ISSN 1808-8546 (ONLINE) 1808-3765 (CD-ROM)

CARACTERIZAÇÃO DE DIGESTATO DE RESÍDUOS ORGÂNICOS RESIDENCIAIS E VIABILIDADE DE USO NA AGRICULTURA IRRIGADA

LETÍCIA THÁLIA SILVA MACHADO[1]; KARL AUGUSTE LEROY[2]; KASSANDRA SUSSI MUSTAFÉ OLIVEIRA[3] E RODRIGO MÁXIMO SÁNCHEZ ROMÁN[4]

[1] *Departamento de Engenharia Rural, Faculdade de Ciências Agronômicas, Universidade Estadual Paulista (UNESP), Avenida Universitária, nº 3780–CEP 18610-034, Altos do Paraíso, Botucatu, SP, Brasil, E-mail: lt.irrigacaoedrenagem@gmail.com.*
[2] *Departamento de Engenharia Rural, Faculdade de Ciências Agronômicas, Universidade Estadual Paulista (UNESP), Avenida Universitária, nº 3780–CEP 18610-034, Altos do Paraíso, Botucatu, SP, Brasil, E-mail: karl.auguste@unesp.br.*
[3] *Departamento de Engenharia Rural, Faculdade de Ciências Agronômicas, Universidade Estadual Paulista (UNESP), Avenida Universitária, nº 3780–CEP 18610-034, Altos do Paraíso, Botucatu, SP, Brasil, E-mail: kassandra.oliveira@unesp.br.*
[4] *Departamento de Engenharia Rural, Faculdade de Ciências Agronômicas, Universidade Estadual Paulista (UNESP), Avenida Universitária, nº 3780–CEP 18610-034, Altos do Paraíso, Botucatu, SP, Brasil, E-mail: rodrigo.roman@unesp.br.*

1 RESUMO

Os digestatos obtidos através da digestão anaeróbia podem ser aproveitados e são benéficos na produção agrícola, para isso, é importante conhecer previamente suas propriedades e características. Objetivou-se com este trabalho realizar a caracterização do digestato obtido a partir do tratamento anaeróbio de resíduos alimentares e avaliar a viabilidade de seu uso na irrigação localizada. Para realização deste trabalho, utilizou-se um biodigestor comercial (HomeBiogas 2.0) em que a biodigestão foi conduzida por 8 meses (abril a dezembro/2021). Neste período foram realizadas análises físico-químicas e biológicas do efluente periodicamente. A partir dos resultados obtidos, constatou-se que o digestato apresentou elementos químicos interessantes para o uso agrícola, dos quais cita-se N, P, K, Ca, Mg, Cu, Fe, Mn, Zn e alta carga orgânica. O digestato apresentou propriedades microbiológicas aceitáveis para aplicação agrícola. Já os teores de Fe, sólidos dissolvidos e suspensos foram acima do recomendado para uso em sistemas de irrigação localizada, com isso, recomenda-se realizar o tratamento do digestato para aplicação por meio desse sistema de irrigação. Concluiu-se que o digestato, se utilizado em conformidade com orientações de profissionais, pode gerar benefícios na produção agrícola, contribuindo como uma fonte de nutrientes para as plantas e fonte de matéria orgânica para o solo.

Palavras-chave: biofertilizante, biodigestor, digestão anaeróbica, HomeBiogas.

MACHADO, L. T. S.; LEROY, K. A.; OLIVEIRA, K. S. M.; SÁNCHEZ-ROMÁN, R. M.
CHARACTERIZATION OF RESIDENTIAL ORGANIC WASTE DIGESTED AND VIABILITY OF USE IN IRRIGATED AGRICULTURE

Recebido em 22/09/2022 e aprovado para publicação em 04/02/2023
DOI: http://dx.doi.org/10.15809/irriga.2023v28n3p48-59

2 ABSTRACT

Digestate obtained through anaerobic digestion can be beneficial in agricultural production, for this, it is important to know their properties and characteristics beforehand. The objective of this study was to characterize the digestate obtained from anaerobic treatment of food waste and evaluate the feasibility of its use in localized irrigation. A commercial biodigester (HomeBiogas 2.0) was used for this work and operated during 8 months (from april to december/2021). The digestate was evaluated for its physical-chemical and biological properties. Digestate presented interesting chemical elements for agricultural use, such as N, P, K, Ca, Mg, Cu, Fe, Mn, and Zn, as well as a high organic load. Additionally, the digestate presented acceptable microbiological sanity for agricultural application. However, the levels of Fe, dissolved solids, and suspended solids were above the recommended values for use in localized irrigation systems. Therefore, it is recommended to treat the digestate before applying it through this irrigation system. It can be concluded that if the digestate is used in accordance with professional guidelines, it can generate benefits in agricultural production, contributing as a source of nutrients for plants and organic matter for the soil.

Keywords: biofertilizer, biodigester, anaerobic digestion, HomeBiogas.

