Biochar as an additive in the composting process

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Abstract— The production of solid wastes from anthropic activities is following a growing increase and the wastes from agriculture and forestry do not escape this trend. In this context, composting emerges as a viable and inexpensive alternative to transform organic waste into compounds that have high potential for use as organic fertilizers. An alternative to optimize the composting process, ensuring compost as agronomic potential and in less time, is the use of Biochar in windrow composting. Based on this assumption, the present work analyses the behavior of pine sawdust and cattle manure compost piles submitted to different Biochar doses (0%; 1%;5% and 10%). The observed result was that Biochar was responsible for increasing the temperature of the windrow, thus indicating greater microbial activity, presented a higher tendency of moisture loss and gave rise to a more alkaline substrate.

Keywords— Cattle manure, Microorganisms,Organic compost, Pinuselliottii.

I. INTRODUCTION

Agro industrial activities are responsible for generating a large volume of organic waste that, if left untreated, is a potential cause of environmental damage (Dias et al., 2010).

However, solid organic waste is a biodegradable material that has the possibility of being recycled when used as soil conditioners, which increase moisture retention, improve texture, and supply macro and micronutrients to the plants. Yet, in order for the solid waste to actually be used for agricultural purposes, the waste must be applied to the soil after undergoing a certain level of stabilization, and among the processes that can promote such stabilization, composting stands out(Dores-Silva et al., 2013).

According to Lim, Lee and Wu (2016) this method stands out due to its social and environmental benefits coupled with a low operating cost. Fornes et al. (2012) adds that composting is a process by which organic matter is stabilized through the aerobic process of native, thermophilic, and mesophilic microorganisms. This process provides the hygienization of the compost, enabling a substrate with low phytotoxicity due to the reduction of pathogens and the sanitation of the organic waste (Lim, Lee& Wu, 2016). Decreased phytotoxicity occurs because the high temperatures help to eliminate phytopathogenic organisms, making the compost safer for use as an organic fertilizer (Ribeiro et al., 2017).

The composting process is influenced by various physicochemical factors such as, temperature, pH, particle size, moisture content, aeration and electric conductivity (Li et al., 2013; Juarez et al., 2015). Monitoring the behavior of these parameters is of utmost importance to indicate the maturity and phytotoxicity of the final compost (Ribeiro et al., 2017).

The temperature variation of the windrow composting, as well as microbial CO_2 production, vary throughout the process due to the succession of microbial communities and their metabolic activities, thus being important parameters in determining the phases of the process as well as the maturation of the compost (Hassen et al., 2001; Silva,Azevedo& De-Polli, 2007).

The use of materials that speed up the composting process and that give rise to substrates with agronomic characteristics that contribute to fertilization and increased microbial activity of the soil, have contributed more efficiently to the development of waste reuse technologies. One of the possibilities for the improvement of the composting process is the application of materials that provide a favorable environment for the decomposer microorganism, causing there to be an increase in its metabolic activity and consequently an optimized process.

Among these materials, Biochar, which can optimize the composting process, stands out (Xiao et al., 2017).

According to Melo and Silva (2018), Biochar is a solid, carbon-rich material that is obtained by the thermochemical transformation of biomass under low oxygenation condition, a process called pyrolysis. This material can be produced from waste rich in organic matter, and is therefore a waste reuse alternative that gives rise to a product that has the potential to be applied as a soil and substrate conditioner in order to better physical, chemical, and biological qualities, with productivity gain for several crops (Hamzah et al., 2013; Kookana et al., 2011).

The use of Biochar can optimize the composting process, due, for example, to its ability to provide, in the windrow, a favorable environment for the development of decomposer microorganisms. This is thanks to its large surface area and the ability to increase the porosity of the compost, serving as physical support for microbial development. However, characteristics of the Biochar used may influence the composting process favorably or unfavorably. Among these characteristics are the concentration used in the windrow, the type of raw material used in the production of the Biochar, the pyrolysis temperature, and the particle size (Sanchez-Monedero et al., 2018).

In this context, the aim of this work was to evaluate the influence of different doses of Biochar in the organic waste composting process.

II. METHODOLOGY

2.1 Composting process

All experiments were conducted at the University of Uberlândia's (UFU's) Monte Carmelo Campus. The compost windrows were prepared using cattle manure and eucalyptus sawdust (*Eucalyptus grandis*), whose amounts were, 12.0 Kg and 1.5 Kg, respectively. These amounts of manure and sawdust were obtained based on the concentration of carbon, nitrogen, moisture (Table 1), and calculated by Equation 1, cited by Brito (2016). Four compost windrows were prepared and Biochar was added to each in concentrations of 0% (B0), 1% (B1), 5% (B5) and 10% (B10) m/m in relation to the total dry mass of the windrow.

The windrows were placed on a cemented, covered surface without any direct interference from sunlight or precipitation.

$$(1)\frac{C}{N} = \frac{(P1[C1(100-U1)]) + (P2[C2(100-U2)])}{(P1[N1(100-U1)]) + (P2[N2(100-U2)])}$$

Where: P is the sample weight in kilograms; C is the percentage of carbon; N is the percentage of nitrogen; U is the moisture of the sample in question as a percentage.

