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Potential use of treated wastewater from a cattle operation in the fertigation of organic carrots

Potencial uso de efluentes tratados da bovinocultura para a fertirrigação de cenoura orgânica

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ABSTRACT

The use of treated effluents rich in nutrients and organic matter has intensified in agricultural crops, contributing to the demand for water and fertilizers. The goal of this work was to assess the effects of fertigation with treated dairy cattle wastewater, for the cultivation of carrot (*Daucus carota*) when applied in four different doses, under field conditions, on nutrient accumulation, productivity, and health quality in the carrot (*D. carota*). Wastewater from treated cattle (WTC) was treated in a pilot treatment unit (PTU). Cultivation was carried out in two beds, and the WTC applied by drippers. Nitrogen (N) was considered the base element for the dose calculation, and a 100% N dose was equivalent to 150 kg ha^{-1}. WTC doses of 0, 100, 200, and 300% N were evaluated. Productivity was evaluated at 70 and 120 days after sowing, in the aerial part (fresh and dry mass and accumulation of nutrients), in the main roots (fresh and dry mass, accumulation of nutrients, diameter, length, and sanitary quality), and as the total productivity of the two organs. As a result, an increase in productivity was observed for all treatments with WTC and accumulation of Ca and Mg. The roots did not present contamination; therefore, the carrots were fit for human consumption. It was concluded that the application of WTC in organic cultivation of carrots is a viable alternative means of plant fertilization, providing higher root productivity than the national average, reaching 72.6 t ha^{-1} for a dose of 100% N, without compromising on sanitary quality and is suitable for human and animal consumption.

Keywords: agricultural waste; *Daucus carota* L.; final disposition of effluent; nitrogen fertilization; agricultural reuse.

RESUMO

A utilização de efluentes tratados, ricos em nutrientes e matéria orgânica, tem se intensificado nas culturas agrícolas, contribuindo para a demanda por água e fertilizantes. O objetivo deste trabalho foi avaliar os efeitos da fertirrigação com água residuária de gado leiteiro tratada para o cultivo da cenoura (*Daucus carota*), quando aplicada em quatro doses diferentes, em condições de campo, no acúmulo de nutrientes, produtividade e qualidade sanitária. As águas residuárias de bovinocultura (ARB) foram tratadas em uma unidade piloto de tratamento (UPT). O cultivo foi realizado em dois canteiros, sendo a ARB aplicada por gotejadores. O nitrogênio (N) foi considerado o elemento base para o cálculo da dose, e uma dose de 100% de N foi equivalente a 150 kg ha^{-1}. Doses da ARB de 0, 100, 200 e 300% de N foram avaliadas. A produtividade foi aferida aos 70 e 120 dias após a semeadura, na parte aérea (massa fresca e seca e acúmulo de nutrientes), nas raízes principais (massa fresca e seca, acúmulo de nutrientes, diâmetro, comprimento e qualidade sanitária) e nas duas partes (produtividade total). Como resultado, observou-se aumento na produtividade para todos os tratamentos com ARB e acúmulo de N, Ca e Mg. As raízes não apresentaram contaminação, portanto as cenouras eram próprias para consumo humano. Concluiu-se que a aplicação da ARB no cultivo orgânico de cenoura é uma alternativa viável de adubação das plantas. Proporciona produtividade de raízes superior à média nacional, chegando a 72,6 t ha^{-1} para uma dose de 100% N, sem comprometer a qualidade sanitária do produto, que é adequado para consumo humano e animal.

Keywords: resíduos agrícolas; *Daucus carota* L.; disposição final do efluente; fertilização nitrogenada; reúso agrícola.

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Introduction

Water use is projected to rise at a rate of up to twice that of global population growth, with estimates reaching an increase of up to 50% by 2025 in developing countries and 18% in developed ones (Bates et al., 2008; Wang et al., 2021). Within this range, agriculture ranks high among the sectors that consume the most water in Brazil and around the world (Naspolini et al., 2020; Severo Santos and Naval, 2020), as about 70% of all available drinking water on the planet is used for the irrigation of agricultural crops (Toumi et al., 2016).

Therefore, irrigated agriculture is one of the sectors most severely affected by water scarcity (Rosa et al., 2020). However, as food production must continue to increase, irrigation plays a fundamental role in agricultural production, laying the burden of responsibility on researchers and technicians to conduct research and identify alternatives to the growing pressure on water use (Hamilton et al., 2020; Silva et al., 2020; Silva et al., 2021).

Parallel to the problem of the water and nutrient demand for agricultural activity, the search for techniques for the treatment of effluents rich in nutrients and organic material has escalated (Moussaoui et al., 2019; Silva et al., 2021). Various alternative solutions can be implemented to bridge the gap between water demand and water supply (WS) for agricultural use, such as wastewater reuse (Moussaoui et al., 2019), which offers the advantage of supplying water and fertilizer. Through the 2030 Agenda for Sustainable Development, the United Nations is also advocating the worldwide adoption of desalination and reuse technologies, as an essential tool to achieve its Sustainable Development Goals (Ricart and Rico, 2019; Seifollahi-Aghmiuni et al., 2019; Tortajada, 2020).

Many countries are already forced to explore wastewater reuse (Aleisa and Al-Zubari, 2017; Moussaoui et al., 2019) because water resources are extremely scarce. However, this practice, in terms of its use in agriculture, is accompanied by advantages, such as water conservation (Chen et al., 2021), as well as the opportunity to apply nutrients such as nitrogen, phosphorus, and potassium via fertigation (Hu et al., 2021; Garg et al., 2022). Furthermore, organic fertilization can totally replace mineral fertilization, but the amount to be used depends on the quality of the available fertilizer and on local conditions, such as soil, climate, and management (EMBRAPA, 2013b). The increased demand for "organic" food, along with health concerns due to the application of chemical fertilizers, has generated the need to apply organic fertilizer in order to meet the increasing requirements of growing plants.

Despite the benefits of wastewater, the nutrients present in excess in reused waters can induce excessive vegetative growth and, with respect to the environment, contaminate surface water and groundwater, if wastewater management is not carried out in a controlled manner (Díaz et al., 2013). Therefore, it becomes crucial to adopt control and investigation instruments and regulations to determine the presence of pollutants and control the quantity of wastewater disposed in the soil (Tripathi et al., 2019; Fleite et al., 2020). Reused water can sometimes possess a high pathogenic load, which can cause diseases in humans and animals that come into contact with it (Moussaoui et al., 2019; Tripathi et al., 2019). Therefore, it is important to ensure that the agricultural crops to be marketed after having received reused water are not contaminated with any pathogenic microorganisms.

