Characterization of humic substances developed during the composting of class II A organic solid waste: A case study in a composting plant in Montenegro, Brazil

Caracterización de sustancias húmicas desarrolladas durante el compostaje de residuos sólidos orgánicos classe II A: Un estudio de caso en una planta de compostaje en Montenegro, Brasil

Caracterização de substâncias húmicas desenvolvidas durante a compostagem de resíduos sólidos orgânicos classe II A: Um estudo de caso em uma central de compostagem em Montenegro, Brasil

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Keywords: Organic waste; composting; humic substances; agriculture

Abstract

Introduction: The abundance of organic waste generated by agro-industrial activities leads to the need to find alternatives for adequate destinations for these. Composting is the most viable alternative due to its low cost, ease of operation and generation of a product with the possibility of economic exploitation. **Objetive:** The objective of this work was to present the dynamics of the composting process in an organic waste processing plant in the municipality of Montenegro, RS, Brazil, as well as to present the results of chemical analyzes for the quantification of humic substances contained in the leachate resulting from the composting process. **Results:** The results of the leachate revealed that it has high levels of humic substances (humic acids between 12.2% and 30.7%, fulvic acids between 12.2% and 45.5%) significantly higher than those found in the literature (9%). **Conclusions:** Leachate has humic characteristics desired for the preparation of a commercial product for use in agriculture and can be configured as an interesting extra income alternative for the economic health of the enterprise.

Palabras clave: Residuos orgánicos; compostaje; sustancias húmicas; agricultura

Resumen

Introducción: La abundancia de residuos orgánicos generados por las actividades agroindustriales lleva a la necesidad de buscar alternativas de destino adecuado para estos. El compostaje es la alternativa más viable por su bajo costo, facilidad de operación y generación de un producto con posibilidad de aprovechamiento económico. **Objetivo:** El objetivo de este trabajo fue presentar la dinámica del proceso de compostaje en una planta de procesamiento de residuos orgánicos en el municipio de Montenegro, RS, Brasil, así como presentar los resultados de los análisis químicos para la cuantificación de sustancias húmicas contenidas en el lixiviado resultante del proceso compostaje. **Resultados:** Los resultados del lixiviado revelaron que presenta altos niveles de sustancias húmicas (ácidos húmicos entre 12.2% y 30.7%, ácidos fúlvicos entre 12.2% y 45.5%) significativamente superiores a los encontrados en la literatura (9%). **Conclusiones:** El lixiviado tiene las características húmicas deseadas para la elaboración de un producto comercial de uso agrícola, y puede configurarse como una interesante alternativa de ingresos extra para la salud económica del emprendimiento.

Palavras-chave: Resíduos orgânicos; compostagem; substâncias húmicas; agricultura

Resumo

Introdução: A abundância de resíduos orgânicos gerados pelas atividades agroindustriais leva à necessidade de encontrar alternativas para destinações adequadas para estes. A compostagem é a alternativa mais viável devido ao seu baixo custo, facilidade de operação e geração de um produto com possibilidade de aproveitamento econômico. **Objeto:** O objetivo deste trabalho foi apresentar a dinâmica do processo de compostagem em uma usina de processamento de resíduos orgânicos no município de Montenegro, RS, Brasil, bem como apresentar os resultados de análises químicas para a quantificação de substâncias húmicas contidas na compostagem lixiviado resultante do processo. **Resultado:** Os resultados do lixiviado revelaram que o mesmo apresenta teores elevados de substâncias húmicas (ácidos húmicos entre 12.2% e 30.7%, ácidos fúlvicos entre 12.2% e 45.5%) significativamente superiores aos encontrados na literatura (9%). **Conclusões:** O lixiviado possui características húmicas desejadas para a elaboração de um produto comercial para uso na agricultura, podendo se configurar como uma interessante alternativa de renda extra para a saúde econômica do empreendimento.