Table 1. Carbon, nitrogen, and moisture content of waste used in composting

	Sawdust	Manure
Total nitrogen (%)	0.30	1.01
Total carbon (%)	55.22	20.94
Moisture (%)	8.99	42.20

The Biochar was produced through incomplete combustion by the slow pyrolysis process in a two-cylinder thermal oven adapted from a model used by Thai agriculturists (Prakongkep, Gilkes &Wiriyakitnateekul, 2015). The biomass source used for Biochar production was pine sawdust (*Pinuselliottii*).

The cattle manure was obtained from rural property in the municipality of Monte Carmelo, MG, which has beef cattle confinement. The Eucalyptus (*Eucalyptus grandis*) and Pine (*Pinuselliottii)* sawdustswere obtained from the wood processing industry also in the municipality of Monte Carmelo, MG.

2.2 Evaluation of the composting process

During the composting process, the temperature of the windrow and the composting environment were evaluated twice daily, in the morning and in the late afternoon. By doing so, average daily temperatures of the windrow and the composting environment were obtained. pH, electrical conductivity, moisture, and the density of the composted material were evaluated weekly.

The pH and electrical conductivity were determined using specific electrodes (combined glass electrode, and conductivity electrode, k=1,0) in aqueous extracts obtained according to European standards EN 13037 (CEN, 1999) and EN 13038 (CEN, 1999), respectively. For the pH, a 5 mL sample of the compost was stirred with 50 mL of 0.01 mol.L^{-1} calcium chloride (CaCl$_2$) solution for 60 minutes. After this time period, the pH was read in the supernatant solution. To determine the electrical conductivity, 20g of compost was stirred with 200.0 mL of distilled water for 30 minutes. After this time period, the supernatant was read.

The moisture in the samples was determined weekly through the thermogravimetric method, where approximately 2g of the composted material were oven dried at 105 ℃ until it was a constant mass. The moisture was calculated by equation 2.

$(2) U = \frac{A-B}{A} x 100 (3)$

Where: U is the moisture (%); A is the wet mas (g); B is the dry mass (g).

The moisture was checked daily by the hand feel method. This test consists of taking a handful of material from inside the windrow and squeezing it with force. The ideal moisture point is when the water begins to well up between the fingers without dripping.

The density was monitored by the method described by MAPA (2008), in which a 500.0 mL beaker was filled up to the 300.0 mL mark with the substrate at the current moisture and was subsequently dropped under the action of its own mass from a height of 10.0 cm for 10 consecutive times. Therefore, the volume (mL) of the compost obtained was measured and the mass of that volume of material verified, discounting the mass of the beaker. The procedure was repeated three times with different subsamples. The wet density value was obtained by applying Equation 3.

$(3) DU = [Mu / V] \times 1000$

Where: DU is the wet density ($Kg.m^{-3}$); Mu is the wet mass (g); V is the volume assumed by the compost (mL).

The microbial activity of the composted material was evaluated at six, twelve and twenty-four days after the beginning of the composting process according to the methodology adapted from Dionísio et al. (2016). To this end, 25.0 g of composted material was added to a 500.0 mL glass flask (Incubation Flask). Then, the test tube containing 10.0 mL of NaOH (0.5 mol L^{-1} standardized) and another test tube containing 10.0 mL of distilled water were placed into the incubation flask.

A blank test was performed corresponding to two incubation flasks containing only one test tube containing 10 mL NaOH (0.5 mol L^{-1} standard) and another tube containing 10.0 mL distilled water. The 500.0 mL glass flasks were hermetically sealed and incubated in an oven at 28 °C for one week (168 hrs). After the incubation period, the test tubes containing NaOH were removed from the incubation flasks, the solution of which was transferred to a 125.0 mL erlenmeyer flask, adding 1.0 mL of $BaCl_2$ (10% m/V) and two drops of phenolphthalein and excess NaOH was titrated with 0.5 mol HCl. L^{-1}. The activity of the composted material was evaluated by C-CO_2 mass per kg of composted material per hour of incubation and calculated according to equation 4.

$(4) RBS = (((V_b - V_a) . M . 6 . 1000)/P_s)/T$

Where: RBS (mg C-CO_2 Kg^{-1} h^{-1}): amount of carbon in the form of CO_2 generated by the microbial activity of the composting material V_b (mL): volume of the hydrochloric acid spent on the titration of the control (white); V_a (mL): volume spent on the titration of the hydroxide contained in the incubation flask containing the composting material; M = molarity of HCl; Ps (g) = mass on the composting material used in the test; T = the sample's incubation time in hours.

III. RESULTS AND DISCUSSION

The results of the temperature variation of the compost windrows and the environment temperature are presented in Figure 1.

It is verified that during aerobic composting, the average temperature curve of the composting piles presented the three classical phases, namely: the thermophilic, mesophilic and maturation phases, which are presented in Figure 1.