3 INTRODUCTION

Currently, organic waste represents the largest fraction of total solid waste generated worldwide. According to Hoornweg and Bhada-Tata (2012), this fraction corresponds to approximately 46% of the total waste. In developing countries, this rate tends to be even higher, as is observed in Brazil, which has a waste production rate above 50%; in Chile, approximately 50%; in Australia, 47%; in Colombia, 54%; in Indonesia, 62%; and in Mexico, 51%, among others.

Even in the face of the significant production of this waste, its finalization is carried out in a predominantly inadequate way, being destined, in most cases, to open areas without proper soil sealing (ABRELPE, 2019; HOORNWEG; BHADA-TATA, 2012), which has major impacts on the environment, social environment and public health. Another aggravating factor that must be considered in regard to disposing of this waste is the increased cost of collecting and transporting urban solid waste and the reduction in the useful life of landfills, since organic waste makes up almost half of the total solid waste generated. . According to Ferreira *et al.* (2018), from a sustainability point of view, organic waste should not be treated as waste and sent to landfills, and it should be reused efficiently in the production and economic cycle.

Among the alternatives for efficient use is the biodigestion process, also known as anaerobic digestion. In this process, anaerobic bacteria decompose organic waste, promoting its neutralization and generating methane and a methanogenic digestate as the main products, which can be used. The methane generated can be used for energy production (BAREDAR; KHARE; NEMA, 2020; PERRUCCI; RODRIGUES, 2018; SILVA, 2021), and the anaerobic digestate can be used as biofertilizer in agriculture (BARŁÓG; HLISNIKOVSKÝ; KUNZOVÁ, 2020; DOYENI *et al.*, 2021; O'REILLY, 2014; RAKASCAN *et al.*, 2021; WEIMERS *et al.*, 2022).

Even today, the use of anaerobic digesters is most often adopted, aiming only at the production of electrical and/or thermal energy. This is due to its great energy generation potential and the fact that it is a sustainable and renewable alternative. However, from an agronomic point of view, the digestate and sludge generated by the process can have great potential as fertilizers, as a source of organic matter and, in smaller proportions, as a source of water (COMPARETTI *et al*., 2013; SILVA *et al.* . , 2012; HOOTON; NI; WANG, 2019). Furthermore, in some works, such as those by Lu and Xu (2021), Tan *et al.* (2020) and Xu *et al.* (2019) have shown the potential that some digestates can have for enriching and correcting soils.

Digestates derived from anaerobic digestion processes have been used as a sole or partial source of nutrients for different crops in hydroponics (CESARO, 2021; PELAYO LIND *et al.*, 2021; RONGA *et al.*, 2019; WEIMERS *et al.*, 2022) or in soil crops (CESARO, 2021; CHEONG *et al.*, 2020; FERNÁNDEZ-RODRÍGUEZ *et al.*, 2021). Crops such as forage (FERNÁNDEZ-RODRÍGUEZ *et al.*, 2021), microalgae (CESARO, 2021), citrus nurseries (TORRISI *et al.*, 2021), and vegetables (PELAYO LIND *et al.*, 2021; RONGA *et al.*, 2019) have already received this biofertilizer as a source of nutrients, bringing good results in crop productivity.

Knowing the composition of anaerobic digestates is essential for carrying out adequate management of these byproducts and for developing regulations and recommendations for their use in agriculture (COELHO *et al.*, 2018*)*. However, the characterization of digestates depends on several variable factors, which make this process difficult, such as the characteristics of the inoculum, type and composition of the substrate, feeding rate, specifications and configurations of the biodigester, climatic and operational conditions, and time. of residence (AKHIAR, 2017; AL SEADI *et al.*, 2008).

Currently, there are many models of biodigesters, including Indian, Chinese, Canadian, batch, tubular flow, and UASB reactors. Commercial portable biodigesters such as HomeBiogas™ 2.0 and 7.0 have been marketed as cost-effective alternatives for home use. This equipment has been marketed because it has a simple and compact structure and is easy to install and operate (BIOMOVEMENT, 2022).

There is still not much information regarding the biological, microbiological and physical-chemical properties of biofertilizers produced by portable domestic equipment, which has limited their use, as with little information on their application and without safe recommendations for use, digestate has been ignored. In some cases, when used without prior knowledge, they can cause environmental damage, the production chain, the cultivated product and the health of the people involved, as discussed by Nkoa (2013).