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1. Introduction

The modernity experienced by the human population has brought with it a series of environmental issues to be worked on so that it is possible to continue evolving as a species (Ekins, 2017). The need for an environment favorable to life on Earth, with clean water, healthy food, and pure air, highlighvts the responsibility with which natural resources must be managed, since their misuse configures the degradation of the environment, causing impacts to populations (Pohlmann et al., 2020).

Organic solid waste that is wrongly disposed of is an example of poor management of natural resources, as it diverts the nutrients present in this waste from the natural cycle (Adipah & Kwame, 2019).

Millions of tons of organic matter are dumped in landfills every year, causing problems with greenhouse gas emissions and pollution (Umar, 2020). These wastes have great potential for use in agriculture, since many soils are in a situation of degradation, largely due to the intensive use of chemical fertilizers and lack of management actions aimed at promoting the increase of organic matter in the soil (Sharma et al., 2019).

Composting is one of the most important techniques in the management of organic solid waste, since it is efficient in the degradation of pathogenic organisms, relatively inexpensive and with potential for waste processing, providing a quality input for use in agriculture. It has been widely studied, due to the diversity of waste produced and the peculiarities of each condition in which this technique can be used (Argun et al., 2017).

Organic agro-industrial waste has the characteristic of being produced close to the urban environment, which makes it difficult to return correctly to the cultivation systems, making composting an adequate alternative for the destination of these materials (Singh et al., 2021).

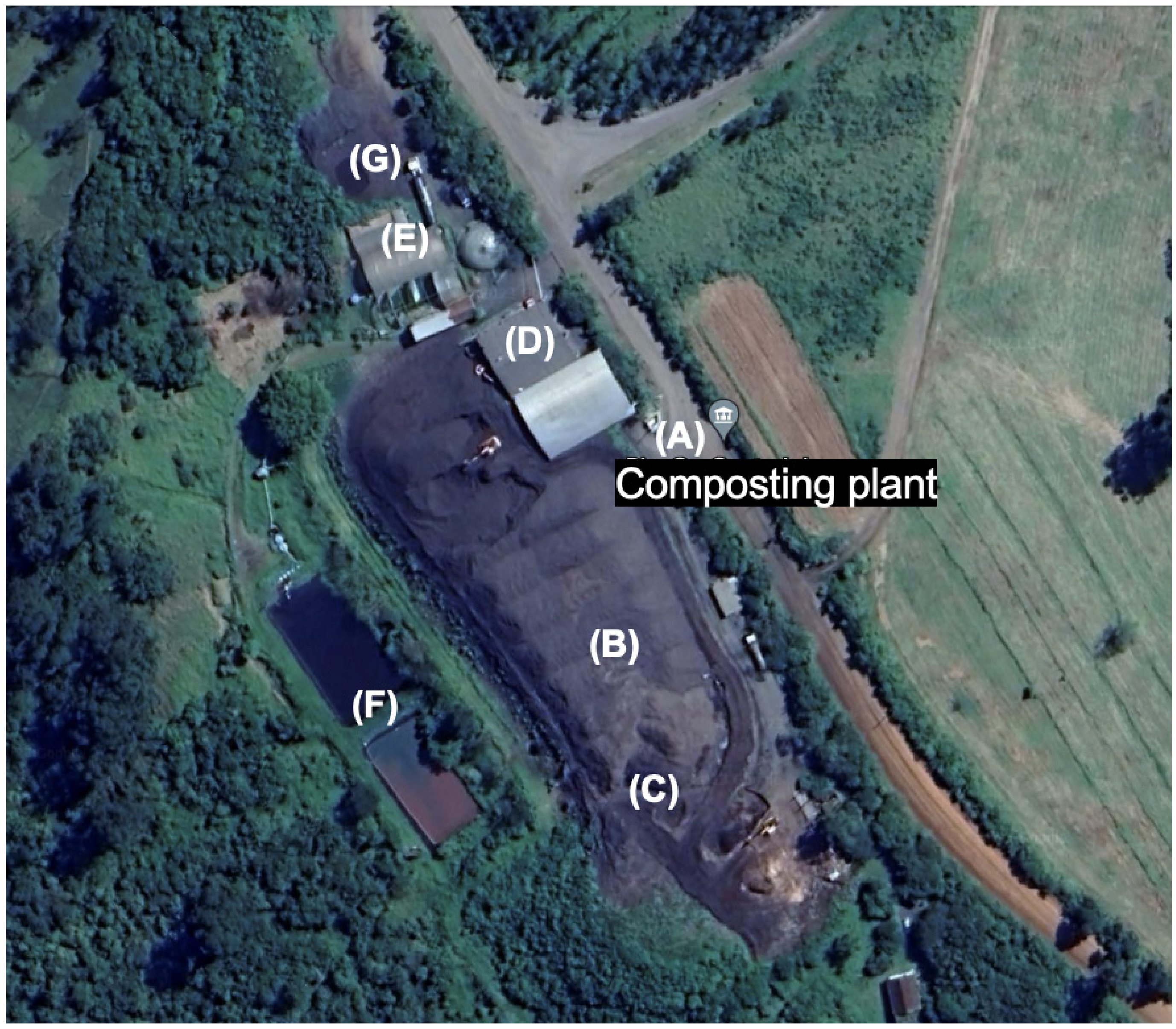
Organic waste composting plants have been contributing to the sustainability of farming systems as they collect this waste, usually from the urban environment, and process it so that it can safely return to agriculture, bringing benefits to the soil and increases in crop productivity. Also, products derived from composting, such as compost leachate, are rich in humic substances that have been studied for their use in agriculture, showing numerous benefits (Pergola et al., 2018). In this way, the present work has as main objectives to report the dynamics of processing of agro-industrial organic wastes of a company located in the municipality of Montenegro (RS, Brazil), as well as to study the leachate of the compost of the company regarding the content of humic substances, intending to establish a relationship between the types of waste processed and their humic characteristics, aiming at the economic exploitation of this by-product.

