



A simple system for ozone application in domestic sewage for agricultural reuse

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Lisiana Crivelenti Voltolini¹; Reinaldo Gaspar Bastos²
Claudinei Fonseca Souza^{3*}

¹Centro de Ciências Agrárias. Programa de Pós-Graduação em Agricultura e Ambiente. Universidade Federal de São Carlos (UFSCar), Via Anhanguera, km 174, CEP: 13600-970, Araras, SP, Brazil.

E-mail: lisianacrivelenti@yahoo.com.br

²Centro de Ciências Agrárias. Departamento de Tecnologia Agroindustrial e Socioeconomia Rural. Universidade Federal de São Carlos (UFSCar), Via Anhanguera, km 174, CEP: 13600-970, Araras, SP, Brazil.

E-mail: reinaldo.bastos@ufscar.br

³Departamento de Recursos Naturais e Proteção Ambiental. Universidade Federal de São Carlos (UFSCar), Rodovia Anhanguera, km 174, Zona Rural, CEP: 13604-900, Araras, SP, Brazil.

*Corresponding author. E-mail: cfsouza@ufscar.br

ABSTRACT

The increasing demand for water in food production highlights the need to seek alternative sources of supply. Treated domestic sewage is a way to mitigate this problem, but it must comply with legislation to be used safely in agriculture. Ozone has been used for disinfection of domestic effluents due to its strong oxidizing character, allowing the adjustment of its parameters for agricultural reuse. This study therefore aimed to evaluate the sanitary and agricultural viability of domestic effluent treated with ozone. The experiment was carried out on laboratory benchtops and doses of 0, 8, 15, 30, 45, and 60 mg L⁻¹ of ozone were applied. The application time for each dose was 0, 14, 27, 54, 81, and 108 seconds, respectively. Microbiological, physical, and chemical parameters were evaluated: total coliforms, *Escherichia coli*, pH, turbidity, dissolved oxygen, electrical conductivity, total organic carbon, total nitrogen, total phosphorus, potassium, magnesium, calcium, and sodium. Ozonation did not significantly alter the physical and chemical composition of wastewater, indicating an important advantage in terms of potential agricultural reuse. However, the pathogenic load of *E. coli* was not reduced enough for the effluent to be used in agriculture. The results suggest an investigation of the effects of ozone on the efficiency of sewage treatment, seeking to understand these interactions to identify ideal doses and exposure time, making wastewater safe for agricultural reuse.

Keywords: agriculture, ozonation, treated effluent.

Sistema simples de aplicação de ozônio em esgoto doméstico visando reúso agrícola

RESUMO

O crescente aumento da demanda por água na produção de alimentos aponta as necessidades de se buscar fontes alternativas de abastecimento. O esgoto doméstico tratado é uma maneira de mitigar este problema, entretanto, para que possa ser utilizado na agricultura,



é necessário adequá-lo às exigências legislativas. O uso do ozônio na desinfecção de efluentes domésticos vem sendo utilizado devido ao seu caráter fortemente oxidante, permitindo o ajuste de seus parâmetros ao reúso agrícola. Desta forma, o objetivo deste trabalho foi avaliar a viabilidade sanitária e agrícola do efluente doméstico tratado com ozônio. O experimento foi realizado em bancadas de laboratório no qual foram aplicadas as dosagens: 0; 8; 15; 30; 45; e 60 mg L⁻¹ de ozônio. O tempo de aplicação, para cada dosagem foi, respectivamente, em segundos: 0; 14; 27; 54; 81; e 108. Foram avaliados parâmetros microbiológicos, físicos e químicos: coliformes totais, *Escherichia coli*, pH, turbidez, oxigênio dissolvido, condutividade elétrica, carbono orgânico total, nitrogênio total, fósforo total, potássio, magnésio, cálcio e sódio. A ozonização não alterou significativamente as propriedades físicas e a composição química da água residuária, indicando importante vantagem em termos de potencial reúso agrícola. Entretanto, a contagem de *E. coli* não foi reduzida suficientemente para que o efluente possa ser utilizado na agricultura. Os resultados indicam a importância da investigação dos efeitos do ozônio na eficiência do tratamento de esgoto, buscando o entendimento das interações com o intuito de identificar dosagens e tempo de exposição ideais para tornar as águas residuárias seguras ao reúso agrícola.

Palavras-chave: agricultura, efluente tratado, ozonização.