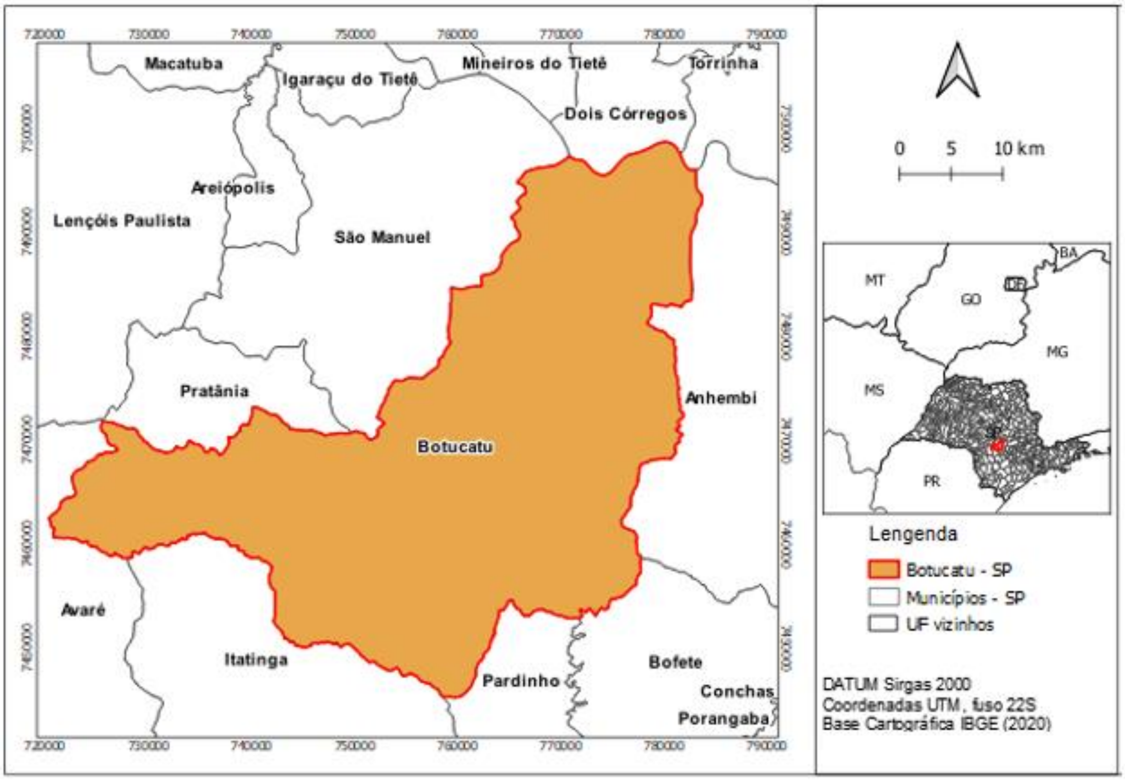
Given the above and the need for more information on anaerobic digestates, highlighted by Nkoa (2013), the aim of this work was to characterize the physicochemical and biological properties of the digestate produced by HomeBiogas™ 2.0 fed domestic organic solid waste and evaluate the feasibility of its application via a localized irrigation system.

4 MATERIALS AND METHODS

4.1 Location

The research was developed at the Department of Rural Engineering and Socioeconomics of the Faculty of Agricultural Sciences of the Universidade Estadual Paulista “Júlio de Mesquita Filho” (FCA/UNESP) campus of Botucatu/SP, located at the coordinates: 22° 51' 9.55” South and 48° 25' 49.55" West, with 786 m of altitude. According to the Köppen classification, the municipality (Figure 1) has a climate classification as Cfa - humid warm temperate (mesothermal) climate, with average annual precipitation of 1,428,4 mm and an average annual temperature of 20.3°C (CUNHA; MARTINS, 2009).

Figure 1. Location map of the municipality of Botucatu-SP



Source: Own authorship (2022)

4.2 Installation and activation of the HomeBiogas™ 2.0 biodigester

The installation and assembly of HomeBiogas ™ 2.0 were carried out following the recommendations of Biomovement (2022). To form the inoculum and activate the biodigester, the entire digestion chamber was filled with water obtained from the Basic Sanitation Company of the state of São Paulo (SABESP), and shortly afterwards, approximately 200 L of fresh manure was added. The manure used was obtained from the cattle confinement of the Faculty of Veterinary Medicine and Animal Science (FMVZ) at UNESP, which at the time contained 9-month-old calves of the F1 Angus breed. The composition of the animals' diet was 80% concentrate (corn and soy) and 20% roughage (sugarcane bagasse), which, according to Costa *et al.* (2016), is a favorable food for the anaerobic digestion process and has great potential for generating biogas. The assembled and operated biodigester is shown in Figure 2.

Figure 2. Representation of HomeBiogas™ installed and in operation [1]

Source: Own authorship (2022)

[1] The authors do not suggest purchasing the product, it was only used in carrying out the work.

After the installation and assembly stages, the system remained at rest so that the microbial communities could multiply, establishing a system that would later hydrolyze the added substrates. The total resting time was 52 days, when the biodigester generated flammable gas for the first stable flame. Only after this moment was the feeding of the biodigester started as described in Topic 4.3.

4.3 Characterization of the organic substrate and biodigester feeding

The substrate used to feed the biodigester was formed by domestic organic solid waste (RSD), basically composed of remains and peels of fruits, vegetables, eggs and leftover meals. The average total solids content of the RSD used was 23%, of which approximately 87.5% was composed of volatile solids and 12.5% was composed of fixed solids. The C/N ratio was 17/1, and the average pH was 5.4.