In the literature, a high degree of disagreement prevails in terms of the health risks caused by the use of wastewater from animal husbandry in agriculture (Fleite et al., 2020; Janeiro et al., 2020; Kumar et al., 2021). Hussar et al. (2003) recorded higher productivity after utilizing treated swine wastewater in carrot fertigation than with the use of a traditional cultivation system (chemical fertilization plus irrigation). Mendes et al. (2016) evaluated the use of treated sanitary effluents in radish cultivation and reported higher contamination levels than stipulated by the established current legislation (Brasil, 2001), considering that both the WS and treated effluent used revealed the same contamination levels in terms of total coliforms and *Escherichia coli*. Dantas et al. (2014) in their study on the feasibility of using treated sanitary effluents in radish cultivation recorded that the harvested product revealed no *Salmonella* sp. contamination and a thermotolerant coliform count below the permissible maximum.

Cattle excreta has been in use as an organic fertilizer for a long time, especially for agricultural crops such as vegetables, many of which are consumed raw (Almeida et al., 2020; Bosch-Serra et al., 2020; Fleite et al., 2020). Thus, natural fertilizers for sustainable productivity and the desired quality of carrot roots are increasingly requested and investigated (Ahmad et al., 2016). These authors further emphasize that an appropriate combination of synthetic and natural fertilizers is a possible way forward to achieve reasonable yield and quality, as balancing the amounts of organic and mineral fertilizers is of great importance toward the improvement of soil fertility status, carrot productivity, and sweetness, as well as the contents of alpha- and beta-carotene (Ahmad et al., 2016); moreover, the production of quality seeds is an essential prerequisite to achieve a good yield of a future crop (Noor et al., 2020).

The goal of this work was to assess the effects of fertigation with treated dairy cattle wastewater (DCW), for the cultivation of carrot (*Daucus carota*) when applied in four different doses, under field conditions, on nutrient accumulation, productivity, and health quality in the carrot (*D. carota*).

Materials and Methods

Characterization and treatment of dairy cattle wastewater and experiment location

In this work, wastewater from treated cattle (WTC) from a pilot treatment unit (PTU) was used with subsequent final disposal, via fertigation, into the soil used to cultivate carrots (*D. carota* L.) of the cultivar "Brasília."

The PTU was composed of the following steps (called in this work P): a dung pit (P1), already in place, with a volume of 7.8 m^3; a septic tank

(P2) with a hydraulic detention time (HDT) of 6.67 days; a set of anaerobic biological filters (P3) consisting of an upflow filter composed by column of filter media with 0.60 m of crushed stone #1 (P3.1) with 2 days of HDT and another with downward flow (P3.2) filled with chopped conduit and 0.18 days of HDT. From the filter set, the dairy cattle wastewater (DCW) was submitted to the constructed wetland (CW) of horizontal subsurface flow on two parallel routes (1 and 2) by means of a flow rate divider box: on route 1 passing through CW 1 cultivated with cattail (*Typha domingensis*) and on route 2 passing through CW 2 cultivated with Vetiver grass (*Chrysopogon zizanioides*) (Figure 1).

The CWs were submitted to the same amount of effluent daily, with 2.14 days of HDT. After each CW, a 1.0-m³ reservoir was installed for the purpose of collecting and quantifying the effluent volume, since among the PTU stages, this is the only one that displays variation between inlet and outlet volumes due to evapotranspiration of the cultivated beds. The PTU, conceived through the association of complementary structures for the treatment, allows satisfactory stabilization of DCW for incorporation into crops as biofertilizer. More specific details about the PTU are recorded in the study by Jorge (2018).

The PTU was installed in the area of the Integrated System of Agroecological Production (SIPA), also known as "Fazendinha Agroecológica km 47" (EMBRAPA, 2013a), with the geographical coordinates 22º46′ S latitude and 43º41′ W longitude at 33 m altitude. The climate, according to the Köppen classification, is Aw (tropical climate with dry winter), with concentrated rainfall from November to March, an average annual rainfall of 1213 mm, and an average annual temperature of 24.5°C (Peel et al., 2007).

The study area was characterized by the Planossolo type of soil (EMBRAPA, 2013a) of a sandy texture (Oliveira et al., 2009). Carrot cultivation was conducted in uncovered beds, with 32 m long, 1.0 m wide, and 0.30 m high. Neither soil correction nor fertilization was performed at the time of sowing, took place in June. After sowing and seedling emergence, thinning was performed to achieve 0.25×0.04 m spacing between the rows and between the plants, respectively. During the carrot cultivation cycle, two manual sessions of weeding were performed, at 15 and 30 days after sowing (DAS).

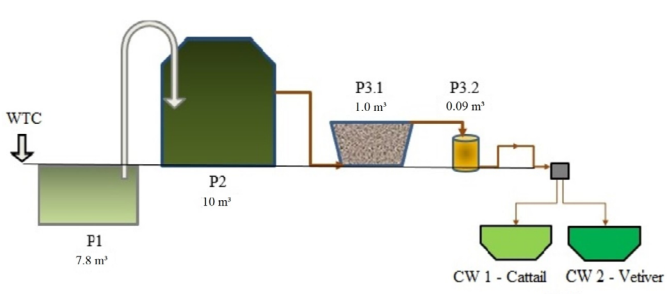


Figure 1 – Flowchart of the stages of the PTU: P1 – dung; P2 – septic tank; P3.1 – upward flow filter; P3.2 – downward flow filter; and CWs – beds grown with cattail (*Typha domingensis*) and Vetiver grass (*Chrysopogon zizanioides*).
WTC: wastewater from treated cattle.

The physical-chemical and microbiological parameters of the DCW used in the fertigation of carrots, characterized according to the Brazilian Association of Technical Standards (ABNT) NBR: 1986 method, are shown in Table 1. Overall, 38 samples were collected at each point of the PTU during the experimental period.

In fertigation, the nitrogen (N) was selected as the reference nutrient, and the application layers were calculated as described by Matos (2006). The WTC slides were calculated as a function of the N doses, in which 150 kg ha⁻¹ was used as the reference 100% N). The amount of N established was in accordance with the results presented by Mubashir et al. (2010); when evaluating the nitrogen fertilization of irrigated carrots and okra, the ideal N dose was 150 kg ha⁻¹, which the authors associate with greater photosynthetic activity and vegetative growth. Similarly, Moniruzzaman et al. (2013) evaluated the effect of varying N doses on the growth and yield of carrots and obtained the maximum production of shoot fresh mass for a dose of 130 kg ha⁻¹, which was the maximum tested.