The four treatments (B0, B1, B5 e B10) reached the thermophilic stage of the process soon on the first day, presenting temperatures of 32°C, while the average environment temperature presented on this first day was 19°C. On the first day it was also possible to observe differences between the average windrow temperatures in relation to the biochar concentration, and the greatest biochar concentrations provided higher temperatures in the compost windrow. Treatment B5 presented the highest temperature among the treatments, being 38.4°C. Treatment B10 was responsible for the second highest temperature, averaging 36.5°C. Treatments B0 and B1 had the lowest averages, both of which presented temperatures of approximately 32°C.

This temperature increase in treatments with higher doses of Biochar reflect a higher microbial metabolism, which can be associated with the ability of the Biochar to provide a composting environment favorable to the development of the organisms involved in the process.

The presence of Biochar and its association with higher temperatures in the compost windrow at the beginning of the process was also observed by Wei et al. (2014) upon analyzing Biochar's influence on the microbial community in the compost pile with chicken manure and tomato stalk. López-Cano et al. (2016) cite in their study that the presence of Biochar in the windrow with sheep manure favored the activation of the composting process, presenting a faster temperature increase than the control. This temperature increase may be caused by the increase in microbial activity due to the environmental conditions that Biochar provides in the compost, those that favor the microbial activity that acts in the process (Sanchez-Monedero et al., 2018).

On the fifth day of composting there was a considerable decrease in the temperature of the windrows, a fact justified by the decrease in moisture. On this day, the moisture was corrected and in turn, there was a temperature increase observed the next day.

The high temperatures, characterized mainly by the substantial difference in relation to the average environment temperature, lasted until the eighth day of composting, when the process left the thermophilic phase, presenting and maintaining lower temperature values (Figure 1A and Figure 1B).
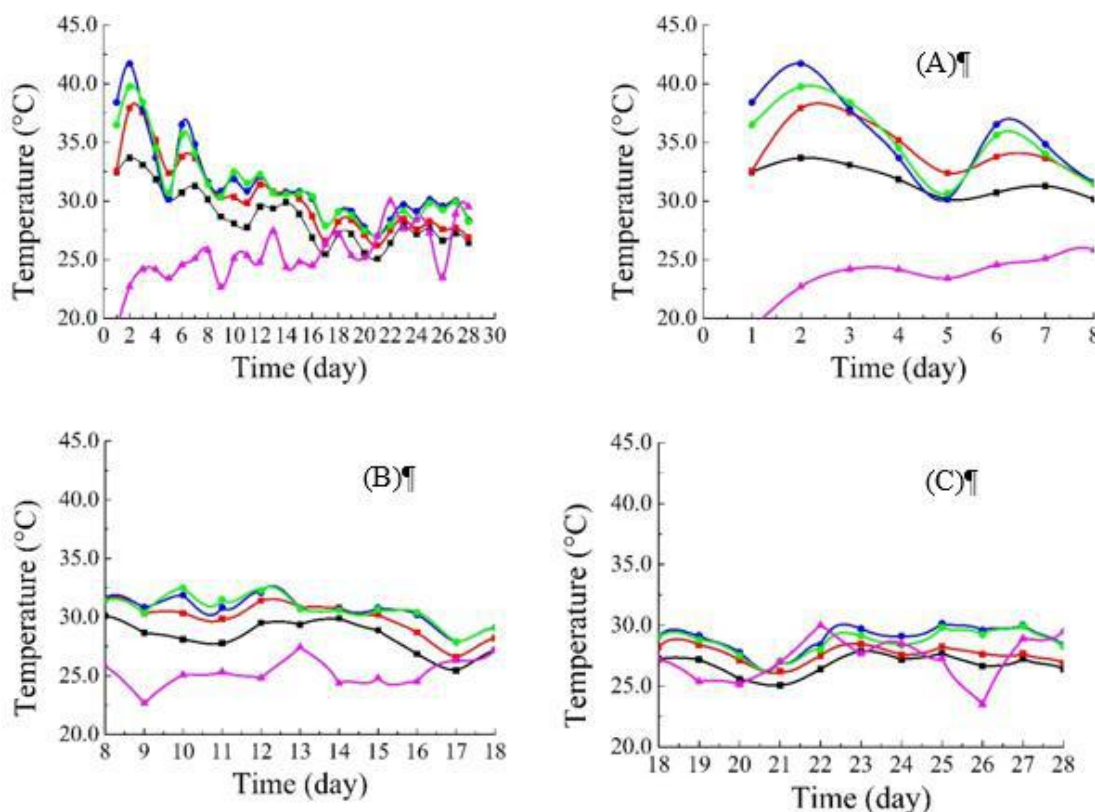

Fig. 1: Variation of the average environment temperature and the compost windrows during the process (A) and highlights for the thermophilic (B); mesophilic (C); and maturation (D) stages.

Note:-■- B0; -■- B1;-●- B5;-●- B10;Δ Ambiente.