1. INTRODUCTION

The irrational use of water resources, including those of the agricultural sector, which is responsible for using 70% of the freshwater available in the world, has been widely discussed considering the estimates of future increased consumption in agriculture (Santos *et al.*, 2015; Rodrigues, 2020).

The impacts caused by population growth in urban centers as a result of sanitary sewage, often dumped untreated into water bodies, cause serious environmental problems and waterborne diseases, especially in rural communities (Voltolini *et al.*, 2018; ONU, 2018; Figueiredo *et al.*, 2021).

In this context, the search for alternative sources of water supply is necessary, and the use of wastewater from domestic sewage in agriculture has been adopted in several countries (Mendonça and Mendonça, 2018).

Agricultural water reuse is a potential environmental, social and economic opportunity, as it can supply nutrients to plants, minimizing the use of commercial fertilizers and reducing production costs (Mendonça and Mendonça, 2018).

However, treated sanitary sewage needs to meet adequate standards to enable its reuse in crops (Garay *et al.*, 2021). In this sense, and specifically in terms of disinfection, ozone treatment has been used due to its strongly oxidizing character in inactivating several groups of microorganisms (Camilo Júnior *et al.*, 2019), which allows the adjustment of effluent parameters. Ozone action is related to its interaction with different organic and organometallic functional groups in the samples, leading to disinfection and mineralization, with the removal of color and turbidity from the effluents. The high oxidizing capacity of ozone also removes algae, iron and manganese, increasing the biodegradability of organic matter with the oxidation of specific pollutants (Camilo Júnior *et al.*, 2019).

Disinfection with ozone aims to obtain an effluent within the microbiological standards recommended by relevant government agencies, such as the Brazilian National Environment Council (CONAMA), for discharge into receiving bodies, and meet environmental guidelines and water quality standards for irrigation (CONAMA, 2005; 2011).

This study therefore aimed to evaluate the sanitary and agricultural viability of domestic effluent treated with different ozone doses.

2. MATERIAL AND METHODS

The experiment was carried out on a bench-scale at the Laboratory of Soil Physics and Water Quality of the Center for Agricultural Sciences of the Federal University of São Carlos (CCA-UFSCar) using a CQJ DChangqing Q-802S ozone generator, with a production capacity of 2000 mg h⁻¹.

Samples of treated domestic sewage were collected directly at the outlet of the Sewage Treatment Station (STS) of the municipality of Araras, State of São Paulo, Brazil, in sterilized containers, always on Thursdays at the same time during October 2021.

The STS is composed of four treatment units plus aerators: a grating system, responsible for the removal of relatively coarse solids; a desander system, used to retain the sand and fine solids present in the effluent; a grease removal box, used to separate the rest of the possible solid material; and facultative ponds with the application of a neutral pH biological bioremediation product.

Five initial ozone doses were used in the experiment, plus the control, in which ozone was not applied (Table 1). The ozone doses were estimated as a function of application time.

Table 1. Ozone doses and application times used in the treatment of domestic effluent.

Estimated dose at the initial time (mg L ⁻¹)	Time (s)
8	14
15	27
30	54
45	81
60	108

The domestic effluent was distributed in five sterilized glass flasks with a capacity of 1000 mL, and the ozone was applied according to the time defined for each dose (Figure 1).

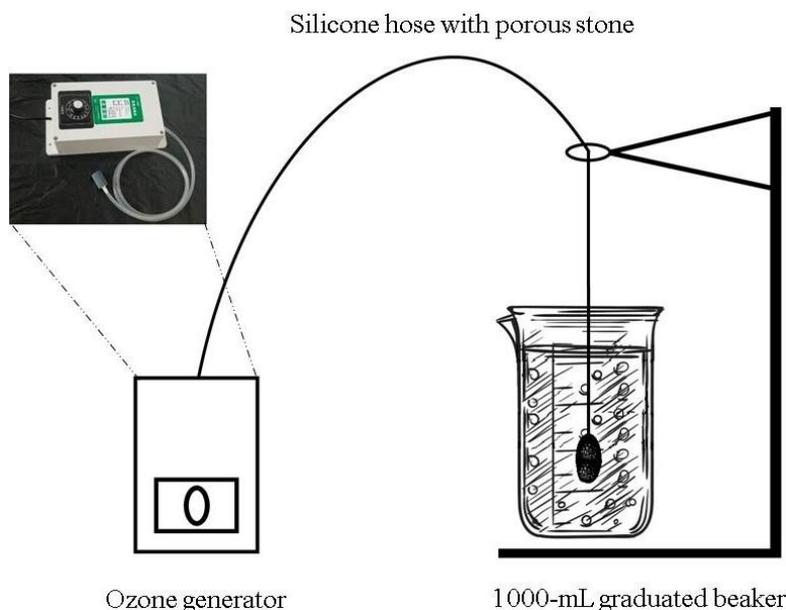


Figure 1. Experimental scheme used to promote different ozone doses in the treated effluent.