2. Material and methods

2.1. Study area

The company consists of a composting plant for non-hazardous waste, located in the municipality of Montenegro, Rio Grande do Sul, Brazil (29°44´21"S, 51°27´47"W). Figure 1 shows the company's headquarters, which has 11 ha and consists of the reception guardhouse (A), the composting yard (B), the waste reception ditch (C), a 648 m^2 shed (D), an office (E), two waste treatment ponds (F) and two waste disposal ponds that serve as a "waiting" place for waste that cannot be immediately sent to composting (G).

Figure 1. Overview of the study area. A): The reception; B) Compost yard; C): Reception ditch; D): Shed; E): Office; F): Treatment ponds; G): Deposition pond.



Source: Google Earth©.

There are five (5) piezometers installed in strategic locations on the plant's premises, which provide groundwater samples that are analyzed every six months to check for contamination of the water table from the company's activities. This monitoring is necessary for the renewal of the establishment's registration with the Ministry of Agriculture, Livestock and Food Supply of Brazil.

The plant is surrounded by tree vegetation planted by the company before its official founding, made up of native species, which helps to contain possible odors exhaled by the composting process.

2.2. Composting plant

The company's compost yard was sized to process 13 000 t per month, configured by two 50 m × 100 m modules, resulting in an area of 1 ha. The waste reception ditch, where all the waste arriving at the plant is deposited, was built with a layer of compacted clay, a 1.5 mm high-density polyethylene geomembrane and 2 m of raw rice husk, and it has an area of 200 m^2 with a depth of 6 m (Figure 2).

The windrows do not have internal streets due to a strategic issue established by the company. By maintaining continuity between them, greater water retention in the windrows and greater control over the amount of liquid drained when heavy rainfall occurs.

Figure 2. Waste reception ditch. View of the waste reception ditch in the study area.

Source: Own authorship.