In the mesophilic phase (Figure 1B), windrow temperatures differed from treatment B0. The treatments with Biochar presented higher windrow temperatures, especially the treatments with more elevated concentrations of Biochar, treatments B5 and B10. It is important to note that the compost windrows of the four treatments maintained temperatures above the environment average until the 17th day of composting, a fact that characterizes this period as mesophilic, since despite presenting temperatures that were lower than in the beginning of the process, the windrow temperatures differed and were higher than the environment temperature.

However, from the 17th day of composting (Figure 1B and Figure 1C), the windrow temperature assumed values similar to the environment temperature, presenting similar variations, which characterized this phase as the maturation phase since the microbial activity is already reduced and consequently there was no heat generated by microbial activity inside the windrow that was sufficient to exceed the environment temperature. This lower temperature behavior in the windrows and the fact that the windrow temperatures did not differ from the environment temperature for 11 days was an indication that the compost was mature, thus representing the end of the composting process, which took place after 28 days.

The water present in the compost windrow is fundamental for microbial growth. It is considered that contents above 65% will cause an anaerobic situation undesirable to microbial metabolism and if the moisture content remains below 40%, it may cause inhibition of microbiological activity (Berticelli et al., 2016). The results

of windrow moisture during the composting process are shown in Figure 2.

Until the 11th day of composting, all treatments remained within the recommended range for the maintenance of microbial activity, and for treatments B0 and B1, higher moisture values of the composting material were observed. From the 17th day of composting on, there was a decrease in the moisture content of the composting

material, especially for the treatments with a higher Biochar concentration, which may be related to observed increases in environment temperature (ranging from 24 ° C to approximately 27 ° C) associated with the presence of higher doses of Biochar in the windrow. This may have influenced the higher aeration and consequently faster moisture loss.
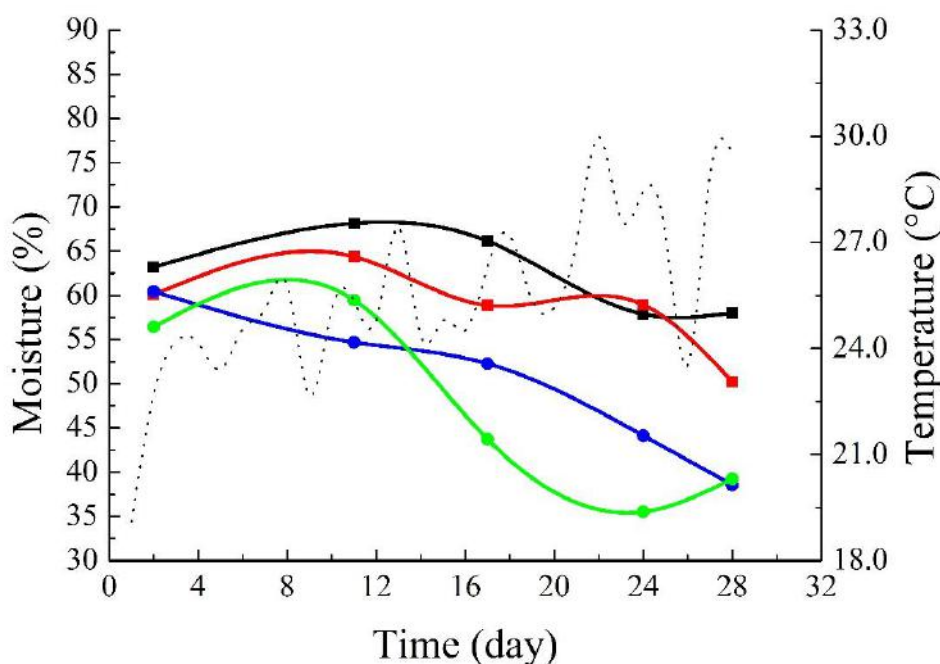

Fig. 2: Moisture of compost piles and variation in environment temperature throughout the process.

Note:-■- B0; -■- B1;-●- B5;-●- B10.

Biochar is reported as an agent that provides increased compost pile aeration, increasing gas exchange essential for microbial metabolism (Sanchez-Monedero et al., 2018), but compost windrow aeration provides water loss, causing the moisture content of the composting material to decrease throughout the process (Berticelli et al., 2016), a fact that explains the tendency for higher water losses in the treatments that had higher amounts of Biochar.

Treatments B0 and B1 remained within the ideal range, however, treatment B10 presented a percentage of water lower than the recommended amount at day 24 of composting (36% moisture). At the end of the process, all treatments were within the appropriate humidity range for microbial activity, and the highest moisture values were observed for treatments B0 and B1 (58 and 50%, respectively), while for treatments B5 and B10, 39%

humidity was observed in both compost windrows. The substrates obtained by treatments B5 and B10 presented moisture values in the recommended value range for the final compost, as stipulated by the Ministry of Agriculture, Cattle and Supplying for organic compounds, which is up to 40%.