The blades necessary for the application of the different doses of nitrogen (N) recommended to the cultures, supplied through the fertigation with the effluent generated by the pilot unit (PTU), were calculated adapting the method described by Matos (2006), Brazilian Society of Soil Science (SBCS, 2004), and EMBRAPA (2013b) according to Equation 1, seeking out to replicate the conditions outlined by Erthal et al. (2010) and Hamacher et al. (2019, 2021) with respect to the final volume applied, 70% water without chlorine was mixed with 30% fresh manure to prepare the WTC used in the experiment.

Table 1 – Characterization of the physical-chemical and biological parameters, in median values, of the DCW applied to carrot cultivation.

Parameters	Median	Parameters	Median
BOD (mg L⁻¹)	238.92	$P\text{-}PO_4^{3-}$ (mg L⁻¹)	112.74
COD (mg L⁻¹)	622.89	P_2O_5 (mg L⁻¹)	83.09
COD/BOD	2.67	$N\text{-}NH_4^+$ (mg L⁻¹)	80.06
TSS (mg L⁻¹)	23.20	$N\text{-}NO_3^-$ (mg L⁻¹)	2.30
DO (mg L⁻¹)	0.60	$N\text{-}NO_2^-$ (mg L⁻¹)	0.13
Turbidity (FTU)	85.56	TNK (mg L⁻¹)	69.03
Color (PtCo)	2,119	K (mg L⁻¹)	107.17
pH	7.00	Ca (mg L⁻¹)	37.41
EC (dS m⁻¹)	2.36	Mg (mg L⁻¹)	28.25
AS $[(mmol_c\ L^{-1})^{1/2}]$	0.51	Na (mg L⁻¹)	16.88
O&G (mg L⁻¹)	18.00	Salm (P/A. 100 mL⁻¹)	B
V.O. (mg L⁻¹)	8.63	T.C. [(log) NMP 100 mL⁻¹]	5.27
A.F. (mg L⁻¹)	10.70	*E. coli* [(log) NMP 100 mL⁻¹]	5.02

EC: electric conductivity; COD: chemical oxygen demand; BOD: biochemical oxygen demand; T.C.: thermotolerant coliforms; A.F.: animal fat; $N\text{-}NH_4^+$: ammoniacal nitrogen; $N\text{-}NO_2^-$: nitrogen nitrite; $N\text{-}NO_3^-$: nitrogen nitrate; TNK: total nitrogen Kjeldahl; O&G: oils and greases; V.O.: vegetable oil; DO: dissolved oxygen; P_2O_5: phosphorus pentoxide; $P\text{-}PO_4^{3-}$: orthophosphate; TSS: total suspended solids; B: being; AS: adsorption of sodium.

$$TA_{AR}=1000\frac{\left[N_{abs}-\left(T_{m1}\ MO\ \rho_s\ p\ 10^7\ 0{,}05\ \frac{n}{12}\right)\right]}{\left[T_{m2}\ N_{org}+(N_{amoniacal}+N_{nitrato})\ TR\right]} \quad (1)$$

Where:

TA_{AR}: annual application rate, $m^3\ ha^{-1}$;
N_{abs}: nitrogen absorption by the cultivation to obtain the desired productivity, kg ha^{-1};
T_{m1}: annual rate of organic matter mineralization previously existing in the soil, kg kg^{-1};
MO: soil organic matter content, kg kg^{-1};
ρ: soil specific mass, t m^{-3};
n: number of months of cultivation;
T_{m2}: annual rate of organic nitrogen mineralization, kg kg^{-1} $year^{-1}$;
N_{org}: organic nitrogen available by the applied residue, mg L^{-1};
$N_{amoniacal}$: ammoniacal nitrogen available by the applied residue, mg L^{-1};
$N_{nitrato}$: nitric nitrogen available by the applied residue, mg L^{-1};
TR: recovery rate of mineral nitrogen by the cultivation, kg kg^{-1} $year^{-1}$.

No correction of soil characteristics nor fertilization for planting was carried out. The soil in the study area was classified as Planossolo with sandy texture (Oliveira et al., 2009) and with adequate fertility. The soil was a crop rotation area. Crops prior to carrots were bertalha and lettuce.

Irrigation and fertigation management

The first of the treatment applications occurred at 45 DAS, after which the total WTC calculated for application during the entire 120-day cultivation cycle was divided into 60 applications, the last one being performed 15 days prior to harvest. In irrigation management, we adopted a fixed irrigation shift equivalent to half a day. On rainy days, irrigation was not performed.

The WTC was applied to the beds using 150 kg ha^{-1} of N as the reference dose, and doses of 0, 100, 200, and 300% of the reference, applied by means of a fertigation system composed of drippers, were evaluated, at rates of 4, 8, and 12 L h^{-1}, as previously discussed, distributed in two 16-mm hoses under each bed, with the respective blades or wastewater levels of treated WTC (0, 294, 589, and 883 mm), applied along the cultivation cycle (Table 2).

Table 2 shows the WTC levels or wastewater levels, based on the concentration of nitrogen present, applied in 60 days, their respective compensations in WS; the blade or the total evapotranspirated level during the carrot growing period, determined by estimate and replenished via irrigation; and the total amount of water applied throughout the experimental cycle, which is the sum of WTC, WS, and ETpc.

Due to this form of parceling, application was avoided before the culture presented a root system capable of exploring the applied WTC, fertigation started at 45 DAS, and the slides or daily levels approached the slide or wastewater levels for the treatment. For reference, the dose of 100% N was used as required by the culture, and treatments 200 and 300% of N were more than double and triple, respectively.

Variables evaluated

At 70 DAS, three plants were harvested from each experimental plot for evaluation of the aerial part (PA) and the main root (R): green and dry matter, nutrient accumulation, and root diameter and length. The productivity of the two organs was estimated from green mass data. With this, carrot productivity was evaluated in relation to the root system so that it was possible to analyze the market potential of the product, including on the possibility of consuming the roots in an *in natura* way.

The carrots were packed in a plastic bag for the fresh mass and in the kraft paper bags for drying in an oven until constant mass. Root length and diameter measurements were evaluated using a digital caliper, and weighing of the material was carried out on an analytical balance with a precision of 0.01 g to determine the green mass and dry mass. These assessments were conducted in the SIPA agricultural products processing room.

Samples of dry mass of PA and R were sent for the determination of the levels of nutrients (N, P, K, Ca, and Mg); analyses were carried out in the plant tissue analysis laboratory, Department of Soils of the Universidade Federal de Viçosa, following the methodology of EMBRAPA (1999). For sending the carrot samples, they were dried and crushed. Similarly, at 120 DAS, 20 plants were harvested per plot for the same analyses.

The health aspects of the plants were evaluated using thermotolerant coliforms and *Salmonella* sp.; for this purpose, at the time of

Table 2 – Total slides or wastewater levels (mm) of water (IW), fertigation (WTC) treated at PTU, and water supply (WS), applied to the soil cultivated with carrots, to provide doses of N (0, 100, 200, and 300%) and on rainy days, irrigation was not performed.