If this continuity between the windrows did not exist, there would be a lot of liquid percolation, aggravating the loss of moisture from the windrows and causing the inconvenience of excess leachate in the treatment lagoons.

Turning the windrows is not impaired by their continuity, since the shovels of the excavators can carry out the complete turning, and the windrows are not soaked because water evaporates due to the high temperatures of the windrows process. Currently, 3 to 4 thousand tons of waste are processed per month, with an average decomposition time of 18 months.

There are two covered deposition ponds designed to receive waste that needs some stabilization before being sent for composting, or that contains a lot of water and needs to be filtered. One of them is currently stopped due to a strong wind that tore the plastic covering.

The leachate from the composting windrows is collected by adding the liquid that percolates from the entire length of the windrows, that is, the material comes from both the newest and most stabilized windrows, and is passed through two biodigesters, a decanter, and a filter. To keep the level of the ponds low and avoid the risk of overflow, the leachate is used to irrigate the sieved compost, which receives 5 000 liters of leachate per day. In addition, because it contains humic characteristics, there is interest in analyzing it for the preparation of a product for application in the soil or plants.

2.3. Waste characterization

The waste received by the company can be divided into three classes, namely C:N high; low C:N ratio; and mineral sources. The waste used by the company and its respective classes are listed below:

a) *High C:N ratio*: Acacia bark, urban pruning material, remaining coal from boilers, sawdust, chips.

b) *Low C:N ratio*: Grease traps, dairy products, food leftovers from supermarkets, brewery waste, soy sludge, fruit pomace, sludge from water treatment plants.

c) *Nutrient sources*: Boiler ash, coal wastes.

Waste with a high moisture content (such as soy sludge and some sludge) is decanted into the deposition pond before being discharged into the ditch. Problems with fires are more frequent in rainy seasons due to the anaerobiosis caused inside the windrows, causing fermentation and methane production and consequent propensity to ignite. Over time, it was verified that the addition of wastes such as ashes and/or fruit pomace in the fire outbreaks helps in the immediate reduction of the temperature and in the fight against the fire, since the use of pure water does not allow to stop the problem.

Problems of lack of heating in the windrows do not occur in this composting plant due to the correct C: N ratio of the mixture of wastes, which favors the adequate process of decomposition of the materials. The branches are not chopped because the course granulometry of this material favors aeration and structuring of windrows.

2.4. Processing of waste compost

• *Mixture*

As soon as the waste arrives at the company, it is deposited in the reception ditch, where it is mixed to reach a C:N ratio of around 30:1 to compose the composting piles. This mixture is carried out as the waste is received in the trench, regardless of its nature, which makes it impossible to achieve the exact C:N ratio. A reserve pile of sawdust and another one of acacia bark are kept at the disposal of the operator who mixes the materials, in order to structurally stabilize the mixed content when needed, that is, the sawdust is added to wastes with a lot of moisture and the bark with the function of structuring the mixture, both aiming to form a product that can be wound up, that does not spread when worked.

• *Assembling the windrows*

As soon as the wastes are mixed in the proper proportion to allow their deposition without being disassembled, they are arranged in windrows in the space designed in the company's yard. The windrows follow an order according to the progress of the composting process, where the windrows closest to the reception ditch are newer, while the windrows closest to the covered pavilion, where the finished compost is sieved, are more stabilized. In this way, a sequential process of the decomposing material takes place until it reaches the covered pavilion, where the compost is finalized.

The dimensions of the windrows vary according to the amount of waste received and the finished compost output, but follow that there is no internal street and, therefore, the windrows maintain continuity with each other, as illustrated in Figure 3.

Figure 3. Waste in the composting process.

Source: Authors.