Analyzing the material density (Figure 3), a decreasing trend was observed, with the substrate obtained at the end of the composting process having a lower density than the initial material being composted, which was observed for all treatments. This behavior indicates that the solid material presented a degradation process, showing a smaller particle size in the final substrate. Such lower density behavior in the final material compared to the original material may be due to moisture loss and organic matter degradation (Berticelli et al., 2016).
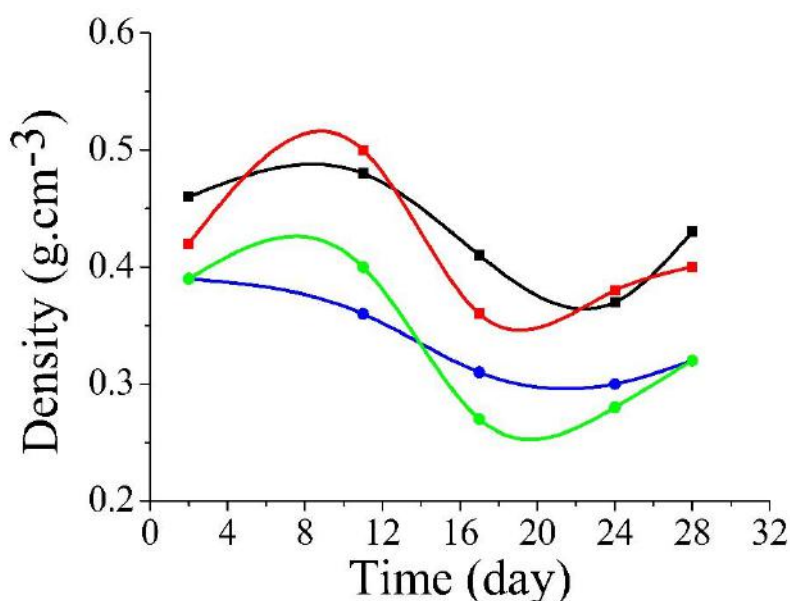
Fig. 3: Density of composted material between the treatments.

Note:-■- B0; -■- B1;-●- B5;-●- B10.

At the beginning of the composting process, treatment B0 presented a higher density (0.46 g.cm^{-3}) followed by treatment B1(0.42 g.cm^{-3}) and lastly, treatments B5 and B10, which both presented the lowest density of 0.39 g.cm^{-3}. That is, the higher the concentration of Biochar in the windrow at the beginning of the composting process, the lower the density of the composting material, which is due to the larger volume occupied by the Biochar, which promotes a lower density for the same mass of composting material.

On the eighth day of composting, a slight increase was observed for all treatments, which is a consequence of the increase of the materials' moisture during this period, except for treatment B5, where there was a decrease in the windrow's moisture (Figure 2). From day 8 on, all composting materials showed a decrease in density which was observed until the 20th day of composting, the beginning of the compost maturation phase. From this moment, a small increase in the composting material's density was observed until the last day of the process, possibly caused by decreased moisture.

The substrates obtained at the end of the composting process showed the same behavior in the density values in relation to the treatments. Treatment B0 (0.43 g.cm^{-3}) presented higher density in relation to the others, the compost from B1, 0.40 g.cm^{-3}, and B5 and B10 both 0.32 g.cm^{-3}. Comparing the density values of the composting material at the beginning of the process with

the density values of the substrates obtained, it can be verified that higher concentrations of Biochar provided lower values of material density, which may be inherent to the fact that Biochar has a higher volume, or it may be attributed to the fact that it provided a higher rate of material degradation in the windrow and therefore a low density.

Results obtained for density are similar to those observed by Jindo et al. (2012) when analyzing the influence of Biochar in composting with chicken manure and cattle manure, where the compost with Biochar presented a lower density than the treatments without its application. The authors correlate this density decrease with the compost's increased porosity and consequently the formation of an environment conducive to microbial development.

The behavior of the composting material`s pH during the different treatments is shown in Figure 4.

It can be observed that there were no major differences between the pH values of the composting material between treatments. All treatments showed the same behavior throughout the composting period, where an increase in acidity can be observed by the 11th day followed by an increase in the pH value of the material up to day 24 and then by day 28 the pH values had again decreased, except for the pH value of treatment B10, which provided a substrate with a higher pH value.
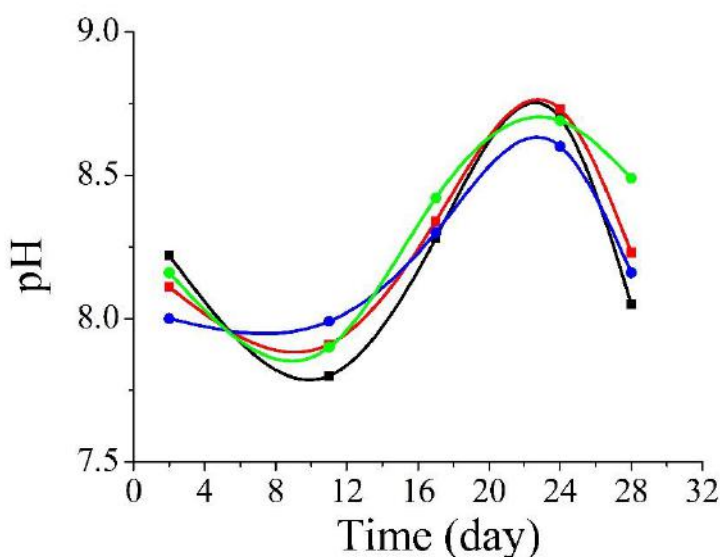
Fig. 4: Behavior of the composting materials' pH between treatments.