Treatments	Doses of N (%)	Blades or wastewater levels with WTC+WS applied (mm)	Drippers for water application (L h^{-1})	Drippers for WTC application (L h^{-1})	Blade or total wastewater levels evapotranspiration (mm) (ETpc)	Total water applied (WTC + WS + IW)
T1	0	0 + 883	12	-	210.32	1,093.32
T2	100	294 + 589	8	4		
T3	200	589 + 294	4	8		
T4	300	883 + 0	-	12		

harvest, five plants were harvested and sent to the Food and Beverage Analytical Laboratory, where the PA and R were separated and washed superficially with running water to remove the soil from the cultivation beds. The standards and criteria for analysis of the sanitary aspect followed the current technical legislation on microbiological standards for food: regulation RDC No. 12 of 2001 (Parameters of the National Health Surveillance Agency — ANVISA) (Brasil, 2001). Food quality analyses were performed at the Food and Beverage Analytical Laboratory of the Food Technology Department of the Universidade Federal Rural do Rio de Janeiro.

Experimental design and data analysis

The experiment was conducted in a completely randomized design with four replicates per treatment. For each treatment evaluated, four experimental plots of area 4 m^2 were planted, in which, via the spacing employed (0.25×0.04 m), the plants of the two central lines in each plot were used for the evaluations, for a total of 640 useful plants per treatment (Carvalho et al., 2021).

The results were then submitted to analysis of variance (ANOVA; $p \leq 0.05$), and when significant effects were observed, testing was performed using polynomial regression models. The models were selected according to the statistical significance (F test), adjustment of the coefficient of determination (R^2), and biological significance of the model. The analyses were performed using the SISVAR version 5.6 software (Ferreira, 2011).

The variability of the data was assessed through ANOVA ($p < 0.05$), and when significant, adjustments to the response models were tested as a function of the applied WTC doses.

Results and Discussion

With the increase in population demand for food, whether of animal or plant origin, the need for the adoption of environmentally appropriate techniques about the optimization of inputs for production increases, ranging from the identification of alternatives to supply nutrients to crops, sources for WS for irrigation, and incorporation of organic material into the soil in agroecological production systems. Faced with this issue, the growing practice of integrated environments that adds plant production to animal husbandry can provide solutions, both for the purification of the increasing volumes of liquid waste from livestock confinement and the production of natural fertilizers. Thus, the focus of this work was on the use of wastewater from cattle farming for food production.

Exogenous application of nitrogen is an efficient means of enhancing plant stress tolerance through modulation of a number of physiobiochemical processes, such as upregulation of the oxidative defense system (Razzaq et al., 2017), and beyond that, the yield potential of the cultivar may influence nutrient demand and should be known when planning for fertilization application (Aquino et al., 2015), because carrots are a highly nutritious vegetable root. Like other plant species, carrot roots absorb minerals from the substrate to meet their nutritional needs and thus the soil requires continuous input of minerals from external sources for continuous plant growth, ideal yield, and desired quality (Ahmad et al., 2016).

Accumulation of green matter and dry matter in the shoot and at the root

Growth of the PA was superior in all treatments applying WTC. Comparing the data of 70 and 120 DAS, it was observed that for the doses tested, the accumulation of mass at 120 DAS was higher than that at 70 DAS. For dry mass of the PA at 120 DAS, the same behavior was noted, with only a smaller variation between dose 0% N and the others, in which the maximum difference did not reach 5 g $plant^{-1}$ (Table 3).

This variation, depending on the doses of N applied, was similar for the accumulation of dry mass at 70 DAS. On this day, plants treated with the 100% dose were the heaviest, followed by those treated with 200 and 300% doses, whereas at 120 DAS, there was no difference in plant dry mass between doses.

The greatest accumulation of fresh mass of carrot root occurred in the WTC application treatments, and the effect was time dependent. This was reflected in greater productivity, which also increased over time after the start of the application of WTC, and the doses most suitable in this regard were those of 200 and 300%. This is in accordance with reports in the literature for carrot cultivation with nitrogen fertilization in irrigated cultivation, with the ideal dose of N ranging from 130 to 150 kg ha^{-1} (Mubashir et al., 2010; Moniruzzaman et al., 2013).

Productivity of the aerial part and root

The shoot and root productivity was positively influenced by the application of WTC (Figure 2). In the PA at 70 and 120 DAS, the treatment with 100% N did not differ from the other treatments with WTC (Figure 2A). The reduction in productivity at 70 and 120 DAS when comparing the treatment with 100% of the N dose in relation to the control was 57 and 67%, respectively, in the period analyzed. The productivity of the control treatment increased by 3 t ha^{-1} from one period to the other, which was very different from the 100% N dose treatment showing an increase of 20 t ha^{-1}.

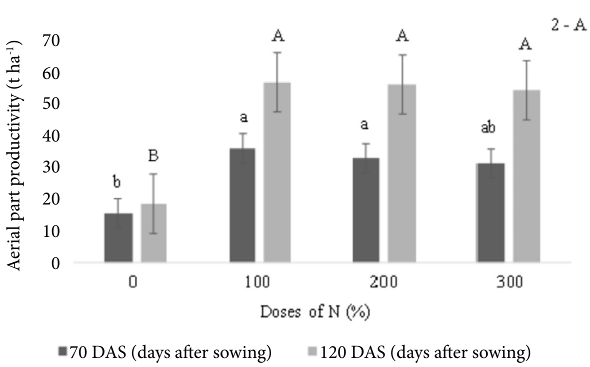
The yield of the main root showed no difference between treatments at 70 DAS. However, at 120 DAS, the application of WTC showed greater productivity gain per hectare (Figure 2B). The reduction in productivity, in a comparison of mean values, was 32 and 46% for 70 and 120 DAS, respectively, in the treatments of 0 and 100% of N for 70 DAS and 0 and 200% for 120 DAS. Thus, the increase was 13 and 38 t ha^{-1} in these same treatments due to the application of WTC.

Regression analysis was performed to assess the effect of dose on productivity, and the adjusted model for this period was quadratic. The results indicated that an application of 214.71% of N via WTC would be required to obtain maximum productivity (83.0 t ha^{-1}). These data can be found in Supplemental files.

Table 3 – Growth parameters measured 70 and 120 days after carrot planting under different N dose conditions, obtained with the WTC fertigation treated at the PTU, to supply 0, 100, 200, and 300% doses of N, and ANOVA results (Fc, Pr > Fc, and CV).