• *Revolving*

Once piled up, the composting process begins, where aerobic microorganisms use organic materials as a source of energy for their development and reproduction. The microbial action generates heat that reaches up to 72°C, which is responsible for the degradation of any pathogenic organisms that may be present in the material. To maintain aerobic conditions to preserve the microorganisms, the windrows of organic material are turned over. This revolving consists of overturning and moving the windrows towards the finished compost pavilion and is carried out with the aid of an excavator at intervals of 30 to 40 days, depending on meteorological conditions and empirically observed parameters, such as the presence of steam on the windrows.

• *Sieving*

When the organic material reaches the required stability parameters, which takes approximately 18 months, it is then sent to the last stage of the process, where it is sieved. Sifting has the purpose of removing larger wastes that have not completely suffered the action of microorganisms, as well as providing a uniform granulometry to the compost. Any residue retained on the sieve is sent back to the beginning of the process, serving as a microorganism inoculant for the new wastes. The sieve used has an operating capacity of 50 m^3 h^{-1}.

2.5. Quantification of humic substances

Seven collections of leachate samples were carried out, six of which were —current— material, directly percolated from the compost piles, and one was from a compost pile kept in storage for eight years, allowing changes in its constitution. The samples were collected from a hose that directs the leachate from the composting windrows to the treatment ponds, taking place at intervals of one to six weeks, aiming to provide representative results of meteorological changes over the collection period.

• *Collection description*

Two liters each of the samples were collected on July 20th and 27th, August 24th, October 5th and 6th, and November 17th, 2022, due to the need to establish methods of drying and handling the material, in accordance with the requirements of the method of analysis of humic substances (Lamar et al., 2014). After establishing the analysis methodology, the samples were collected in 500 ml PET (Polyethylene Terephthalate) bottles and kept at room temperature until the moment of analysis.

Meteorological conditions in the seven days prior to each collection were recorded for subsequent correlation with the results of the analyses, since rainy days tend to dilute the concentration of compounds present in the leachate, and very dry days tend to the opposite.

• *Determination of humic and fulvic acid levels*

To determine the levels of Humic Acids (HA) and Fulvic Acids (FA) the methodology developed by Lamar et al. (2014), which is adopted by the United States Humic Products Trade Association (HPTA) for quantification of Humic Substances (HS) in organic fertilizers. This method is based on the gravimetric determination of purified HA and FA. To determine the adequate amount of sample to obtain measurable and accurate results, a preliminary test was performed using 10 ml and 20 ml of the leachate (two replicates each) of the sample collected on 07/20/2022. The 20 ml aliquot was more representative and more accurate, due to the higher concentration of HS present in this volume. Therefore, all subsequent analyzes were performed with 20 ml aliquots, in duplicate, to compare results and perform averages.

• *Determination of the concentration of solids in the leachate*

The concentration of solids in the leachate must be determined so that the HA and HF content can be expressed on a dry weight basis. For this, two 20 ml aliquots of each material collected were weighed on an analytical scale with 3 decimal places in a pre-weighed glass beaker. Then the suspension was dried in an oven (FabbeCenter 119) at 60°C. After drying the sample and cooling, the weight of the flask + dry sample was determined. After calculating the dry mass weight of the sample, the solids concentration was calculated according to Equation 1. Afterwards, the arithmetic mean between the two repetitions was calculated to use a more precise value to calculate the humic substance contents.

$$[\text{solids } (\%)] = (\text{dry mass}) \qquad (1)$$

This data is used to calculate the dry mass of each leachate aliquot analyzed in the determination of humic substances (Equation 2):

$$\text{dry mass} = \frac{\text{wet mass} \times [\text{solids } (\%)]}{100} \qquad (2)$$

• *Fractionation and purification of humic substances*

To determine the AH and AF content, 20 ml of the leachate were weighed on an analytical scale with 3 decimal places, in a plastic beaker. This aliquot was then increased to 500 ml with 0.1 mol l^{-1} NaOH in a 1 L plastic beaker, and the solution was then acidified with 4 mol l^{-1} HCl until pH = 1 (approximately 12 ml), measured with the aid of pH measuring tapes, under magnetic stirring (Velp Scientific - AREX Magnetic Stirring) at 250 rpm. This solution was covered with plastic film and kept at rest for 12 h so that the HA, which are not soluble in this pH range, are precipitated and decanted to the bottom of the container.

