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Chemical characteristics of the compost of waste from the production and slaughter of small ruminants

Características químicas na compostagem de resíduos da criação e abate de pequenos ruminantes

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ABSTRACT

The aim of this study was to assess the chemical characteristics of a continuous aerobic composting process with passive aeration of feed material from the production and slaughter of small ruminants at different moisture levels. The composting process was performed in a brick barn with solid residues (manure and carcass parts) from the slaughter of goats and sheep along with chopped dry elephant grass and tree trimmings. The treatments employed three moisture contents (30, 50, and 70% water) and four sample collections at timed intervals (0, 30, 60, and 120 days), with three repetitions. The variables evaluated were the chemical attributes of the generated compost. The compositing process increased the concentrations of the elements Ca, Mg, S, Cu, Fe, Mn, and Zn and reduced the pH, lignin, and lignin/nitrogen ratio. The levels of N, P, and B increased up to 111, 61, and 94 days, respectively, whereas no change in the K content occurred. At the end of the process at 120 days, the contents of N, P, Ca, Mg, S, B, Cu,

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Fe, Mn, Zn, and electrical conductivity were increased by 33.7, 6.3, 17.5, 16.3, 666, 22, 31.3, 49.7, 30.4, 29.4 and 16.1%, respectively. The pH and lignin values decreased by 8.4 and 27.2%, respectively.
Key words: goats, organic compost, sheep

RESUMO

O objetivo deste estudo foi avaliar as características químicas de um processo contínuo de compostagem aeróbia com aeração passiva com material de alimentação proveniente da produção e abate de pequenos ruminantes, realizado com diferentes níveis de umidade. O processo de compostagem foi realizado em celas de tijolos, com resíduos sólidos (esterco e partes de carcaça) do abate de cabras e ovelhas, juntamente com capim-elefante seco picado e aparas de árvores. Os tratamentos empregaram três teores de umidade nas pilhas (30, 50 e 70%) e intervalos de tempo (0, 30, 60 e 120 dias) de avaliação do material compostado, com três repetições. As variáveis avaliadas foram os atributos químicos do composto gerado. O processo de compostagem aumentou as concentrações dos elementos Ca, Mg, S, Cu, Fe, Mn e Zn e reduziu o pH, o teor de lignina e a razão lignina/nitrogênio. O N, P e B apresentaram maior teor com 111, 61 e 94 dias, respectivamente. O K não teve sua concentração alterada. O teor de água de 70% produziu os maiores teores de N e menor razão lignina/N. Ao final do processo de compostagem, em 120 dias, houve aumento dos teores de N, P, Ca, Mg, S, B, Cu, Fe, Mn, Zn e condutividade elétrica em 33,7; 6,3; 17,5; 16,3; 666; 22; 31,3; 49,7; 30,4: 29,4 e 16,1%, respectivamente. E houve decréscimo nos valores de pH e lignina em 8,4 e 27,2%, respectivamente.
Palavras - chave: caprinos, composto orgânico, ovinos

INTRODUCTION

The raising of sheep and goats is an important economic activity. In Brazil, the flock consists of 29 million animals, mainly in the Northeast region, which accounts for 93% and 67% of the goats and sheep in the country, respectively (Holanda Filho et al., 2019).

This activity generates large amounts of waste, which causes severe environmental impacts when inadequately handled, since when appropriate disposal programs are not in operation, the carcasses are buried in certain situations. Composting enables the reintroduction of byproducts from agricultural activities to the productive cycle, minimizing environmental contamination through the generation of organic fertilizers (Santos et al., 2014).

According to Valente et al. (2009), composting involves controlled aerobic decomposition and stabilization of organic matter under thermophilic temperature conditions through biological heat production, to obtain a final product that is stable, sanitized, and rich in humic compounds that can be used in proper doses in the soil without environmental risks.

Paiva et al. (2012) studied compost piles and the different methods for using poultry carcasses and litter, and stated that maintaining proper moisture is essential to assure the metabolic and physiological activities of the

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microorganisms. In this respect, Valente et al. (2009) identified moisture levels between 40% and 70% as necessary to decompose parts of animal carcasses.

For an efficient composting process, it is necessary to add water, and an excess could generate a slurry or an anaerobic process. In contrast, if the quantity of water is less than that required, water stress could inhibit the microbiological process of composting. Over- or under-watering could also affect the concentration of nutrients in the resultant organic compost. The hypothesis of this work was that different levels of water applied in the composting process change the content of nutrients. The maximum nutrient contents were verified at the end of the composting process.

