2018), high Na^+ contents result in problems such as soil dispersion and reduced water infiltration, favoring the formation of superficial crusts and intensifying erosion processes. Messias, Távora, Silva, and Nascimento (2006) studied Na^+ percolation in soils in the state of Pernambuco, Brazil, and found that, in clayey soil, there was greater dispersion in Na^+ distribution along the profile over time, thus characterizing a delay in percolation. In another study, Oliveira, Rebouças, Dias, Portela, and Diniz (2016) analyzed the impact of applying desalination reject brine in soils of the Brazilian semi-arid region and observed that Na^+ diffusivity was equal to 45.90 cm^2 h^{-1}, whereas in sandy soils it varied from 103.40 to 127.76 cm^2 h^{-1}. This explains the higher Na^+ contents in the superficial layers of the soil.

The Ca^{2+} contents on the surface ranged from 2.44 to 3.01 $cmol_c$ dm^{-3} for treatments T2, T3, T4, and T5, which are classified as good according to Ribeiro, Guimarães, and Alvarez (1999). In the subsurface, the T5 treatment added 4.30 cmolc dm^{-3} of Ca^{2+} at depths from 0.20 to 0.30 m, classified as very good (Ribeiro et al., 1999). On the surface, the T4 treatment added 3.01 cmolc dm^{-3} of Ca^{2+}, reaching a maximum value of 3.96 $cmol_c$ dm^{-3} in the 0.10-0.20 cm layer and reducing in the other layers in this treatment.

Using dairy effluent for the irrigation of elephant grass, Lima et al. (2013) observed Ca^{2+} contents ranging from 7.56 to 6.89 $cmol_c$ dm^{-3}, subsequently reducing as soil depth increased. According to Ribeiro (1999), Ca^{2+}

is retained on the negatively charged surfaces of clays, which may explain the higher contents of these ions in the subsurface layers because there was a higher clay content from 0.20 to 0.40 m.

Regarding the behavior of Mg^{2+}, there were large oscillations with the application of the treatments. In the superficial layers, there was a higher supply of this nutrient in T4, starting with 1.92 $cmol_c$ dm^{-3} and reaching 2.5 cmolc dm^{-3} between 0.10 and 0.20 m. Although T3 only added 0.94 $cmol_c$ dm^{-3} in surface, lower than in the control (T1), 1.88 cmolc dm^{-3}, between 0.20 and 0.30 m, it added 2.82 $cmol_c$ dm^{-3}, maximum value for this parameter.

According to the classification of Ribeiro et al. (1999), Mg^{2+} contents are classified as very good for T4 and T5 in the surface layer, as well as for T3 in the subsurface. In the other treatments, the contents are classified as good.

Similar to Ca^{2+}, Mg^{2+} adheres to the negatively charged surfaces of clays, which leads to a higher content of the element where there is a higher predominance of clay, in the studied case, from 0.20 to 0.40 m depth (Ribeiro et al., 1999).

Teffera, Li, Astatkie, and Gebru (2019) and Umburanas et al. (2023) associate the accumulation of Ca^{2+} and Mg^{2+} in the subsurface with the accumulation of K^+ in the surface, which favors the leaching of other exchangeable bases because such cations compete with K^+. This may favor the clay dispersion process, compromising the physical properties of the soil.

Oliveira et al. (2017) investigated the contamination of clayey and sandy soils when irrigated with desalination reject brine and found that there is no divergence between the retardation factors of Ca^{2+} and Mg^{2+} in these soils, so the percolation of these ions depends on their concentration in the solution and the presence of a large number of negative charges in the soil. Hence, in the present study, the accumulation of Ca^{2+} and Mg^{2+} in the subsurface may be associated with the large accumulation of Na^+ on the surface, the predominant ion in the dairy effluent (Table 2), and is responsible for displacing Ca^{2+} and Mg^{2+} from the ionic exchange sites of the clays in the surface soil layers.

Although not significant, there was an increase in N content in the soil, particularly in treatments T4 and T5 at depths from 0.1 to 0.4 m (D2, D3, and D4), with variation from 0.88 to 1.34 g dm^{-3} (Table 3, Figure 1 D).

Shilpi et al. (2018) reported an increase in the N content in the soil after using dairy effluents as an alternative source to supply nutrients and meet the water demand of crops.

Huang et al. (2017) emphasize the importance of N determination, highlighting the high mobility of nitrate in the soil profile, which is an important indicator of N losses below the root zone, with a potential risk of moving to surface and ground waters.