Doses of N (%)	Aerial part		Root	
	Fresh matter (g plant^{-1})	Dry matter (g plant^{-1})	Fresh matter (g plant^{-1})	Dry matter (g plant^{-1})
-- Periods 70 DAS --				
0	19.37 b*	5.02 a	36.04 a	1.35 b
100%	45.04 a	8.01 a	52.93 a	3.32 a
200%	41.23 a	8.57 a	52.18 a	3.16 a
300%	39.14 ab	7.46 a	42.07 a	2.74 ab
Fc	5.819	0.361	1.719	5.084
Pr > Fc	0.0108	0.7823	0.2162	0.0168
CV (%)	26.30	18.87	27.23	30.10
-- Periods 120 DAS --				
0	23.18 b	5.01 b	55.33 b	5.50 a
100%	71.09 a	9.18 a	90.74 ab	7.81 a
200%	70.27 a	8.99 a	102.78 a	8.02 a
300%	67.96 a	8.03 ab	96.38 a	7.48 a
Fc	15.015	5.551	6.286	1.971
Pr > Fc	0.0002	0.0126	0.0083	0.1721
CV (%)	20.72	20.92	19.62	22.91

*Average followed by the same letter does not differ by Tukey's test (p ≤ 0.05) in the same column of the day. Values represent the means; n = 4; DAS: days after sowing.



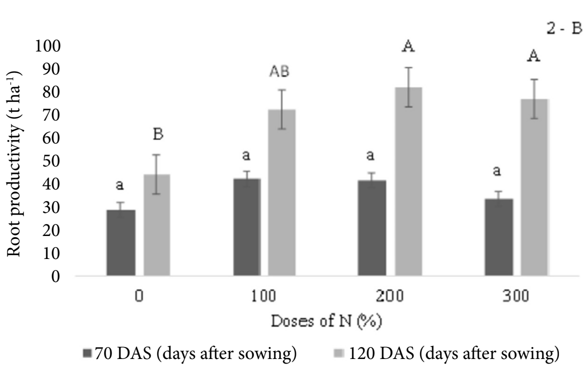


Figure 2 – Standard error bar of productivity (t ha^{-1}) of the aerial part (A) and root (B) of carrot at 70 and 120 DAS. Average followed by the same letter in the day's column does not differ by Tukey's test (p ≤ 0.05). n = 4 (number of repetitions).

The higher final fresh weight of the roots in the treatment with 300% N, when compared with 100% N, demonstrates that root weight was influenced by the greater accumulation of water, possibly due to the excess of nutrients supplied, in which it supplanted the need and capacity of assimilation by plants. This is in line with the results suggested by Hochmuth et al. (1999), who emphasized that increased nitrogen fertilization can reduce the accumulation of dry matter, which is an important factor in deciding the choice of a dosage for carrot cultivation and the harvest period, as the root is the commercial part of greatest interest, since the supply of fertilizers at the correct time and in the appropriate doses is important to obtain satisfactory productivity (Colombari et al., 2018). With higher production, it should also be considered that dose above 100% of the plant's requirement can result in losses and environmental contamination. In addition, the disposal of treated effluent on the ground is beneficial as it minimizes impacts on surface water courses. Therefore, adjusting the highest dosage (so that the surplus does not need to be disposed in the watercourse) that has the highest production, with less soil and groundwater contamination, is essential.

It is, therefore, important to note that, although the effect of the treatments on the carrot root yield was not significant, according to the ANOVA at 70 DAS, the maximum occurred for the 100% N dose, a result similar to that obtained by analyzing the estimated productivity for the PA of the carrot, whose maximum productivity at 70 DAS was obtained for the 100% N dose applied, via WTC (data not shown).

Salgado et al. (2006) reported that data on the root yield of carrot cv. Brasília produced 43.5 and 44.5 t ha^{-1} and 35.9 and 36.8 t ha^{-1}, respectively; when the cultivation was intercropped with curly and smooth lettuce and in the crop singles, the root yield was 42.3 and 42 t ha^{-1} and 42.1 and 45.9 t ha^{-1}, respectively. In a study by Santos et al. (2011), also at SIPA, comparing the different mulches in the organic cultivation of cv. Brasília, productivity of 29.48–36.64 t ha^{-1} on average was reached. From the above results in the present study, the control yields were equivalent; however, following application of the effluent, an increase of almost 40 t ha^{-1} in the yield of commercial roots was observed. This result may be related to the amount of nutrients supplied to the plants or the provision of nutrients at intervals, which would have increased assimilation. In relation to the control treatment, the lack of fertilization in the control may have led to this reduction in productivity, because possibly if it had received conventional fertilization, the production would be equivalent to T2.

In a test of different levels of water deficit using drip replacement in the cultivation of cv. Brasília installed at SIPA, which was fertilized using only bovine manure (3 t·ha^{-1}), the total productivity was 30.7–62.7 t·ha^{-1} (Carvalho et al., 2016), similar to that obtained by Santos et al. (2011), which was in the range of 31.7–62.8 t·ha^{-1}. Carvalho et al. (2005), in a comparison of the productivity of different carrot cultivars conducted following organic and conventional management systems, obtained yields of 12.45–16.61 t·ha^{-1} and 14.25–23.78 t·ha^{-1} for Brasília-DF and cv. Brasília, respectively.

Resende and Braga (2014), in their research on the productivity of cultivars and carrot populations in the organic cultivation system, under the sub-medium conditions of the São Francisco Valley in Petrolina/PE, obtained total and commercial root productivity for cv. Brasília of 96.3 and 81.7 t ha^{-1}, respectively. In an experiment under similar conditions, Resende et al. (2016b) also tested the performance of cv. Brasília, in organic management; however, this was performed during a period of high temperatures, and under these conditions, the total and commercial yields of roots ranged between 53.5 and 58.6 t ha^{-1}. In the present work, the experimental period occurred in winter-spring (July to October), with moderately cold winters and hot summers, with an average temperature of 22.5°C.

Main root diameter and length

The diameter of the main root of the carrot was influenced only at 120 DAS, presenting a larger diameter in the WTC application treatments (Figure 3A). There was no difference between treatments in root length, regardless of the period analyzed (Figure 3B).

Moniruzzaman et al. (2013), who tested the increasing doses of N (0–130 kg ha^{-1}), observed that the value of root width and root diameter increased with increasing of doses, although the root diameter at the maximum dose showed a decrease. The authors concluded that the ideal dose of N used in the cultivation of carrot, cv. *New Coroda*, for cultivation under Bangladeshi conditions was 100 kg ha^{-1}.