The biodigester was fed by adding 1 kg of RSD daily. The substrate was not subjected to any size reduction or heat treatment process. Due to the ejection of liquid from the biodigester chamber as the gas was generated, 4 to 8 L of water was added daily, along with the RSD.

4.5 Digestate analysis

The digestate generated at the HomeBiogas 2.0 outlet, without receiving any type of treatment, such as drying or filtration, was subjected to physical-chemical and biological analyses. The analyses were carried out at the FCA/UNESP Water Quality Laboratory at weekly, fortnightly and/or monthly intervals between June and December 2021. The parameters evaluated, as well as the methodology used to carry out each analysis, are presented in Table 1.

Table 1. Quality parameters of the effluents analyzed and methodologies adopted

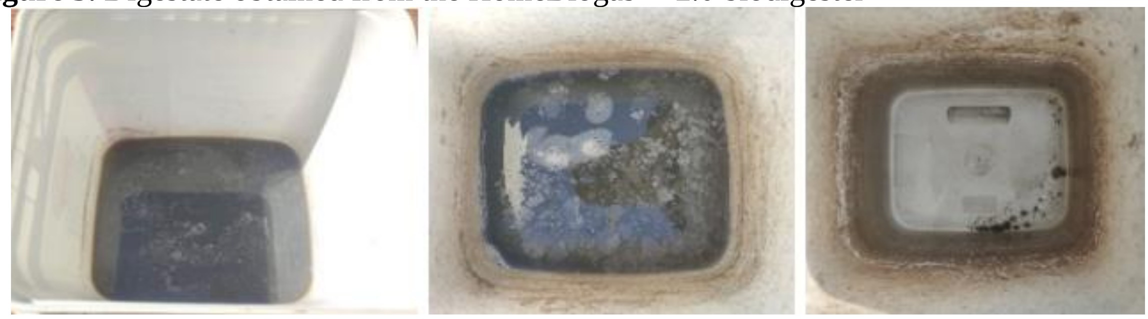
Parameter	**Method**	**Reference** [2]
pH	Eletrometric Method	4500-H^+ B
CE ($mS.cm^{-1}$)	Laboratory Method	2510 B
DBO ($mg.L^{-1}$)	Respirometric Method	5210 D
DQO ($mg.L^{-1}$)	Closed Reflux, Colorimetric	5220 D
N ($mg.L^{-1}$ de N)	Persulfate Digestion Method	4500-N C
P ($mg.L^{-1}$ de $PO4^{3-}$)	Persulfate Method	4500-P
K ($mg.L^{-1}$ de K)	Potassium Permanganate spectrophotometric Method	4500-K B
Coliformes Totais (NMP 100 mL^{-1})	Enzyme Substrate Test with Multi-well procedure	9223 B
E. Coli (NMP 100 mL^{-1})	Enzyme Substrate Test with Multi-well procedure	9223 B
Salmonella spp.	Quantitative MPN	9260 B
SST ($mg.L^{-1}$)	Total Solids Dried at 103-105ºC	2540 B
ST ($mg.L^{-1}$)	Total Suspended Solids Dried at 103-105ºC	2540 D
SDT ($mg.L^{-1}$)	ST-SST	-
SF ($mg.L^{-1}$)	Fixed and Volatile Solids Ignited at 550°C	2540 E
SV ($mg.L^{-1}$)	Fixed and Volatile Solids Ignited at 550°C	2540 E

[2] All references come from the 23rd edition of the Standard Methods for the Examination of Water and Wastewater APHA (2017); BOD- Biochemical Oxygen Demand; COD – Chemical Oxygen Demand; EC- Electrical Conductivity; N- Nitrogen; P- Phosphorus; K- Potassium; ST- Total Solids; SST- Total Suspended Solids; TDS- Total Dissolved Solids; SF- Fixed Solids; SV- Volatile Solids.

5 RESULTS AND DISCUSSION

The volume of digestate generated daily by HomeBiogas™ 2.0 after system stabilization was between 4 and 8 L. The biofertilizer was composed of liquid and solid, with the liquid being the most significant part. In Figure 3, shown below, three images are shown that illustrate the digestate produced by the biodigester. In the first two images, the accumulation of digestate can be seen over a period of 24 hours, which corresponded to the interval used to perform the collection. In the third image, the bucket after removing the digestate is shown, highlighting the presence of larger solid particles that used to be deposited at the bottom of the container.