The elaborated system comprises a cylindrical glass beaker 0.15 m long and 0.105 m in diameter. Internally, physical obstacles such as barriers were not inserted to reduce ozone's

passage speed, commonly applied in closed systems, thus increasing their efficiency; only a porous stone diffuser was used. This decision was based on the possibility of studying a treatment simplification for direct application in irrigation water storage tanks under field conditions, mainly targeting family farming in isolated communities. The flow rate of the ozone generator is 2.0 g h^{-1} . A plastic hose is attached to the ozone generator, which transfers the ozone produced by the equipment to the effluent, and a porous stone is attached to its end to allow for better gas diffusion.

Considering that the contact time of ozone with the effluent is decisive in the treatment efficiency, the system used simulated ozonation through a cylindrically shaped device with the diffusion of ozone in the effluent through the porous diffuser located at its base, promoting the displacement of the upward flow of ozone bubbles. The beaker was used to apply ozone to 1 L of effluent, so the container needed to be 0.15 meters long to retain this 1 L, plus a possible spillage of the effluent because of the bubbling process. The excess gas, the gaseous mixture portion not retained in the liquid mass, came out through the beaker top.

The effects of ozone application were evaluated through physicochemical and microbiological parameters in the treated domestic effluent from the Sewage Treatment Station (STS) located in the municipality of Araras, State of São Paulo, Brazil. The pH, electrical conductivity (EC), turbidity, dissolved oxygen (DO), total organic carbon (TOC), total nitrogen (TN), total phosphorus (TP), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), sodium adsorption ratio (SAR), biochemical oxygen demand (BOD), and total and thermotolerant coliform counts were evaluated under the different experimental conditions. The efficiency in each parameter was calculated from the difference between the means of domestic sewage without ozone application and sewage after treatment with different ozone doses, according to Equation 1 (Von Sperling, 2005):

$$E = \frac{C_s - C_d}{C_s} \times 100 \quad (1)$$

Where E is the removal efficiency (%), C_s is the sewage concentration without ozone application, and C_d is the sewage concentration after ozone dose application.

The data were subjected to analysis of variance to verify the significance of each parameter, and the Tukey test was performed at a 5% probability ($p \leq 0.05$) to compare paired means.

3. RESULTS AND DISCUSSION

Table 2 shows the results of the analyses from the different applied ozone doses, which were discussed and compared to the literature and CONAMA Resolution (CONAMA, 2005).

The procedure for counting total coliforms and *E. coli* required dilutions of the order of 10^3 to 10^4 times due to the high microbiological load present in the effluent, which made it difficult to obtain aliquots fully representative of the microbiological parameters. The increase in doses was inversely proportional to both evaluated microbiological loads, but ozone doses for these experimental conditions did not show a significant difference from each other. The dose of 60 mg L^{-1} was the one that most reduced the total coliform and *E. coli* load, with efficiencies of 32 and 21%, respectively.

The experimental results are promising, but they show a reduction in the microbiological load of the evaluated parameters, which is insufficient for the studied domestic effluent to be reused in agriculture in Brazil. According to CONAMA Resolution 357/2005 (CONAMA+, 2005), the maximum values allowed are 200 MLN 100 mL^{-1} (Class 1 Water), 1000 MLN 100 mL^{-1} (Class 2 Water), and up to 4000 MLN 100 mL^{-1} (Class 3 Water), Table 3.

Table 2. Mean values of the evaluated parameters from the different applied ozone doses.