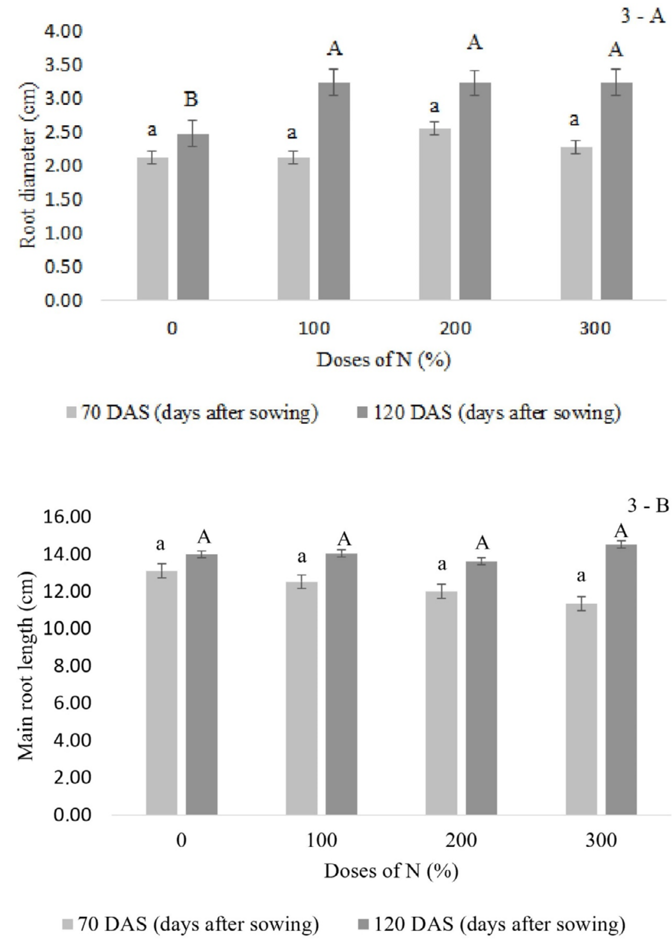


Figure 3 – Standard error bar of main root diameter (A) and length (cm) (A) of carrot at 70 and 120 DAS. Average followed by the same letter in the day's column does not differ by Tukey's test ($p \leq 0.05$). n = 4 (number of repetitions).

Different types of fertilizers affect the yield and nutritional quality of carrots. The material and biochemical structure of the soil is reinforced by the application of fertilizers. The growth of the plant, the carrying capacity of the soil, and the material condition of the soil were increased by the use of poultry manure. However, N is an important nutrient for the production of different crops and a good source of organic fertilizers (Ahmad et al., 2016).

Nutrient accumulation in the aerial part and root

The increase in the N content increased with the increase in the percentage of N in the doses applied. However, this increase was not time dependent of the period analyzed, since the highest accumulation was at 70 DAS, unlike the P that had greater accumulation at 120 DAS (Table 4). Table 4 shows the results of the regression analysis, adjusted for the effect of the different doses N (%), applied via sheets of ARB, when the ANOVA was significant.

Regarding the N levels (dag·kg^{-1}) accumulated in the roots, it is clear that these increased from 70 to 120 DAS, whereas in the control treatment, this increase from the first collection to the second was in media 33%, and in the treatment with the 300% dose of N, it was 37% (Table 5).

Table 4 – Average values of the N, P, K, Ca, and Mg levels (dag kg^{-1}) in the aerial part of the carrot and dry matter of the carrot, at 70 and 120 DAS, obtained from the WTC fertigation, treated at the PTU, to supply 0, 100, 200, and 300% doses of N, and ANOVA results (Fc, Pr>Fc, and CV).

Doses of N (%)	Nutrient accumulation in the aerial part				
	N	P	K	Ca	Mg
	(dag kg^{-1})				
	---------- Periods 70 DAS ----------				
0	2.632 b**	0.401 a	1.986 a	2.672 a	0.325 a
100	3.049 ab	0.470 a	2.255 a	2.635 a	0.311 a
200	3.122 ab	0.429 a	1.948 a	2.513 a	0.316 a
300	3.339 a	0.443 a	2.120 a	2.375 a	0.339 a
Fc	4.107	0.607	0.285	0.946	0.577
Pr>Fc	0.0321	0.6232	0.8357	0.4489	0.6412
CV (%)	9.62	17.13	25.24	10.84	9.73
	---------- Periods 120 DAS----------				
0	1.814 b	0.359 b	2.200 a	2.997 a	0.340 a
100	2.071 ab	0.474 ab	2.607 a	2.821 a	0.352 a
200	2.249 ab	0.471 ab	2.825 a	2.495 a	0.318 a
300	2.566 a	0.503 a	3.635 a	2.404 a	0.351 a
Fc	3.604	4.376	2.509	0.368	1.038
Pr > Fc	0.046	0.0267	0.1083	0.7777	0.4107
CV (%)	26.08	23.95	38.46	32.01	27.95

DAS: days after sowing; **average followed by the same letter does not differ by Tukey's test ($p \leq 0.05$) in the same column of the day. Values represent the means. n = 4.

Table 5 – Average values of the N, P, K, Ca, and Mg levels (dag kg^{-1}) in the root dry matter of the carrot, at 70 and 120 DAS, obtained from the WTC fertigation, treated at the PTU, to supply 0, 100, 200, and 300% doses of N and ANOVA results (Fc, Pr > Fc, and CV)

Doses of N (%)	Nutrient accumulation in the roots				
	N	P	K	Ca	Mg
	(dag kg^{-1})				
	---------- Periods 70 DAS ----------				
0	0.757 b**	0.279 b	1.738 a	0.354 a	0.128 a
100	1.264 a	0.407 a	2.248 a	0.401 a	0.150 a
200	1.341 a	0.423 a	2.173 a	0.393 a	0.137 a
300	1.538 a	0.434 a	2.383 a	0.407 a	0.163 a
Fc	9.207	14.076	1.089	2.389	2.412
Pr > Fc	0.0019	0.0003	0.3911	0.1198	0.1175
CV (%)	17.87	9.76	25.03	7.35	13.99
	---------- Periods 120 DAS----------				
0	1.005 b	0.381 c	2.451 a	0.392 a	0.151 b
100	1.615 ab	0.526 b	2.068 a	0.431 a	0.166 ab
200	1.716 ab	0.604 ab	1.941 a	0.452 a	0.166 ab
300	2.110 a	0.643 a	3.283 a	0.461 a	0.188 a
Fc	6.946	4.376	1.579	22.725	3.177
Pr > Fc	0.0058	0.0267	0.2458	0.0000	0.0634
CV (%)	21.54	23.95	39.54	9.00	10.08

DAS: days after sowing; **average followed by the same letter does not differ by Tukey's test ($p \leq 0.05$) in the same column of the day. Values represent the means. n = 4.