Note:-■- B0; -■- B1;-●- B5;-●- B10.

At the beginning of the process, a slight acidity of the compost was expected due to the production of acids by decomposer bacteria; however, after the compost windrow's temperature increase and a decrease in the available oxygen, the microorganisms began producing ammonia (NH_3) and at this stage the nitrogen tends to be mineralized, making the composting material more alkaline. Nevertheless, the ammonia produced tends to be lost by volatilization or consumed in the process, causing the pH to fall again (Zhang et al., 2014; Handreck, 1978).

The substrates obtained for each treatment had alkaline characteristics, with treatment B10 having a higher pH value (8.49) and treatment B0 having a pH of 8.05. These results are indicative of Biochar's alkalizing ability. Similar behavior was observed by Dias et al. (2010) when studying the effects of Biochar (*Eucalyptus grandis*), coffee fruit peel, and sawdust as additives in the compost with chicken manure, where the substrate containing Biochar presented the highest pH value.

The results of the electrical conductivity of the composting material and of the final substrate obtained between treatments are presented in Figure 5.

There was an increase in electrical conductivity (EC) throughout the composting process and EC values began to diverge from the 17th day of composting between treatments, where the final substrates obtained showed higher EC values than the EC values at the beginning of the composting process. Initially, the EC values for the treatments ranged from 1.56 mS.cm-1 (treatment B5) to 2.16 mS.cm-1 (treatment B0). In the final substrate, those with the highest concentrations of Biochar presented higher levels of electrical conductivity values, where the EC was 3.16 mS.cm-3 for treatment B0 and 4.13 mS.cm-3 for treatment B10. Increased conductivity throughout the composting process may be caused by a loss of mass with oxidation of organic matter, increasing the concentration of salts in the compost (Sanchez-Monedero et. al, 2001).

Electrical conductivity estimates the concentration of ions make available by the composting material or final substrate in aqueous medium, and, therefore, provides data about the material's salinity and whether it may present phytotoxicity problems, thus being a relevant parameter when the substrate is used for agricultural purposes (Brito et. al., 2014; Massukado& Schalch, 2015).
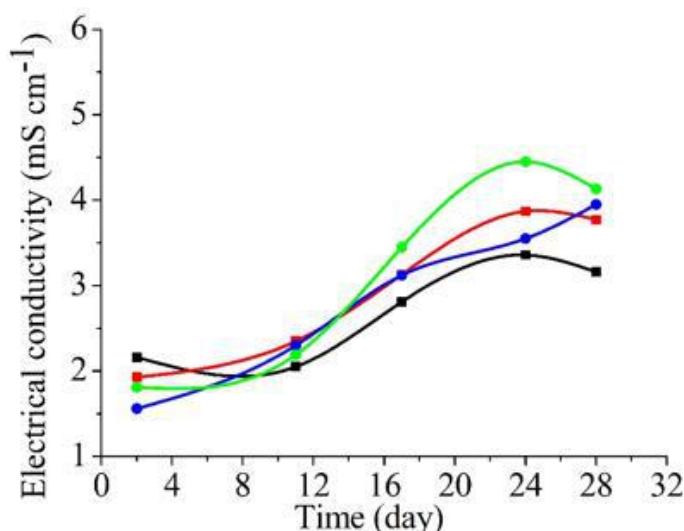
Fig. 5: Variation of electrical conductivity between treatments throughout the composting process.

Note: -■- B0; -■- B1;-●- B5;-●- B10

According to the authors Nisar et al. (2019); Li, Yang and Zhang (2019); Ibrahim (2016), elevated electrical conductivity values and a high concentration of organic acids inhibit seed germination. According to Kiehl (1998), the final compost must have conductivity values below 4 mS cm-1 for complete benefit as organic fertilizer. The substrates obtained in this work, specifically those referring to treatments B0, B1 and B5, had conductivity values (3.16; 3.77; 3.95mS cm-1, respectively) as indicated by this author. Only substrate B10 showed EC values (4.13 mS cm -1) slightly above the ideal range.

Microbiological respiration in the compost windrow was determined based on the amount of carbon in the form of CO_2 generated by the compost material's microbial activity, and the results are presented in Figure 6.