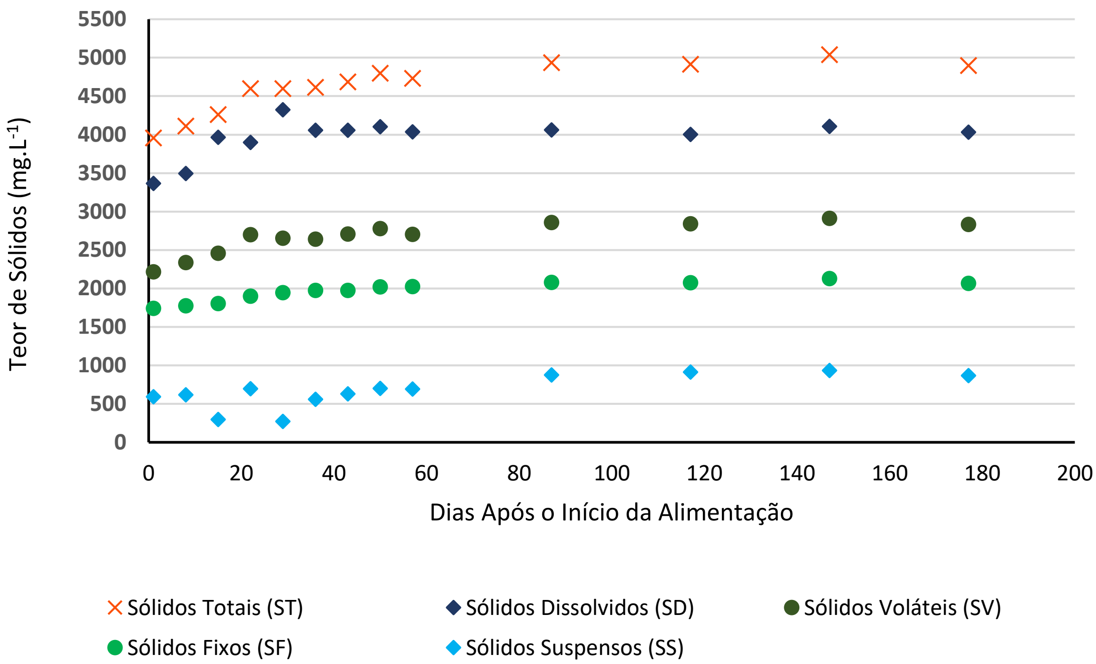
Figure 3. Digestate obtained from the HomeBiogas™ 2.0 biodigester



Fonte: Autoria própria (2022)

Regarding the solids content, the digestate presented a lower total solids (TS) content at the beginning of the analyses (Figure 4) because during this period, the feeding with organic waste began. Over time, approximately 80 days after the start of feeding, it is possible to observe that the system tended toward a linear behavior, which indicated the stabilization of the system's microbial activity under the added daily organic load. The average ST content after stabilization was 4,946.42 mg. L $^{-1}$ with a standard deviation of 63.7 mg. L $^{-1}$.

Figure 4. Behavior of the solids content of the effluent obtained by Homebiogas™ 2.0 over time



Source: Authors (2022)

Similar to ST, dissolved solids (SD), suspended solids (SS), volatile solids (SV) and fixed solids (SF) tend to show stable behavior after 80 days from the start of feeding, obtaining average levels after stabilization of 4,049.75 mg. L $^{-1}$ for SD, 896.67 mg. L $^{-1}$ for SS, 2,859.75 mg. L $^{-1}$ for SV and 2,086.67 mg. L $^{-1}$ for SF.

From the aforementioned results, it was found that the digestate presented SS and SD levels well above those recommended by Nakayama and Bucks

(1986), demonstrating that its use could cause major problems if conducted and applied via localized irrigation systems. In view of this, to carry out its application via these localized irrigation systems, it is essential that posttreatment be carried out for the digestate.

The chemical and biological characteristics of the biofertilizer, as well as the results of the RAS calculation, are presented in Table 3. Through the results, it is possible to verify that the digestate generated has a pH close to neutral, with a basic tendency; this effect is common in the effluents of anaerobic reactors (ANGOURIA-TSOROCHIDOU; THOMSEN, 2021; BARZEE *et al.*, 2019; JABEEN *et al.*, 2015; VOĆA *et al.*, 2005). Furthermore, it is important to highlight that the pH of the biofertilizer was maintained between 7 and 8, which is in accordance with the recommended range for agricultural biofertilizers established in CONAMA Resolution N°503 of 2021, which varies between 5 and 9.

Similar to SS and SD, the Fe content was also higher than that recommended by Nakayama and Bucks (1986), increasing the restriction on the direct use of this effluent via localized irrigation systems.

The EC value was high, which highlights the high concentration of dissolved ions, an expected response as it is the digestion of rich elements with a high organic load (ANGOURIA-TSOROCHIDOU; THOMSEN, 2021; BARZEE *et al*., 2019*;* VOĆA *et al.*, 2005). With the EC and RAS values, the digestate was classified as C4S1 (RICHARDS, 1954), indicating a low risk of sodicity and a very high risk of soil salinization, pointing to the need for planned and controlled use.