Parameter	Estimated initial ozone dose (mg L ⁻¹)					
	0	8	15	30	45	60
Total C. (MLN** 100 mL ⁻¹)	3.5 x 10 ⁶ a	3.1 x 10 ⁶ a	2.9 x 10 ⁶ a	2.8 x 10 ⁶ a	2.6 x 10 ⁶ a	2.4 x 10 ⁶ a
<i>E. coli</i> (MLN 100 mL ⁻¹)	8.0 x 10 ⁵ a	7.8 x 10 ⁵ a	7.4 x 10 ⁵ a	7.1 x 10 ⁵ a	6.7 x 10 ⁵ a	6.3 x 10 ⁵ a
pH	7.69 ± 0.08 a	7.74 ± 0.09 ab	7.73 ± 0.17 abc	7.86 ± 0.1 bc	7.83 ± 0.16 bc	7.95 ± 0.16 c
Turbidity (NTU)	120.08 ± 8.26 a	113.41 ± 5.4 b	109.66 ± 4.7 bc	108.58 ± 5.2 c	109.33 ± 5.2 bc	107.5 ± 3.6 c
DO (mg L ⁻¹)	3.37 ± 0.66 a	3.7 ± 0.63 ab	4.2 ± 0.33 b	5.7 ± 0.54 c	5.8 ± 0.49 cd	6.6 ± 0.67 d
TOC (mg L ⁻¹)	82.13 ± 9.74 ab	81.85 ± 12.67 ab	81.77 ± 6.05 a	80.56 ± 9.61 ab	77.67 ± 6.06 ab	77.09 ± 4.73 b
EC (µS cm ⁻¹)	789.93 ± 19.84 a	793.16 ± 8.9 a	785.42 ± 18.4 a	783.04 ± 6.6 a	781.95 ± 16.7 a	773.77 ± 13.6 a
TN (mg L ⁻¹)	29.5 ± 3.19 a	28.25 ± 5.0 a	30.7 ± 2.14 a	28.73 ± 4.65 a	27.93 ± 3.02 a	28.41 ± 1.8 a
TP (mg L ⁻¹)	4.00 ± 0.33 a	3.7 ± 0.3 a	3.75 ± 0.43 a	3.81 ± 0.29 a	3.81 ± 0.21 a	3.9 ± 0.23 a
K (mg L ⁻¹)	22.02 ± 4.51 a	21.98 ± 5.59 a	21.9 ± 5.58 a	21.09 ± 6.25 a	20.33 ± 7.5 a	19.8 ± 7.83 a
Ca (mg L ⁻¹)	10.15 ± 2.28 a	9.48 ± 1.9 a	9.82 ± 3.58 a	8.93 ± 3.06 ab	7.49 ± 1.96 bc	6.47 ± 3.22 c
Mg (mg L ⁻¹)	26.08 ± 1.73 a	25.91 ± 2.02 a	25.79 ± 1.30 ab	25.5 ± 1.73 ab	25.33 ± 1.15 ab	24.91 ± 0.79 b
Na (mg L ⁻¹)	87.71 ± 4.85 ab	87.65 ± 6.14 ab	87.63 ± 0.94 ab	87.27 ± 3.85 ab	87.29 ± 11.96 a	87.29 ± 6.88 b
SAR (mmol _c L ⁻¹)	4.23 ± 0.27	--	--	--	--	--
BOD (mg L ⁻¹)	197.7 ± 6.1	--	--	--	--	--

**Most likely number in 100 mL of effluent. *Coefficient of variation (%).

Total C.: total coliforms; *E. coli*: Thermotolerant coliform; DO: dissolved oxygen; TOC: total organic carbon; EC: electrical conductivity; TN: total nitrogen; TP: total phosphorus; K: potassium; Ca: calcium. Mg: magnesium; Na: sodium. SAR: sodium adsorption ratio; BOD: biochemical oxygen demand.

Means followed by the same letter in the same row do not differ statistically from each other (Tukey, $p \leq 0.05$).

Table 3. Maximum values of relevant parameters established by freshwater classifications 1, 2 and 3, in accordance with CONAMA Resolution 357/05.

Parameter	Class 1	Class 2	Class 3
TOC (mg L ⁻¹)	3.0	5.0	10.0
DO (mg L ⁻¹)	> 6.0	> 5.0	> 4.0
Turbidity (NTU)	40	100	100
pH	6 - 9	6 - 9	6 a 9
TP (mg L ⁻¹)	0.10	0.10	0.15
<i>E. coli</i> (MLN 100 mL ⁻¹)	200	1000	4000

Likewise, it would not meet the microbiological recommendations of the World Health Organization (WHO), in which the maximum limit for *E. coli* for agricultural use of sanitary sewage is 10⁵ MLN 100 mL⁻¹ for localized irrigation of plants that grow far from the soil level and more restricted values for plants that grow close to the soil or that can be eaten raw (Bastos *et al.*, 2014).