The purpose of this study was to assess a continuous aerobic composting process using waste from the production and slaughter of small ruminants, to ascertain the variation in the chemical characteristics of the resulting compost based on the use of different moisture levels and times.

MATERIAL AND METHODS

The experiment was performed in the composting sector of the Embrapa Goat and Sheep Research Unit (Embrapa Caprinos e Ovinos), located in the municipality of Sobral, Ceará state, Brazil, using the same piles and season (April to June 2012), as described by Souza et al. (2019).

The composting process used solid residues from the production and slaughter of goats and sheep (carcass, manure, chopped grass, and leaf waste) and was performed in a brick barn with a cement floor (area of 128 m^2) and tile roof. The composting cells measured 3.5 × 2.0 × 1.60 m (length × width × height) and were made of wood planks. Composting was conducted continuously with passive aeration, by convection without rotating the pile or revolving the process. The residues were retained for at least 120 days. Essentially, the process was stationary. After the carcass was placed, revolving was stopped except for when demotivating on the established dates. Water was introduced only when new materials were added to the pile.

The first layer of each pile covered the cement floor at the bottom of each cell and was formed by 0.40 m of straw material and manure (a mixture of 50% goat/sheep manure and 50% rejected material from feed troughs – dried chopped elephant grass or tree trimmings) covering the entire internal extension. These materials were selected from disposed matter commonly found from farms in the semi-arid region of Brazil. The mixture considered manure as a source of N and the feed (forage) waste as a source of C.

The second layer consisted of carcass parts and other solid wastes from slaughter that were placed in rows at a distance of 0.20 m from the side walls and between other carcasses, with the addition of 30, 50 or 70% of water by total weight of the carcasses in this layer. These water percentages added were determined from a previous experiment whereby the recommendation was between 30 and 50% (not published).

The third layer was formed by 0.40 m of the same structural material (mixture of sheep/goat manure, feed trough waste, and dried chopped elephant grass), which completely covered the carcass parts along the entire extension of each

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cell. This layer served as the base for the next layer of carcass and other solid material from slaughter, and continued in this manner until the pile reached a height of approximately 1.4–1.5 m (first a layer of structural material, followed by a residue layer, and finally another structural layer).

There were an average of seven layers, four with structural material and three with carcasses and other solid slaughter materials, to a height of 1.4 – 1.5 m. The amount of water was added based on the quantitative (mass) of each layer (carcass and other solid slaughter materials), and the pile was completed with a layer of structural material, following the method of Souza et al. (2019). The continuous system with passive aeration was similar to that described by Abreu et al. (2011) for the treatment of chicken carcass parts and litter.

The experiment was conducted in a randomized block design, in a split-plot scheme, with the treatments consisting of three moisture levels (30, 50, and 70%) in proportion to the weight of carcass material and four composting times (0, 30, 60, and 120 days), with three repetitions. The plot denotes the moisture levels, and the subplot represents the times. The total number of cells was nine, and the moisture level was randomized (n=3). Daily temperatures during the 120 days of the experiment were used to calculate the average degradation rate of the material in each pile (based on O_2 consumption), the maximum degradation temperature, the optimal temperature (4 °C less than the maximum degradation temperature), and the maximum temperature obtained in the pile. The O_2 consumption rate was obtained from the equation proposed by Nielsen & Berthelsen (2002), Equation 1.

Equation: $$k = A * e^{(a*(T-To))} * \frac{1}{e^{(b*(T-T1))}+1} \quad (1),$$

where k is the rate of decomposition; T is the actual temperature; A, a, and b are constants, which may be calculated theoretically, but in practice, must be determined empirically (Nielsen & Berthelsen, 2002); To is an arbitrary temperature constant (40 °C); and T1 is the inflection point temperature, denoted as approximately 4 °C less than the optimum temperature.

The lowest and highest rates corresponded to the lowest and highest moisture levels, respectively. The same pattern occurred with the maximum observed temperature as well as the optimal temperature. Therefore the lowest temperatures were observed for the 30% moisture level and the highest with 70% moisture (Table 1).