Table 3. Chemical and biological characteristics of the digestate obtained as HomeBiogas effluent

Parameters	Average	Standard deviation	C.V. (%)
pH	7.22	0.58	8.0
CE ($mS.cm^{-1}$)	4.72	0.58	12.2
N_{total} ($mg.L^{-1}$)	349.74	91.17	26.1
P ($mg.L^{-1}$)	95.40	54.39	57.0
K ($mg.L^{-1}$)	544.19	138.20	25.4
Ca ($mg.L^{-1}$)	160.77	20.86	13.0
Mg ($mg.L^{-1}$)	115.86	35.43	30.6
Na ($mg.L^{-1}$)	132.65	78.49	59.2
Cu ($mg.L^{-1}$)	0.08	0.06	76.9
Fe ($mg.L^{-1}$)	2.72	1.44	53.1
Mn ($mg.L^{-1}$)	1.09	0.80	73.3
Zn ($mg.L^{-1}$)	0.30	0.08	28.0
RAS	1.95	-	-
DQO ($mg.L^{-1}$)	5855.37	559.93	9.6
DBO ($mg.L^{-1}$)	3131.28	546.37	17.4
CT (NMP 100 mL^{-1})	91779.29	121222.13	132.1
E.Coli (NMP 100 mL^{-1})	530.92	436.83	82.3
Salmonella spp.	0	0	0

Source: Own authorship (2022)

Although biofertilizer is generated from residential organic waste, the nutrient content and EC obtained in this experiment were low when compared to the values obtained by Voća *et al.* (2005) and Barzee *et al.* (2019), who also work with food waste. This variability can occur due to several factors, but it is believed that this was mainly due to the large amount of water in the system and the low amount of organic load inserted daily into the biodigester that was used in this work.

The digestate obtained by HomeBiogas 2.0, with the organic load of residential organic waste inserted daily, presented an average NPK ratio of 3.7;1;5.7, in addition to containing micronutrients and organic matter, as shown in Table 3, and can generate improvements in the microbiological characteristics of the soil, an increase in soil organic matter and an increase in agricultural productivity if used in a controlled and planned manner.

In addition to the parameters already mentioned, it was noted from Table 3 that the digestate presented counts for total coliforms and *E. coli*, with averages after stabilization of $9.2.10^{4}$ NMP.100 mL $^{-1}$ and 530.92 NMP.100 mL $^{-1}$, and did not show the presence of *Salmonella* spp. From this, it was found that the digestate presented satisfactory microbiological characteristics for application in agricultural crops, as the *E. coli content* was lower than 1,000 MPN.100 mL $^{-1}$ and there was no presence of *Salmonella* spp., thus meeting the criteria established by the CONAMA resolution (2021) and international standards established by WHO (2006).

6 CONCLUSION

The digestate obtained by HomeBiogas™ 2.0 presented interesting physicochemical and microbiological characteristics for agricultural use and can act as a source of organic matter for soils and a source of nutrients for any agricultural crop. Its application must occur in a planned manner, taking into account the nutritional demands of the crop, the raw material used in the biodigester and the operating conditions of the biodigester. The properties of the soil and the irrigation system must also be evaluated before applying biofertilizer to the crop. Furthermore, as the levels of solids and iron were measured above the values recommended for application via localized irrigation, presenting a high risk of obstruction, it is recommended to carry out an additional treatment of the digestate if there is interest in using it in this type of method. of irrigation.

7 REFERÊNCIAS

AKHIAR, A. **Characterization of Liquid Fraction of Digestates After Solid-liquid Separation from Anaerobic Co-digestion Plants**. Thesis (Doctorate in Chemical and Process Engineering) – Université Montpellier, Montpellier, 2017.

AL SEADI, T.; RUTZ, D.; PRASSL, H.; KOTTNER, M.; FINSTERWALDER, T.; SILKE VOLK, R. J. **Biogas Handbook**. Esbjerg: University of Southern Denmark Esbjerg, 2008.

APHA. **Standard methods**: For the examination of water and waste water. 23. ed. Washington, DC: American Public Health Association, 2017.

ANGOURIA-TSOROCHIDOU, E.; THOMSEN, M. Modelling the quality of organic fertilizers from anaerobic digestion – comparison of two collection systems. **Journal of Cleaner Production**, Amsterdam, v. 304, p. 1-11, 2021.

ABRELPE. **Panorama dos resíduos sólidos no Brasil**. São Paulo: ABRELPE, 2019.

BAREDAR, P.; KHARE, V.; NEMA, S. **Design and Optimization of Biogas Energy Systems**. Chennai: Academic Press, 2020.

BARŁÓG, P.; HLISNIKOVSKÝ, L.; KUNZOVÁ, E. Yield, Content and Nutrient Uptake by Winter Wheat and Spring Barley in Response to Applications of Digestate, Cattle Slurry and NPK Mineral Fertilizers. **Archives of Agronomy and Soil Science**, London, v. 66, n. 11, p. 1-16, 2020.