Bilotta and Daniel (2006) studied ozone and UV radiation in the inactivation of pathogenic indicators in sanitary sewage and observed that the dose of 30 mg L⁻¹ was the most effective for *E. coli*, generating a 3-log cycle reduction. The mean reduction for thermotolerant coliforms was 2.3 log cycles.

Shi *et al.* (2021) observed a significant inactivation of 5.3 log-cycles for *E. coli* when applying a dose of 5 mg L⁻¹ in secondary effluent. The authors reported that ozone disinfection efficiency is affected by the nature of the compounds present in the wastewater, especially the dissolved organic material, which can serve as protection, explaining the partial survival of *E. coli* under moderate and high ozone doses.

Importantly, after comparing the results with the literature, the methodology presented here is based on a simplification of ozone application to provide viability of agricultural reuse water for farmers under field conditions.

The highest pH mean was obtained for the dose of 60 mg L⁻¹ (7.95 ± 0.16). Doses of 8, 15, 30, and 45 mg L⁻¹ did not present statistical differences, as well as the dose of 60 mg L⁻¹ when compared to 45, 30, and 15 mg L⁻¹, with means of 7.83 ± 0.16, 7.86 ± 0.1, and 7.73 ± 0.17, respectively. These values do not prevent the effluent from being discharged into Class 1, 2, or 3 waters, for which the maximum limit for release is between 6 and 9, according to CONAMA Resolution 357/2005. These results maintained the pH within the range allowed by CONAMA Resolution 430/2011, that is, between 5 and 9, for the discharge of effluents into waters classified as 1, 2, and 3 despite the slight increase after ozone dose applications.

Camilo Junior *et al.* (2019) evaluated physical attributes of domestic sewage after ozone application and reported an increase in pH when increasing the doses, reaching 8.4 with the application of 10 mg L⁻¹, deferring from the effluent without ozonation, but statistically equal to the other doses, corroborating the results obtained in this study.

The pH value in the ozonation process influences the effluent degradation mainly due to changes in the reaction mechanism. The acidic medium increases the direct oxidation potential, that is, molecular ozone reacts directly with organic substances (Carvalho, 2015).

According to Camilo Júnior *et al.* (2019), ozone application on the effluent promotes the release of hydroxide ions (OH⁻), making them predominant compared to hydrogen ions (H⁺), which may explain the increase in pH in the studied effluent. This effect is even more relevant when doses are applied at times of exposure to the effluent. According to the authors, most of the ozone decomposes into OH⁻ when the pH is above 8.0, inducing an increasingly alkaline condition. However, the pH was not relevant for the direct oxidation of ozonation under these

experimental conditions, in which the mean value of the effluent before ozone application was 7.69 ± 0.08 .

Moreover, the effluent had a mean turbidity value of 120.08 ± 8.2 , which was reduced within the significance level as ozone doses increased, with the highest removal in turbidity being 10.4% with 60 mg L^{-1} of application. The low turbidity removal may have been a result of the application time, requiring longer times of application ozone for this effluent. Camilo Junior *et al.* (2019) also observed decreasing turbidity values as doses increased. However, they found higher values, reaching 40% of removal at the dose of $12 \text{ mg O}_3 \text{ L}^{-1}$ at an exposure time of 120 minutes to the treated domestic effluent.

Dissolved oxygen had a mean of $3.36 \pm 0.66 \text{ mg L}^{-1}$ in the effluent without ozone application, differing statistically from all applied doses, except for the dose of 8 mg L^{-1} . Likewise, the dose of 60 mg L^{-1} differed statistically from all the others, except for the dose of 45 mg L^{-1} .

Spiliotopoulou *et al.* (2018) found the same DO pattern in an experiment with ozonation in a recirculating aquaculture system. The authors observed that ozone enriches the water with oxygen as the doses increase. Bhatta *et al.* (2015) also observed this phenomenon, in which dissolved oxygen values increased after ozonation.

This increase in the oxygenation rate occurs both as a result of the presence of oxygen in the ozone gas and because the O_3 applied to the effluent is quickly converted into O_2 due to its high solubility (Camilo Júnior *et al.*, 2019).