The results of the amount of carbon generated by composting material's microbial activity did not indicate differences between the treatments in this parameter. However, there were differences in relation to the composting time, and the results can be used to evaluate the phases of the composting process. These results also corroborate the temperature results of compost windrow.
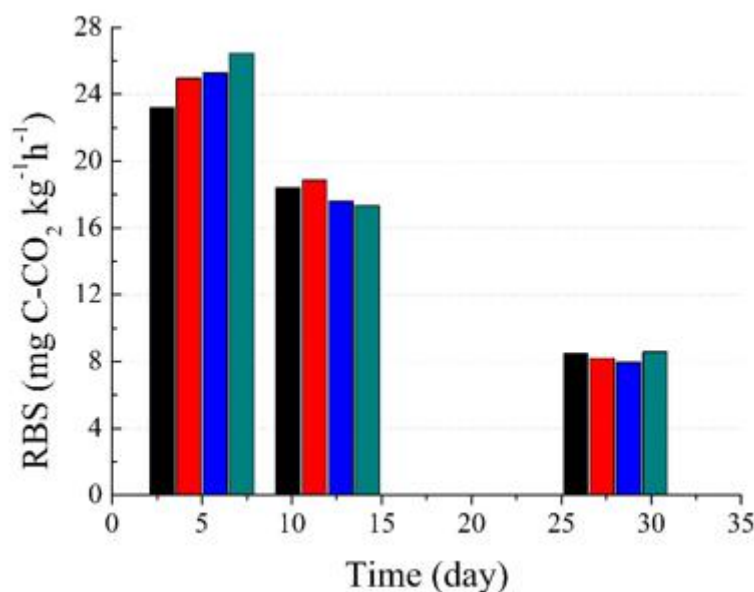

Fig. 6: Amount of carbon in the form of CO_2 generated by the microbial activity of the composting material.

Nota: ■ B0; ■ B1; ■ B5; ■ B10

The release of CO_2 is basically due to the oxidation of organic matter by microorganisms present in the composting material, such as aerobic and anaerobic bacteria and fungi, which use the O_2 as the final electron acceptor (Dionísio et al., 2016; Pereira& De Freitas, 2012). Based on this assumption, the quantification of CO_2 produced during the composting process can be a good parameter to indicate the degradation levels of organic matter as well as the microbial activity in the different stages of the process.

The data presented by the microbial respiration of the composts allow the differentiation of the two significant process phases, namely the biodegradation phase and the maturation phase. According to Berticceli et al. (2016), in the biodegradation phase there is intense microbial activity and rapid transformation of organic matter, which leads to a high consumption of O_2 and higher temperatures in the compost windrow. In contrast, in the maturation phase the microbial activity is lower and consequently the windrow temperature is similar to the environment temperature. At this moment, the transformations that occur in the material are responsible for the humification of the matter, a fact that occurs due to the polymerization of stable organic molecules (Moreira& Siqueira, 2006).

On the fifth and twelfth day of composting all treatments showed high temperatures (Figure 1A and Figure 1B) indicating the biodegradation phase, which corroborates the results of more intense C-CO_2 generation at these times in the composting process indicating higher microbial material and also that the microorganisms present in the compost windrow use labile fraction of the material during these periods.

On day 26, the results of the C-CO_2 amount corroborate with the temperature values from this period (Figure 1C), or rather, lower microbial activity in the compost windrow, lower temperature to the point of not standing out from the environment temperature, indicating the maturation phase of the composting material, which is due to the decreased concentration of labile organic substances and a higher concentration of more recalcitrant substances. These compounds generally have a more complex chemical structure, which decreases the microbial activity and, therefore, a smaller amount of C-CO_2 is generated and a consequent decrease of the windrow temperature takes place.

IV. CONCLUSIONS

The results obtained in this work make it possible to conclude that the use of Biochar provided an increase in the windrow's temperature in the mesophilic and thermophilic stages.

Applications of 5% and 10% Biochar provided moisture loss from the windrow.

Windrows with 5% and 10% Biochar produced substrates with lower density.

The 10% dosage provided a windrow with higher pH value.

Biochar provided compounds with higher electrical conductivity values.

There were no differences between treatments regarding microbial C-CO_2 production.

Increases of 5% Biochar in the compost windrow showed itself to be the best dose for increasing the microbial activity within the windrow.

REFERENCES

[1] Berticelli, R. et al (2016). Compostagem como alternativa de biorremediação de áreas contaminadas. *Ciatec, 8*, 12-28.

[2] CEN- European Committee for Standardization (1999).**Sludge, treated biowaste and soil - Determination of pH**[European Standard - EN 13037].Brussels, European Committee for Standardization.

[3] CEN- European Committee for Standardization (1999).**Sludge, treated biowaste and soil - Determination of electrical conductivity** [European Standard - EN 13038].Brussels, European Committee for Standardization.

[4] Dias, B. O. et al. (2010). Use of biochar as bulking agent for the composting of poultry manure: Effect on organic matter degradation and humification.*Bioresource Technology, 101,* 1239-1246.

[5] Dionísio, J. A et al. (2016). *Guia prático de biologia do solo*.Curitiba:SBCN/NEPAR.

[6] Dores-Silva, P. R. et al. (2013). Processo de estabilização de resíduos orgânicos: vermicompostagem versus compostagem. *Química Nova, 36* (5), 640-645.

[7] Brito, A. D. S. et al. (2014). Variação diurno-noturna do potencial mátrico e gradiente de potencial total da água no solo.*Revista Brasileira de Ciência do Solo, 38*, 128-134.

[8] Fornes, R. et al. (2012). Composting versus vermicomposting: A comparative study of organic matter evolution through straight and combined processes.*Bioresource Technology, 118*, 296-305.