BARZEE, T. J.; EDALATI, A.; EL-MASHAD, H.; WANG, D.; SCOW, K.; ZHANG, R. Digestate Biofertilizers Support Similar or Higher Tomato Yields and Quality Than Mineral Fertilizer in a Subsurface Drip Fertigation System. **Frontiers in Sustainable Food Systems**, Lausanne, v. 3, article 58, p. 1-13, 2019.

BIOMOVEMENT. **HomeBiogas**. [*S. l.*]: HOMEBIOGAS, 2022. Disponível em: https://www.homebiogas.com/. Acesso em: 10 jan. 2022.

CESARO, A. The valorization of the anaerobic digestate from the organic fractions of municipal solid waste: Challenges and perspectives. **Journal of Environmental Management**, London, v. 280, article 111742, p. 1-13, 2021.

CHEONG, J. C.; LEE, J. T. E.; LIM, J. W.; SONG, S.; TAN, J. K. N.; CHIAM, Z. Y.; YAP, K. Y.; LIM, E. Y.; ZHANG, J.; TAN, H. T. W.; TONG, Y. W. Closing the food waste loop: Food waste anaerobic digestate as fertilizer for the cultivation of the leafy vegetable, xiao bai cai (Brassica rapa). **Science of the Total Environment**, Amsterdam, v. 715, article 136789, p. 1-12, 2020.

COELHO, J. J.; PRIETO, M. L.; DOWLING, S.; HENNESSY, A.; CASEY, I.; WOODCOCK, T.; KENNEDY, N. Physical-chemical Traits, Phytotoxicity and Pathogen Detection in Liquid Anaerobic Digestates. **Waste Management**, Oxford, v. 78, p. 8-15, 2018.

COMPARETTI, A.; FEBO, P.; GRECO, C.; ORLANDO, S. Current State and Future of Biogas and Digestate Production. **Bulgarian Journal of Agricultural Science**, Bulgaria, v. 19, n. 1, p. 1-14, 2013.

CONAMA. Resolução CONAMA nº 503, de 14 de dezembro de 2021. Define critérios e procedimentos para o reúso em sistemas de fertirrigação de efluentes provenientes de indústrias de alimentos, bebidas, laticínios, frigoríficos e graxarias. **Diário Oficial da União**: seção 1, Brasília, DF, n. 503, p. 1-9,14 de dez, 2021.

COSTA, M. S. S. M.; LUCAS, J.; COSTA, L. A. M.; ORRICO, A. C. A. A highly Concentrated Diet Increases Biogas Production and the Agronomic Value of Young Bull’s Manure. **Waste Management**, Oxford, v. 48, p. 521-527, 2016.

CUNHA, A. R.; MARTINS, D. Climatic classification for the districts of Botucatu and São Manuel, SP. **Irriga**, Botucatu, v. 14, n. 1, p. 1-11, 2009.

DOYENI, M. O.; STULPINAITE, U.; BAKSINSKAITE, A.; SUPRONIENE, S.; TILVIKIENE, V. The Effectiveness of Digestate Use for Fertilization in an Agricultural Cropping System. **Plants**, Basel, v. 10, n. 8, p. 1-13, 2021.

FERNÁNDEZ-RODRÍGUEZ, M. J.; MANCILLA-LEYTÓN, J. M.; JIMÉNEZ-RODRÍGUEZ, A.; BORJA, R.; RINCÓN, B. Reuse of the digestate obtained from the biomethanization of olive mill solid waste

(OMSW) as soil amendment or fertilizer for the cultivation of forage grass (Lolium rigidum var. Wimmera). **Science of The Total Environment**, Amsterdam, v. 792, article 148465, p. 1-8, 2021.

FERREIRA, A. K. C.; DIAS, N. D. S.; SOUSA JUNIOR, F. S.; FERREIRA, D. A. C.; FERNANDES, C. D. S.; LUCAS, L. E. F.; TRAVASSOS, K. D.; SÁ, F. V. S. Physicochemical and Microbiological Properties and Humic Substances of Composts Produced with Food Residues. **Journal of Agricultural Science**, Cambridge, v. 10, n. 1, p. 180-189, 2018.

HOORNWEG, D.; BHADA-TATA, P. **What a Waste**: A Global Review of Solid Waste Management. 15. ed. Washington, DC: World Bank, 2012.

HOOTON, E.; NI, Y. S.; WANG, C. Is biodigester effluent a suitable replacement for commercial fertilizers ? Assessing the efficacy of liquid biogas digestate for cultivation of tomato (solanum lycopersicum) crops in barbados. **Journal of Sustainable Tropical Agriculture**, Montreal, p. 1-40, 2019.

JABEEN, M.; ZESHAN; YOUSAF, S.; HAIDER, M. R.; MALIK, R. N. High-solids Anaerobic Co-digestion of Food Waste and Rice Husk at Different Organic Loading Rates. **International Biodeterioration and Biodegradation**, Barking, v. 102, p. 149-153, 2015.