Doses of 45 and 60 mg L^{-1} showed higher rates of total organic carbon reduction relative to the effluent without ozone application, with the dose of 60 mg L^{-1} showing the highest removal efficiency, reducing the parameter by 6.1%. The TOC removal efficiency was not expressive, and the results did not differ statistically, except for doses of 15 and 60 mg L^{-1} .

Hamid *et al.* (2019) compared the effect of ozone, biological activated carbon filtration, and pre-treatments combined in the microfiltration of secondary effluents and found that the ozone treatment also showed a low reduction of dissolved organic carbon.

Souza *et al.* (2020) applied ozone through complex systems to the post-treatment of wastewater from organic livestock farms and observed a removal efficiency of 23% of BOD for the dose of 7.8 mg L^{-1} at the exposure time of 30 minutes. BOD was reduced by 37% by increasing the exposure time to 60 minutes.

Ozonation does not normally significantly reduce the carbon content of wastewater. In this sense, the obtained values (around 80 mg L^{-1}) make it unfeasible to release this effluent only after O_3 application in Class 1, 2, or 3 waters. CONAMA Resolutions 357/2005 and 430/2011 limit TOC to a maximum of 10 mg L^{-1} for discharging the effluent into Class 3 waters, which allow the irrigation of tree, cereal, and forage crops. However, there is no TOC specification for direct agricultural reuse according to the relevant agencies.

Electrical conductivity showed no statistical difference between doses applied to the treated effluent. Similarly, Camilo Júnior *et al.* (2019) evaluated ozonation as a post-treatment of domestic sewage effluent with doses 0, 4, 10, 17, 25, and 35 mg L^{-1} and observed no significant variations for EC, with values practically the same after applying different doses. Also, Trevizani *et al.* (2019) evaluated ozonation in the removal of color in effluent from the textile industry and found no significant differences in EC between effluents before and after application of $108 \text{ mg O}_3 \text{ L}^{-1}$.

According to Camilo Júnior (2019), higher ozone concentrations promote partial oxidation of particles faster than as a function of time, which increases the number of solids in the solution, maintaining EC values without large variations during ozonation as a function of doses.

Nitrogen showed a trend similar to that of carbon in ozonated sewage samples, i.e., a slight variation and no significant difference between doses. Rossi *et al.* (2021) also observed a similar result when studying the effect of ozone and ultrasound on the agricultural reuse of primary effluents. On the other hand, these authors reported that a slight increase in TN would probably be related to a release of nitrogen material from particulate organic matter.

Lakretz *et al.* (2017) studied organic compounds from secondary effluents pre-treated with ozone and also observed no significant changes in nitrogen compounds after ozonation. They observed a slight decrease in ammonium and a small increase in nitrate, which can be explained by the oxidation of ammonium and nitrite residues. In this case, the increase in nitrate may be partially attributed to organic nitrogen oxidation. Ozone may have interacted preferentially with the microbiological load present in the effluent and the organic load, justifying the low TN reduction, which indicates a positive factor for agricultural reuse of the effluent.

The results of total phosphorus showed no significant differences between the applied ozone doses. The dose of 8 mg L⁻¹ presented content of 3.7 mg L⁻¹ (the lowest value), with a removal percentage of 7.5%. Martínez *et al.* (2011) observed similar results when studying ozone in the treatment of wastewater suitable for irrigation by applying the dose of 11 to 13 mg L⁻¹. In this research, the potential of nutrients absorbed by plants from the studied effluents was not reduced by the disinfection using ozone. According to the authors, the effects of ozone treatment on nutrients present in the effluent have received little attention so far. Thus, the lack of published studies in this area makes it difficult to predict which effects to expect.

The results found for this experimental reality do not favor the release of effluent to Class 1, 2, or 3 water bodies, according to CONAMA Resolution 357/05, as the obtained mean values exceed the values allowed by the legislation. However, the effluent could be used for agricultural purposes in soils poor in phosphorus from an agronomic point of view, as occurs in several Brazilian territories, especially in areas with Red-Yellow Latosol and Dystrophic Yellow Latosol (Souza *et al.*, 2020).

Potassium showed an inversely proportional behavior with the increase in doses. However, the applied doses showed no significant differences.

Martínez *et al.* (2011) also found no significant results in the removal of K in a study using ozone applied in wastewater, reporting its ineffectiveness against sulfates, nitrates, potassium, and sodium. Likewise, the results obtained by Camilo Júnior *et al.* (2019) showed great homogeneity of the mean values of K as a function of the time of exposure of ozone to the effluent and the applied doses, indicating that ozonation does not influence its value.