Although N can be easily lost by leaching, fertigation provides flexibility by splitting N application, and, in addition, this nutrient is readily available for uptake by plants (Ribeiro et al., 1999). Under semi-arid climate conditions, high evaporation rates and low rainfall levels reduce the risk of N leaching. Evaluating the characteristics of an Ultisol irrigated with dairy effluent after treatment, Oliveira, Alves, Batista, Lima, and Di Souza (2014) found the highest N content in the surface layer, 2.17 g kg^{-1}, with a reduction in the subsurface.

Conclusion

In summary, fertigation using dairy effluent with 40% of the annual loading rate in Ultisol poses no risk of water and soil contamination by N leaching (eutrophication). Fertigation with dairy effluent in proportions of up to 20% of the annual loading rate poses no risk of soil degradation due to excessive accumulation of ions. Nevertheless, fertigation with dairy effluent in proportions higher than 30% of the annual loading rate poses a risk of salinization of the superficial soil layers and clay dispersion due to the high accumulation of Na^+, in addition to the moving of exchangeable bases Ca^{2+} and Mg^{2+} to deeper layers, which further increases the risks of soil degradation due to excess Na^+. Studies are recommended to test lower values of the annual loading rate (5, 10, and 15%) to mitigate impacts that may be caused by Na^+ on the soil.

It is recommended to carry out a study with lower values of the annual loading rate (5, 10, and 15%) to mitigate impacts on the soil that may be caused by Na^+.

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References

Aguiar, J. B., Martins, A. M., Almeida, C., Ribeiro, H. M., & Marto, J. (2022). Water sustainability: A waterless life cycle for cosmetic products. *Sustainable Production and Consumption*, *32*, 35-51. DOI: https://doi.org/10.1016/j.spc.2022.04.008

Ahmad, T., Aadil, R. M., Ahmed, H., ur Rahman, U., Soares, B. C. V., Souza, S. L. Q, ... Adriano, G. C. (2019). Treatment and utilization of dairy industrial waste: A review. *Trends in Food Science and Technology*, *88*, 361-372. DOI: https://doi.org/10.1016/j.tifs.2019.04.003

Arenas-Sánchez, A., Rico, A., & Vighi, M. (2016). Effects of water scarcity and chemical pollution in aquatic ecosystems: State of the art. *Science of the Total Environment*, *572*, 390-403. DOI: https://doi.org/10.1016/j.scitotenv.2016.07.211

Bella, K., & Rao, P. V. (2021). Anaerobic digestion of dairy wastewater: Effect of different parameters and co-digestion options—A review. *Biomass Conversion and Biorefinery*, *13*, 2527-2552. DOI: https://doi.org/10.1007/s13399-020-01247-2

Boudiombo, J. S. B., Madden, D. G., Cusack, B., Cronin, P., & Ryan, A. (2023). State of the art and prospects of zeolites and metal organic frameworks (MOFs) for nitrogen and phosphorus removal in dair wastewater. *Chemosphere*, *329*, 138531. DOI: https://doi.org/10.1016/j.chemosphere.2023.138531

Coelho, D. C. L., Batista, R. O., Silva, P. C. M., & Mesquita, F. O. (2015) Produção de capim elefante utilizando percolado de aterro sanitário. *Bioscience Journal*, *31*(3), 830-840. DOI: https://doi.org/10.14393/BJ-v31n3a2015-22400

Costa, A. G., Alves, S. M. C., Batista, R. O., Mendes, H. C., & Souza, D. I. M. (2018). Chemical characteristics of irrigated ultisol with dairy effluent dilutions. *Floresta e Ambiente*, *25*(3). DOI: https://doi.org/10.1590/2179-8087.055117

Costa, D. O., Vale, H. S., Batista, R. O., Travassos, K. D., Gurgel, M. T., & Lemos Filho, L. C. D. A. (2020). Metal contents in soils irrigated with diluted treated produced water from oil. *Revista Brasileira de Engenharia Agrícola e Ambiental*, *24*(10), 672-678. DOI: https://doi.org/10.1590/1807-1929/agriambi.v24n10p672-678

Costa, D. D. O., Vale, H. S. M., Batista, R. O., Travassos, K. D., & Portela, J. C. (2019). Chemical characteristics of soil irrigated with produced water treatment and underground water. *Dyna*, *86*(210), 143-149. DOI: https://doi.org/10.15446/dyna.v86n210.79115