LIND, O. P.; HULTBERG, M.; BERGSTRAND, K. J.; LARSSON-JÖNSSON, H.; CASPERSEN, S.; ASP, H. Biogas Digestate in Vegetable Hydroponic Production: pH Dynamics and pH Management by Controlled Nitrification. **Waste and Biomass Valorization**, Dordrecht, v. 12, n. 1, p. 123-133, 2021.

LU, J.; XU, S. Post-treatment of food waste digestate towards land application: A review. **Journal of Cleaner Production**, Amsterdam, v. 303, p. 1-12, 2021.

NAKAYAMA, F. S.; BUCKS, D. A. **Trickle Irrigation for Crop Production**. Amsterdam: Elsevier, 1986.

NKOA, R. Agricultural benefits and environmental risks of soil fertilization with anaerobic digestates: a review. **Agronomy for Sustainable Development**, Paris, v. 34, n. 2, p. 473-492, 2013.

O’REILLY, M. C. **Characterization of anaerobic digestates for their nitrogen fertility value and improved nutrient management**. Theses (Master of Science in Environmental Sciences) – University of Guelph, Guelph, 2014.

PERRUCCI, G. G. S.; RODRIGUES, G. O. **Resíduos Orgânicos e a Aplicação Doméstica do Biogás Gerado**. Trabalho de Conclusão de Curso (Curso de Engenharia Ambiental) – Escola Politécnica, Universidade de São Paulo, São Paulo, 2018.

RAKASCAN, N.; DRAZIC, G.; POPOVIC, V.; MILOVANOVIC, J.; ZIVANOVIC, L.; REMIKOVIC, M. A.; MILANOVIC, T.; IKANOVIC, J. Effect of digestate from anaerobic digestion on Sorghum bicolor L. production and circular economy. **Notulae Botanicae Horti Agrobotanici,** Cluj-Napoca, v. 49, n. 1, p. 1-13, 2021.

RICHARDS, L. A. **Diagnosis and improvement of saline and alkali soils**. Washington, DC: United States Salinity Laboratory, 1954. (United States Department of Agriculture Handbook, 60).

RONGA, D.; SETTI, L.; SALVARANI, C.; DE LEO, R.; BEDIN, E.; PULVIRENTI, A.; MILC, J.; PECCHIONI, N.; FRANCIA,

E. Effects of solid and liquid digestate for hydroponic baby leaf lettuce (Lactuca sativa L.) cultivation. **Scientia Horticulturae**, Amsterdam, v. 244, p. 172-181, 2019.

SILVA, C. E. V. **Sustentabilidade**: Avaliação da produção de biogás em um biodigestor de pequena escala. Dissertação (Mestrado em Ambiente e Desenvolvimento) – Universidade do Vale do Taquari, Lajeado, 2021.

SILVA, W. T. L.; NOVAES, A. P.; KUROKI, V.; MARTELLI, L. F. A.; MAGNONI, L. Avaliação Físico-química de Efluente Gerado em Biodigestor Anaeróbio para Fins de Avaliação de Eficiência e Aplicação como Fertilizante Agrícola. **Quimica Nova**, São Paulo, v. 35, n. 1, p. 35-40, 2012.

TAN, F.; ZHU, Q.; GUO, X.; HE, L. Effects of digestate on biomass of a selected energy crop and soil properties. **Journal of the Science of Food and Agriculture**, London, v. 101, n. 3, p. 927-936, 2020.

TORRISI, B.; ALLEGRA, M.; AMENTA, M.; GENTILE, F.; RAPISARDA, P.; FABRONI, S.; FERLITO, F. Physico-chemical and multielemental traits of anaerobic digestate from Mediterranean agro-industrial wastes and assessment as fertiliser for citrus nurseries. **Waste Management**, Oxford, v. 131, p. 201-213, 2021.

VOĆA, N.; KRIČKA, T.; ĆOSIĆ, T.; RUPIĆ, V.; JUKIĆ, Ž.; KALAMBURA, S. Digested residue as a fertilizer after the mesophilic process of anaerobic digestion. **Plant, Soil and Environment**, Praha, v. 51, n. 6, p. 262-266, 2005.

WEIMERS, K.; BERGSTRAND, K.-J.; HULTBERG, M.; ASP, H. Liquid Anaerobic Digestate as Sole Nutrient Source in Soilless Horticulture—Or Spiked With Mineral Nutrients for Improved Plant Growth. **Frontiers in Plant Science**, New Haven, v. 13, p. 1-13, 2022.

WHO. **Guidelines for the** s**afe use of wastewater, excreta and greywater guidelines.** Wastewater use in agriculture. Genebra: World Health Organization, 2006. v. 2.

XU, M.; XIAN, Y.; WU, J.; GU, Y.; YANG, G.; ZHANG, X.; PENG, H.; YU, X.; XIAO, Y.; LI, L. Effect of biogas slurry addition on soil properties, yields, and bacterial composition in the rice-rape rotation ecosystem over 3 years. **Journal of Soils and Sediments**, Heidelberg, v. 19, n. 5, p. 1-8, 2019.