[9] Hamzah, Z. et al. (2013).Characterization of physicochemical properties of biochar from different agricultural residues.*Advances in Environmental Biology, 7 (12)*, 3752-3757.

[10] Handreck, K. (1978).*Composting: making soil improver from rubbish*. Glen Osmond:Csiro Division of Soils.

[11] Hassen, A. et al. (2001). Microbial characterization during composting of municipal solid waste.*Bioresource Technology, 80(3)*, 217-225.

[12] Ibrahim, E. A. (2016). Seed priming to alleviate salinity stress in germinating seeds. *Journal of Plant Physiology, 192*, 38-46.

[13] Jindo, K. et al. (2012). Biochar influences the microbial community structure during manure composting with agricultural wastes. *Science Of The Total Environment, 416*, 476-481.

[14] Juárez, M. F-D. et al. (2015). Co-composting of biowaste and wood ash, influence on a microbially driven-process. *Waste Management, 46*, 155-164.

[15] Kiehl, E. J. (1998).*Manual de compostagem*. Piracicaba: Sociedade Brasileira de Ciência do Solo.

[16] Kookana, R. S. et al. (2011). Biochar application to soil: agronomic and environmental benefits and unintended consequences. *Advances in Agronomy, 1112*, 103-143.

[17] Li, Q. et al. (2019). Higher endogenous bioactive gibberellins and α-amylase activity confer greater tolerance of rice seed germination to saline-alkaline stress. *Environmental and Experimental Botany, 162*, 357-363.

[18] Li, Z. et al. (2013). Experimental and modeling approaches for food waste composting: A review. *Chemosphere, 93 (7)*, 1247-1257.

[19] Lim, S. L. et al. (2016). Sustainability of using composting and vermicomposting technologies for organic solid waste biotransformation: recent overview, greenhouse gases emissions and economic analysis. *Journal Of Cleaner Production, 1(111)*, 262-278.

[20] López-Cano, I. et al. (2016). Biochar improves N cycling during composting of olive mill wastes and sheep manure. *Waste Management, 49*, 553-559.

[21] Massukado, L. M., Schalch, V. (2015). Avaliação da qualidade do composto proveniente da compostagem da fração orgânica dos resíduos sólidos domiciliares. *Rev. Dae, 183*, 9-15.

[22] Melo, E. I. de, Silva, L. F. V. da (2018). Biocarvão como condicionador de substrato para produção de mudas de alface. *Agropecuária Técnica, 39(2)*, 107-111.

[23] MINISTÉRIO DA AGRICULTURA, PECUÁRIA E ABASTECIMENTO (23 de outubro de 2008). **Instrução Normativa SDA Nº 31, de 23 de outubro de 2008** [Instrução Normativa]. Secretaria de Defesa Agropecuária, Brasil.

[24] Moreira, F.M.S., Siqueira, J. O. (2006). *Microbiologia e Bioqúimica do Solo* (2ª edição). Lavras: Editora da Universidade Federal de Lavras.

[25] Nisar, F. et al. (2019). Germination and recovery responses of heteromorphic seeds of two co-occurring Arthrocnemum species to salinity, temperature and light.*South African Journal of Botany, 121*, 143-151.

[26] Pereira, A. R. B., De Freitas, D. A. F. (2012). Uso de micro-organismos para a biorremediação de ambientes impactados. *Electronic Journal of Management, Education and Environmental Technology (REGET), 6(6)*, 995-1006.

[27] Prakongkep, N., Gilkes, R. J., &Wiriyakitnateekul, W. (2015). Forms and solubility of plant nutrient elements in tropical plant waste biochars. *Journal of Plant Nutrition and Soil Science, 178(5)*, 732–740.

[28] Ribeiro, N. Q. de et al. (2017).*Microbial additives in the composting process. Ciência e Agrotecnologia, 41(2)*, 159-168.

[29] Sánches-Monedero, M.A., Roig, A., Paredes, C., & Bernal, M. P.(2001)**.** Nitrogen transformation during organic waste composting by the Rutgers system and its effects on pH, EC and maturity of the composting mixture.*Bioresource Technology, 78*, 301-308.

[30] Sánches-Monedero, M. A. et al. (2018). Role of biochar as an additive in organic waste composting. *Bioresource Technology, 247*, 1155-1164.

[31] Silva, E. E. da, Azevedo, P. H. S. de & De-Polli, H. (2007). **Determinação da respiração basal (RBS) e quociente metabólico do solo (qCO2) (**Comunicado técnico, 99). Seropédica, RJ, EmbrapaAgrobiológica.

[32] Wei, L. et al. (2014). Biochar influences the microbial community structure during tomato stalk composting with chicken manure. *Bioresource Technology, 154*, 148-154.

[33] Xiao, R. et al. (2017). Recent developments in biochar utilization as an additive in organic solid waste composting: A review. *Bioresource Technology, 246*, 203-213.

[34] Zhang, J. et al (2014). The use of biochar-amended composting to improve the humification and degradation of sewage sludge. *Bioresource Technology, 168*, 252-258.