After the expected time, the acidic supernatant was collected in a plastic beaker and the precipitated HA, separated by decantation, was centrifuged (Fanem Excelsa II-Mod 206 BL) for 10 min in 50 ml Falcon tubes for complete phase separation. The HA fraction was placed in a previously weighed graduated glass container and sent for drying in an oven at 60°C.

The acidic supernatant containing the AF was placed in a 1 L beaker and passed, through a peristaltic pump (Masterflex Mod 7014-20), through the Amberlite DAX-8 resin (SUPELITETM) in acid form, packed in a 40 × glass column 250 mm. The AF are adsorbed on the resin and the hydrophilic compounds of low molecular weight percolate freely. Next, 50 ml of deionized water were passed through the resin column to remove excess salts and low molecular weight organic compounds that had not been properly percolated. Afterwards, the AF are eluted with the passage of NaOH 0.1 mol l^{-1} in a volume sufficient for its complete removal (approximately 25 ml), being collected at the bottom of the column. Next, the column was washed with 100 ml of deionized water and then 50 ml of HCl 0.1 mol L^{-1} were added for reconditioning and use for the next sample.

Subsequently, the FA in the basic form was passed on the Amberlite IR120 cation exchange resin in the acid form to remove the contaminating cations. Having passed through the two resins, the material was placed in a graduated glass beaker, previously weighed, and placed to dry in an oven at 60°C.

Once dry, the flasks containing the AF were weighed again for further quantification of the AH and AF contents of the leachate. This procedure was repeated for all 7 analyzes of the leachate samples.

3. Results and discussions

3.1. Quantification of humic substances

Humic substances are defined as supramolecular associations of heterogeneous and relatively small molecules that form because of the degradation and decomposition of dead biological material (Piccolo, 2002). HA and FA are considered soil conditioners, bioregulators and biostimulants, have the potential to promote physiological changes in cultivated plants that contribute to their better development (Caron et al., 2015).

The results of the analyses, submitted to the necessary calculations to arrive at the final levels of SH, on a dry basis, can be seen in Table 1, together with the temperature and precipitation data in the week before each collection.

TABLE 1. SUMMARY OF THE RESULTS OF THE DETERMINATION OF HUMIC SUBSTANCES.

Sample	Collection date	HA Level	FA level	Average maximum T	Precipitation
		(%)		(°C)	(mm)
1	July 20, 2022	12.20	45.05	19	75.2
2	July 27, 2022	29.31	24.59	16.1	15.2
3*	July 27, 2022	29.23	20.97	26.1	15.2
4	August 24, 2022	15.86	19.87	21.1	6.6
5	October 5, 2022	16.36	13.31	22.4	7
6	October 26, 2022	30.71	15.53	26.9	0
7	November 17, 2022	28.45	12.20	28.6	18.2

Sample 3 was collected in a storage compost windrow 8 years ago.
Source: Prepared by the authors.

The determination of the levels of HS and its interpretation considering the meteorological alterations throughout the developed study reveal that there was alteration in the contents of HA and HF (Table 1). Sample No. 1, which had the highest precipitation in the week prior to collection, resulted in the highest AF content. This may be related to the higher solubility of FA, since they are soluble in water at any pH range. In general, there was little rain in the weeks prior to the other collections, where it was observed, except for sample No. 4, higher levels of HA in relation to FA, converging with the hypothesis that greater precipitation provides higher levels of FA in the leachate.

The temperature did not seem to be a relevant factor to generate differences in the HS contents of the leachate. This is possibly since the composting process, being an exothermic process, raises the mass of waste to higher temperatures than the environment, reducing the effect of external temperature. In addition, the temperatures recorded during the study period were below 29°C, not enough to cause relevant disturbances to the composting process.