Among the nutrients N, P, K, Ca, and Mg (dag kg^{-1}), in the carrot root dry matter, cultivated under different layers of WTC, K was the most responsive to the WTC doses applied with its concentration in the roots, increasing with the doses both at 70 and 120 DAS, this dose-dependent increase in WTC representing an increase in media of 37 and 38%, respectively (Table 5).

On analyzing the P, Ca, and Mg contents (dag kg^{-1}) in the root dry matter, we could verify a rise in the levels between 70 and 120 DAS, with an increase in media of 48, 13, and 15%, respectively, for the highest dose of N. Regarding the levels of P accumulated in the carrot root at 70 and 120 DAS, it was observed that for WTC doses equivalent to 100 and 300% of N, the increase in the contents was more pronounced at 120 DAS than at 70 DAS, representing 22 and 7%, respectively; from the models adjusted for P at 70 and 120 DAS, the maximum estimated levels corresponded to the 223.33 and 275.0% doses of N applied via WTC (Supplemental Files).

For average levels of Ca and Mg accumulated at 120 DAS, despite being significant, when the adjustments of the linear regression model by ANOVA (Supplemental Files) were evaluated, in relation to Ca, the difference between the content obtained with the minimum dose (0% N) and maximum dose (300% N) via WTC was 0.069 dag kg^{-1}, while for Mg, it was 0.037 dag kg^{-1}.

For the cultivar Forto, carrots have a more accentuated accumulation of nutrients and dry matter in the PA up to 88 DAS, and from that point, there is a tendency for greater accumulation to occur in the roots (Cecílio Filho and Peixoto, 2013); however, the crop season and cultivar influenced the yield, nutrient content in the leaves and roots, and extraction and export of nutrients by the carrot crop (Aquino et al., 2015; Resende et al., 2016a; Razzaq et al., 2017; Olsson et al., 2018).

The use of WTC complemented by phosphate fertilizer on the plantation and the potassium split into two applications has been recommended for other crops, for example, in the cultivation of sugarcane, as some WTC, such as that used in this work, may have lower nutrient concentrations (Mendonça et al., 2016). Studies in relation to other nutrients do not present the relationship of the doses and functional capacity, but other conditions may require supplementation, especially to P and K. In other studies, with DCW, however, without water treatment, the supply of different doses of N (100, 200, 300, and 400%) promoted; for all treatments, there was an improvement in the total performance of the electron transport chain in citronella plants, demonstrating that the photosynthetic efficiency of the plant increased as the nitrogen dose provided by DCW increased (Hamacher et al., 2019).

However, in this work, the greater supply of N did not have a synergistic effect on productivity, which stood out from the other treatments, mainly at doses of 200 and 300%, as there was also more sodium in the WTC, which had an antagonistic effect on the promotion of growth. Note that the pH is in the neutral range, the electrical conductivity and the adsorption of sodium do not represent a risk of soil sodification, although it should be used judiciously due to the sodium content. This low electrical conductivity (2.36), when compared with that in untreated DCW (14.00), was high when used by Hamacher et al. (2021) in citronella cultivation. These authors also found a difference in the amount of sodium, in contrast to this study, comprising, respectively, 1.18 and 16.88 mg L^{-1}.

Although sodium, drug adsorption ratio, and electrical conductivity are within acceptable criteria for application, the continued application of wastewater can lead to an increase in sodium levels in the soil, especially with lower water depth and low precipitation; however, as the experiment was carried out in an open field, precipitation occurred during the cultivation period.

Depending on the source, when the volume of DCW is calculated correctly, there is the possibility of not depending on external inputs (mineral fertilizer) to maintain productivity in these cultivation conditions. The association of irrigation with the supply of N doses increased the accumulation of dry biomass in plants of *Tithonia diversifolia*, where the largest accumulation of dry biomass was obtained when 100% of the water was replaced by ETc (evapotranspiration of the crop) and nitrogen fertilization was applied at 150 kg ha^{-1} (Silva et al., 2021). For citronella, the use of DCW produced the same biomass gains as inorganic fertilization; however, the use of DCW did not interfere in the production of citronella essential oil (Hamacher et al., 2019).

When analyzing the levels of K, it is noted that this is among those that presented higher concentration in the tissue of the PA of the carrot, being that at 70 DAS the value maximum was obtained at a dose of 200% N, while at 120 DAS the accumulation increased and maximum at 300%. For P, the data presented with increasing volumes as a function of the increase in N doses (%) applied; however, based on the model for the accumulation response as a function of the application of the WTC, the maximum P content in the shoot was estimated at 120 DAS of 0.529 dag kg^{-1} for the dose of 248.75% from WTC.

Thus, in these experimental conditions, the different treatments provided adequate mineral nutrition, in relation to the analyzed element (N), as the soil must have adequate chemical and physical properties (Farhangi-Abriz and Ghassemi-Golezani, 2019) and the higher N rate of the dairy cattle slurry (DCS) proved useful for the circular nutrient economy, while improving the physical and chemical quality of the soil and the sustainability of the agricultural system as a whole (Bosch-Serra et al., 2020); however, depending on the type of treatment used, organic nitrogen can only be partially removed (~70%), and the ammonia nitrogen remained mainly in the liquid (Fleite et al., 2020). Still, temperate pasture species constitute a source of protein for dairy cattle (Almeida et al., 2020), and the presence of these compounds may explain how some substances may be more present in DCW than in others, due to the lower capacity to remove some processes, all of which influence the composition of the DCW.

This greater maintenance of nutrients may have contributed to the increase in the N content in the roots between the periods of 70 and 120

DAS and may have been because this period is the one in which nutrients are most accumulated in the roots (Cecílio Filho and Peixoto, 2013); thus, this differentiation was rising and became amplified as the doses increased.

A work conducted in the same experimental area as the present study evaluated the performance of the cultivar Brasília under organic management using different dead vegetation coverings and verified that the nutrient contents in the carrot roots varied from 1.28 to 2.16 dag·kg^{-1} for N, 0.266 to 0.28 dag·kg^{-1} for P, 3.095 to 3.72 dag·kg^{-1} for K, 0.343 to 0.444 dag·kg^{-1} for Ca, and 0.159 to 0.165 dag·kg^{-1} for Mg (Santos et al., 2011). According to Aquino et al. (2015), the average nutrient content in winter carrot cultivars could be around 1.36, 0.43, 4.69, 0.078, and 0.109 dag·kg^{-1} for N, P, K, Ca, and Mg, respectively. Assunção et al. (2016) obtained, on average N, P, and K levels of 1.15, 0.37, and 4.61 dag·kg^{-1}, respectively, for the summer carrot cultivar and 1.5, 0.5, and 6.66 dag·kg^{-1}, respectively, in winter. It is noted that, from among the values presented, the K contents in the summer and winter cultivars were higher than that obtained in the present study. Dube et al. (2018) observed that increasing sludge water concentration increased yield and uptake of nutrients without accumulating pollutants in the tissues to phytotoxic levels in both soils for *Brachiaria* and the sandy loam soil for lucerne.