Considering the per capita production of sanitary sewage of 150 L per inhabitant per day and linking it to the irrigation demand added to the use of fertilizers, this result can be significant for different crops, reducing the demand for mineral fertilizers (Camilo Júnior *et al.*, 2019), which directly reflects on the reduction of production costs.

The lowest magnesium mean was obtained using the dose of 60 mg L⁻¹, with a reduction of 4.4%, differing statistically from the effluent without application.

Martínez *et al.* (2011) also found a low Mg reduction when applying ozone in wastewater at a dose of 11 to 13 mg L⁻¹. However, the authors found no significant effect on the effluent after ozone application.

Souza *et al.* (2020) observed similar results when evaluating ozonized bovine effluent and its aptitude for agricultural reuse. The authors observed that Na, Ca, and Mg concentrations were not influenced by ozone, remaining identical to the concentrations analyzed before the oxidant application.

The low or almost zero reduction of magnesium by ozone indicates that the disinfection potential of the oxidant is favorable to agricultural reuse because it does not change the nutrient concentrations.

Calcium showed a reduction in the means with increasing ozone doses. The dose of

60 mg L⁻¹ removed 36.1% of the parameter under these experimental conditions and indicated a significant difference relative to the doses of 0, 8, 15, and 30 mg L⁻¹.

Martínez *et al.* (2011) found similar results when evaluating the ozone effect on wastewater to adapt it to irrigation. The authors observed a reduction of approximately 3 mg L⁻¹ of Ca after applying a dose between 11 and 13 mg L⁻¹ of ozone to the effluent. However, the results showed no significant difference despite the similarity in calcium reduction.

The 36.1% reduction in the parameter indicates that ozone interacted with calcium, but the lack of studies relating the effect of ozone on nutrients contained in wastewater makes it difficult to predict which effects to expect. The effects, such as the mechanism of oxide formation, therefore need to be investigated to advance the understanding of these interactions, making wastewater suitable for agricultural reuse through the application of certain ozone doses without compromising the present Ca.

According to the results for Ca found in this experimental reality, the applied doses must be considered, as there was a trend to reduce the parameter, providing consistent evidence that the doses can influence Ca contents.

Furthermore, the results showed that ozone had little effect on Na. The lowest mean obtained was that of 30 mg L⁻¹, with a reduction of 0.4%. The dose of 60 mg L⁻¹ was statistically different from the dose of 45 mg L⁻¹ and this difference could be partially attributed to the great variability of the sample data for the dose of 45 mg L⁻¹.

Martínez *et al.* (2011), in agreement with Rich and Vervalle (1995), reported the ineffectiveness of ozone against sodium. Camilo Junior *et al.* (2019) studied different doses and exposure times of ozone to the effluent and found great homogeneity of values, indicating that sodium was not influenced by ozone doses or the time of exposure to the effluent.

The effluent sodium adsorption ratio was calculated, and its value was lower than 3.54 ± 0.4 mmol_c L⁻¹. An electrical conductivity close to 1200 μS cm⁻¹ and SAR above 4 mmol_c L⁻¹ lead to a risk classified as moderate, which can cause soil salinization and, consequently, reduce the infiltration rate (Ayers and Westcot, 1999; Rolim *et al.*, 2016).

Excess salts can harm plant growth by restricting the absorption of water and nutrients by the roots due to an increase in the soil's osmotic potential (Carolino *et al.*, 2017). However, the studied effluent does not present these risks given the EC and SAR values.

In short, the ozone treatment may not have contributed in terms of disinfection, but it had an additional beneficial effect on the quality of reused water, as crops need the nutrients that make up the effluents.

4. CONCLUSION

The initially studied ozone doses under the experimental conditions did not reduce the count of total coliforms and *E. coli* sufficiently so that the treated domestic effluent could be used in agriculture, according to the current legislation.

Ozone application did not promote relevant changes to the physicochemical parameters, maintaining the potential for reuse of treated wastewater for crop irrigation.

The results also suggest the need for further investigations of the effects of ozone in a closed application system relative to the efficiency of the primary and secondary treatment of domestic sewage so that we can advance the understanding of the interactions to identify the ideal doses and times of exposure, making wastewater safe for agricultural reuse.

5. ACKNOWLEDGEMENTS

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