In addition to physical parameters such as temperature and precipitation, the difficulty in obtaining a mass of waste that is always homogeneous in relation to the proportion of constituent materials is a factor that contributes to the variation in HS levels. The need to immediately deposit the waste received by the company in the ditch leads to a variable composition of the composting piles which, even turned over and mixed later, continue to present partially heterogeneous characteristics.

Considering the HA and FA levels reported on different labels of products on the market — in a study comparing HS analysis methods (Dhein, 2019), analyzing five commercial products, found levels of up to 9% —using the same methodology used in this work—, it can be stated that the leachate studied here has higher levels of these substances (Table 1). This characterizes it as a viable product alternative to provide the benefits to soil and plants described in the literature, such as improved rooting and nutrient absorption, in addition to resistance against pathogens and biotic stress. Therefore, the use of the product tends to benefit crops, although experiments are needed to determine the best dose and time of application for each type of crop and soil.

The action of HA and FA on the morphology of roots, providing an increase in biomass and root size and the growth of root hairs and fine roots, which allows the plant to better explore the soil profile and have favorable conditions to survive in case of water deficit. In addition, they stimulate the activity of H+ –ATPase in the plasma membrane, with a mechanism like that of auxins, and exert a positive influence on the transport of ions, facilitating absorption, as well as promoting an increase in chlorophyll content (Canellas & Olivares, 2014; Zandonadi, 2006).

Paiva (2020) studied the modes of application of HS and found that application to the soil at planting time had better results in corn production, when compared to the application divided between the soil and the plant.

Bender (2018), in experiments with lettuce, found similar results comparing the application of a total dose of mineral fertilizer NPK (nitrogen – phosphorus – potassium) with 1⁄2 dose of NPK + use of HA, concluding that it is possible to reduce fertilization chemical in 50% without damages in the yield of the culture, in the conditions of the experiment.

Humic substances constitute an interesting tool for use in agriculture and can bring numerous benefits to cropping systems, including cost reduction with synthetic mineral fertilizers. Furthermore, the development of a product based on this leachate and enriched with fertilizer salts could provide superior benefits for plants, see experiments by Bender (2018), where the association of mineral fertilizers with humic substances potentiated the effect of fertilizers resulting in better yield parameters in lettuce.

The storage and homogenization of the leachate can be an alternative for the standardization of HS concentrations, allowing to obtain more similar contents over time and facilitating the use of this material for the development of a commercial product.

Another alternative use for the leachate is the one that already occurs in the company, where the liquid is reapplied in the windrows. This alternative is suitable because it is avoiding soil and water table contamination, while adding functional characteristics to the compost produced and saving water that would be necessary to maintain humidity in the windrows.

4. Conclusions

Regarding the quantification of the levels of HS present in the compost leachate, it was possible to verify that there is a variation in the levels over time, which can be influenced both by meteorological issues and by operational reasons, such as the proportion of waste in the compost piles, which is defined by the arrival of waste at the company. With the results of the analyses, it is possible to guarantee minimum levels of HS provided by the leachate.

To standardize the product, it would be necessary to store and homogenize the leachate, allowing equalized levels to be obtained, or to change the dynamics of the arrival of the wastes, aiming to promote a mixture with always similar proportions of the received wastes.

Humic substances are an interesting tool for use in agriculture and can bring numerous benefits to cropping systems, including reducing costs with chemical fertilizers. As future studies, it is suggested to carry out experiments in the field or in a greenhouse with agricultural crops to ratify the fertilization potential of humic substances.

The company's compost leachate has humic characteristics desired for the preparation of a commercial product for use in agriculture and can be configured as an interesting extra income alternative for the economic health of the enterprise.

Credit author statement

Gabriela Melissa Koetz: Methodology, Writing-Reviewing, and Editing.
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Deborah Dick: support in analyzes.
Pedro Selbach: Visualization, Investigation, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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