Droppings are commonly recycled as fertilizers, although attention should be paid to the environmental impacts of this practice (Bosch-Serra et al., 2020). It is also possible to observe that this DCW contains organic material, and with the mineralization of the organic material, alkaline earth acids (such as K, Na, Ca, and Mg) and other ions become available in the medium (Matos, 2014). However, it should be noted that the excess of nutrients can provide a so-called toxicity zone for the vegetable (Baldi et al., 2018).

Sanitary quality of carrots

The standards and quality analysis for food from the sanitary aspect followed the current legislation of technical regulation on the microbiological standards 2001 (Brazil, 2001) and they were evaluated of foods and elaborated Analytical Laboratory of Foods, Department of Food Technology at the university where the study was carried out. The standards and criteria for the analysis of the health aspect of the carrot root produced in all the treatments complied with the current legislation regarding technical regulations on the microbiological standards for food, RDC Nº 12 of 2001 (Brasil, 2001); for the thermotolerant coliforms, the maximum count limit is up to 3 (log) NMP g^{-1}, while for *Salmonella* sp., it must be nil or absent in 25 g of the analyzed sample (Brasil, 2001), thus representing no risk of contamination of consumers of the product *in natura* (Table 6). The carrot roots produced in all the treatments complied with the current technical legislation on microbiological standards for food, regulation RDC Nº 12 of 2001 (Brasil, 2001). This result may be related to the closing period of fertigation, 15 days prior to harvest, as well as the basic washing procedure, performed immediately post-harvest, to remove the excess soil, as recommended by Baumgartner et al. (2007), Lima Junior et al. (2012), and Dantas et al. (2014).

Table 6 – Parameters of the National Health Surveillance Agency (ANVISA) – RDC Nº 12 of 2001, which regulates microbiological standards for food treated with WTC fertigation

Analysis	Legislation standards	Samples
Thermotolerant coliforms	< 3 NMP g^{-1}	Absent
Salmonella sp.	Absence in 25 g of the sample	Absent

The acceptable quality of wastewater for irrigation depends on the crop to be irrigated, soil conditions, and the water distribution system adopted (FAO, 1985; Dube et al., 2018). Conama legislation Nº 503/2021 also deals with some agro-industrial effluents for use in fertigation (Brasil, 2021).

As there is no specific from Rio de Janeiro regulation related to the reuse of effluents from dairy farming, the maximum permissible values (MPV) were considered for the release of effluent into the receiving body (without changing its class), based on the Resolution of the National Council for the Environment-CONAMA 357/2005 amended by 430/2011 (Brasil, 2011), at the federal level, and in the State Standard of Rio de Janeiro NT-202.R-10 (FEEMA, 1986), at the state level.

This was verified, even though the WTC used showed a concentration of microbiological contamination indicators above that allowed by legislation, being the presence of *Salmonella* sp. 5.27 log thermotolerant coliforms (NMP 100 mL^{-1}) and 5.02 *E. coli* log (NMP 100 mL^{-1}). Thus, with these parameters above legislation, the use of this WTC requires attention, as it does not meet the standards for application as a fertilizer in organic production systems.

It is expected that, when a grace period is provided between the last application of the effluent and the harvest, the environment/soil will be able to control the microorganism populations, thus preventing contamination of the food (Fonseca et al., 2000). Mendes et al. (2016) evaluated the use of treated sanitary effluent in radish cultivation and found that contamination levels in the roots exceeded the norms established by the current legislation (RDC: No. 12/2001 — ANVISA). However, from the results presented, both the supply water and the treated effluent used contained the same total levels of coliforms and *E. coli*. For the authors, the presence of these contaminants in the waters used encouraged the rapid growth of these microorganisms in the soil, which led to root contamination.

A study on the feasibility of using treated sanitary effluent in the Rosa Elze Sewage Treatment Plant (WWTP) in radish cultivation conducted in the municipality of São Cristóvão — SE showed that the harvested product did not reveal *Salmonella* sp. contamination and that the count of thermotolerant coliforms was below the permissible maximum (≤ 3 NMP g^{-1}), concluding that the employment of this effluent was a viable option for radish cultivation under those conditions (Dantas et al., 2014). In a similar study, Dantas et al. (2020) evaluated the use of the treated effluent in the same WWTP, in carrot and beet cultivations, where, for these cultivars as well as for the radish, no tuber contamination was verified. Sou et al. (2011) presented the preliminary results of research involving the use of treated domestic effluent in the irrigation of vegetables and observed the presence of *E. coli* in the PAs of lettuce, but no contamination of eggplant and carrot roots.

Conclusions

The use of DCW may already be indicated for some crops; however, it is necessary to use accessible treatment technologies and appropriate post-harvest strategies to reduce current health risks to acceptable levels.

There is an urgent need for economical technologies to treat wastewater at desirable levels as wastewater contains a large amount of organic matter, nutrients (mainly K, N, and P), and salts; minor constituents such as metals (Cu, Zn, and Fe); and organic compounds (antibiotics, hormones, and other ionophores), in addition to harboring pathogens (*Giardia*, *E. coli*).

The application WTC (based on N) in carrot cultivation is effective for supplying adequate nutritional quality. The supply of nutrition through organic residues has been increasingly important, not only from the environmental aspects but also from the need for alternative sources of fertilization, in view of the need to replace mineral fertilization.

No contaminating residues for *E. coli* and *Salmonella* sp. were found in the carrot and thus the produce has sufficient sanitary quality for human consumption in this aspect. It is also important to give a destination for this waste, which is often underutilized, to reduce environmental risks and reduce the costs related to family-run agricultural operations, which will reduce poverty and unemployment in rural areas and involve young people in the production of vegetables.

Contribution of authors:

JORGE, M.F.: Project Administration; Data Curation; Formal Analysis; Methodology; Writing – Original Draft; Writing – Review & Editing; SILVA, L.D.B.: Project Administration; Data Curation; Formal Analysis; Methodology; Writing – Original Draft; Writing – Review & Editing; Supervision; HÜTHER, C.M.: Project Administration; Writing – Review & Editing; CECCHIN, D.: Project Administration; Writing – Review & Editing; ALVES, D.G.: Data Curation; Formal Analysis; Methodology; Writing – Original Draft; GUERRA, J.P.F.: Formal Analysis; MELO, A.C.F.: Formal Analysis; NASCENTES, A.L.: Formal Analysis.

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