Dubreuil, V., Fante, K. P., Planchon, O., & Sant'anna Neto, J. L. (2019). Climate change evidence in Brazil from Köppen's climate annual types frequency. *International Journal of Climatology*, *39*(3), 1446-1456. DOI: https://doi.org/10.1002/joc.589

Ferreira, D. F. (2019). SISVAR: A computer analysis system to fixed effects split-plot type designs: Sisvar. *Brazilian Journal of Biometrics*, *37*(4), 529-535. DOI: https://doi.org/10.28951/rbb.v37i4.450

Huang, J., Duan, Y. H., Xu, M. G., Zhai, L. M., Zhang, X. B., Wang, B. R., ... & Nan, S. U. N. (2017). Nitrogen mobility, ammonia volatilization, and estimated leaching loss from long-term manure incorporation in red soil. *Journal of Integrative Agriculture*, *16*(9), 2082-2092. DOI: https://doi.org/10.1016/S2095-3119(16)61498-3

Khan, N., Ray, R. L., Sargani, G. R., Ihtisham, M., Khayyam, M., & Ismail, S. (2021). Current progress and future prospects of agriculture technology: Gateway to sustainable agriculture. *Sustainability*, *13*(9), 4883. DOI: https://doi.org/10.3390/su13094883

Krishna B., R., Bhuvaneshwari, S., Majeed, F., Manoj, M, M., Jose, E., & Mohan, A. (2022). Different treatment methodologies and reactors employed for dairy effluent treatment-A review. *Journal of Water Process Engineering*, *46*, 102622. DOI: https://doi.org/10.1016/j.jwpe.2022.102622

Lima, V. I. A., Alvez, S. M. C., Oliveira, J. F., Batista, R. O., Pinheiro, J. G., & Di Souza, L. (2013). Desempenho do sistema de tratamento de água residuária de laticínios e os efeitos de sua disposição em Argissolo. *Water Resources and Irrigation Management*, *2*(2), 93-101. Retrieved from https://www3.ufrb.edu.br/seer/index.php/wrim/article/view/1613

Liu, J., Liu, Q., & Yang, H. (2016). Assessing water scarcity by simultaneously considering environmental flow requirements, water quantity, and water quality. *Ecological Indicators*, *60*, 434-441. DOI: https://doi.org/10.1016/j.ecolind.2015.07.019

Marques, B. C. D., Cunha, V. T., Cunha, V. T., Silva, K. B, & Batista, R. O. (2016). Desempenho de gotejadores operando com água residuária de laticínios em escala laboratorial. *Irriga*, *21*, 140-155. DOI: https://doi.org/10.15809/irriga.2016v21n1p140-155

Mesquita, F. D. O., de Vasconcelos, E. S. A. G., de Lira, E. C., Felix, E. D. S., Batista, R. O., de Paiva, L. A. L., ... Araújo, J. D. S. (2023). Multivariate analysis of physical and chemical soil attributes under forage palm cultivation and agriculture reuse in the semiarid region. *Journal of Agricultural Science*, *15*(2), 56. DOI: doi.org/10.5539/jas.v15n2p56

Messias, A. S., Távora, B. E., Silva, R. C. R., & Nascimento, A. E. (2006). Percolação de sódio através de solos do Estado de Pernambuco, Brasil. *Revista de Biologia e Ciências da Terra*, *Suplemento especial*, 65-72. Retrieved from https://www.redalyc.org/pdf/500/50009907.pdf

Mesquita, F. O., Pedrosa, T. D., Batista, R. O., & de Andrade, E. M. (2021). Translocation factor of heavy metals by elephant grass grown with varying concentrations of landfill leachate. *Environmental Science and Pollution Research*, *28*(32), 43831-43841. DOI: https://doi.org/10.1007/s11356-021-13765-1

Miranda, M. F. A., Freire, M. B. G. dos S., Almeida, B. G., Freire, A. G., Freire, F. J., & Pessoa, L. G. M. (2018). Improvement of degraded physical attributes of a saline-sodic soil as influenced by phytoremediation and soil conditioners. *Archives of Agronomy and Soil Science*, *64*(9), 1207-1221. DOI: https://doi.org/10.1080/03650340.2017.1419195

Muniz, G. L., Borges, A. C., da Silva, T. C. F., Batista, R. O., & de Castro, S. R. (2022). Chemically enhanced primary treatment of dairy wastewater using chitosan obtained from shrimp wastes: Optimization using a Doehlert matrix design. *Environmental Technology*, *43*(2), 237-254. DOI: https://doi.org/10.1080/09593330.2020.1783372

Muniz, G. L., da Silva, T. C. F., & Borges, A. C. (2020). Assessment and optimization of the use of a novel natural coagulant (*Guazuma ulmifolia*) for dairy wastewater treatment. *Science of the Total Environment*, *744*, 140864. DOI: https://doi.org/10.1016/j.scitotenv.2020.140864

Ofori, S., Puškáčová, A., Růžičková, I., & Wanner, J. (2021). Treated wastewater reuse for irrigation: Pros and cons. *Science of The Total Environment*, *760*, 144026. DOI: https://doi.org/10.1016/j.scitotenv.2020.144026

Oliveira, J. F., Alves, S. M. C., Batista, R. O., Lima, V. I., & Di Souza, L. (2014). Avaliação de sistema de tratamento de laticínio e o efeito do efluente gerado nos atributos físico-químico de um argissolo vermelho. *Engenharia na Agricultura*, *22*, 58-66. DOI: https://doi.org/10.13083/1414-3984.v22n01a07

Oliveira, A. M. P., Rebouças, C. A. M., Dias, N. S., Portela, J. C., & Diniz, A. A. (2016). Contamination potential of specific ions in soil treated with reject brine from desalination plants. *Revista Caatinga*, *29*(3), 569-577. DOI: https://doi.org/10.1590/1983-21252016v29n306rc

Oliveira, A. M. P., Rebouças, C. A. M., Dias, N. S., Souza Júnior, F. S., SÁ, F. V. S., Sousa Neto, O. N. et al. (2017). Dynamics of ions in soils irrigated with saline reject. *Journal of Agricultural Science*, *9*(11), 190-197. DOI: https://doi.org/10.5539/jas.v9n11p190

Pereira, M. S., Borges, A. C., Heleno, F. F., Squillace, L. F. A., & Faroni, L. R. D (2018). Treatment of synthetic milk industry wastewater using batch dissolved air flotation. *Journal of Cleaner Production*, *189*, 729-737. DOI: https://doi.org/10.1016/j.jclepro.2018.04.065

Ramos-Suarez, M., Zhang, Y., & Outram, V. (2021). Current perspectives on acidogenic fermentation to produce volatile fatty acids from waste. *Reviews in Environmental Science and Bio/Technology*, *20*(2), 439-478. DOI: https://doi.org/10.1007/s11157-021-09566-0

Ribeiro, A. C., Guimarães, P. T. G., & Alvarez, V. H. (1999). *Recomendações para o uso de corretivos e fertilizantes em Minas Gerais*. Viçosa, MG: Comissão de Fertilidade do Solo do Estado de Minas Gerais. Retrieved from http://anda.org.br/wp-content/uploads/2018/10/boletim_04.pdf

Shilpi, S., Seshadri, B., Sarkar, B., Bolan, N., Lamb, D., & Naidu, R. (2018). Comparative values of various wastewater streams as a soil nutrient source. *Chemosphere*, *192*, 272-281. DOI: https://doi.org/10.1016/j.chemosphere.2017.10.118

Teffera, Z. L., Li, J., Astatkie, T., & Gebru, Z. M. (2019). Effects of irrigation systems on physicochemical properties of soil at different depths: A case study at a farm near Ziway Lake, Ethiopia. *Irrigation and Drainage*, *68*(2), 165-175. DOI: https://doi.org/10.1002/ird.2292

Teixeira, P. C., Donagemma, G. K., Wenceslau, A. F., & Teixeira, G. (2017). *Manual de métodos de análise de solo* (3. ed. rev. e ampl.). Brasília, DF: Embrapa. Retrieved from http://www.infoteca.cnptia.embrapa.br/infoteca/handle/doc/1085209

Umburanas, R. C., de Souza, M. P., Koszalka, V., Eurich, K., Lopes, É. C. P., Camilo, E. L., ... & Müller, M. M. L. (2023). Long-term impact of gypsum and nitrogen levels on soil chemical properties and maize forage and grain yield under no-tillage in a subtropical region. *International Journal of Plant Production*, *17*, 147-164. DOI: https://doi.org/10.1007/s42106-022-00227-y

Ungureanu, N., Vlăduţ, V., & Voicu, G. (2020). Water scarcity and wastewater reuse in crop irrigation. *Sustainability*, *12*(21), 9055. DOI: https://doi.org/10.3390/su12219055