Table 1. Mean values of oxygen consumption and temperature as functions of water addition

Moisture	k max[1,2]	T k max[2]	T max[2]	T optimal[2]
%	(mg O_2 g^{-1} VS h^{-1})	-------------- °C --------------		
30	2.795	52.6	60.8	56.8
50	3.312	55.5	63.4	59.4

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70	3.535	56.2	64.4	60.4

Note: Average maximum oxygen consumption rates: k max = composting as a function of temperature in the piles; T k max = temperature observed for inflection of k; T max = maximum temperature observed in the piles; and T optimal = optimal temperature as 4 ºC less than the maximum temperature. [1]Unit: VS – volatile solids. [2] From the equation proposed by Nielsen & Berthelsen (2002)

At each evaluation time, three samples were collected from each pile (base, middle, and top), to form a compound sample (with three piles by treatment, n = 3), using an auger, to analyze the macronutrients (nitrogen – N, phosphorous – P, potassium – K, calcium – Ca, magnesium – Mg, and sulfur – S) and micronutrients (boron – B, copper – Cu, iron – Fe, manganese – Mn, and zinc – Zn) as well as pH ($CaCl_2$) and electrical conductivity (E.C.) according to the method of Abreu et al. (2006), and lignin as described by Silva & Queiroz (2002). The values of the chemical characteristics were subjected to a test of the means (Tukey test, $p<0.05$) for the main treatments (moisture levels) and regression analysis for the collection times. The SISVAR program (Ferreira, 2011) was employed for all calculations.

RESULTS

With respect to the chemical characteristics of the composting process, the moisture content of 70% resulted in a higher nitrogen content and lower lignin/N ratio than that of 30% (Table 2).

Table 2. Mean values, significance, and coefficient of variation of macro- and micronutrients, pH, electrical conductivity, lignin, and lignin/nitrogen ratio in connection with the moisture levels employed and collection times

Moisture (M)	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn	pH (CaCl2)	E.C.	Lignin	Lignin /N
%	------------------ g kg^{-1} ------------------						------------- mg kg^{-1} --------------						mS cm^{-1}	g kg^{-1}	
30	20.3b	5.4	17.6	16.5	6.2	1.2	28	28	3613	196	151	6.6	3.13	123	6.2a
50	20.6ab	5.4	19.5	17.1	6.2	1.2	28	32	3363	200	153	6.5	3.34	126	6.3a
70	23.2a[1]	5.3	18.5	17.2	6.2	1.4	26	32	3727	201	150	6.5	3.21	118	5.3b
P value	0.03*	0.44 ns	0.13 ns	0.81 ns	0.98ns	0.21ns	0.37ns	0.61 ns	0.38 ns	0.90ns	0,76ns	0.10ns	0.12 ns	0.61ns	0.03*
CV_1(%)	8.5	3.9	9.9	14.9	14.9	20.8	12.1	33.9	16.4	14.2	6.2	1.9	5.9	15.5	9.7
Time (T)[£]															
0	17.3	5.2	18.6	15.3	5.9	0.7	27	26	3045	172	131	6.9	2.95	145	8.4

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30	22.5	5.4	17.9	16.7	5.8	0.6	30	30	3177	192	147	6.3	3.05	114	5.2
60	21.5	5.6	18.5	17.3	6.3	0.9	32	31	3602	209	156	6.5	3.4	117	5.5
120	24.1	5.3	19.1	18.3	6.8	2.7	23	35	4445	223	172	6.2	3.5	113	4.8
P value	<0.01**	0.01**	0.75 ns	<0.01**	<0.01**	<0.01**	<0.01**	0.04*	<0.01**	<0.01**	<0.01**	<0.01**	<0.01**	<0.01**	<0.01**
CV_2(%)	12.2	4.3	10.8	7.2	6.7	39.2	9.5	19.7	11.5	5.4	7.6	3.1	7.4	10.9	12.2
P value M × T	0.15ns	0.32 ns	0.75 ns	0.11 ns	0.30ns	0.21ns	0.17ns	0.49 ns	0.05 ns	0.05ns	0.05ns	0.09ns	0.05 ns	0.22ns	0.73ns

Note: The samples were collected for analysis (macro-and micronutrients) at the end of the composting process at 123 days (to Moisture-M). ^{ns}, *, and ** = not significant, significant at 5%, and 1% probability, respectively. CV_1 = coefficient of variation of the main treatment. CV_2 = coefficient of variation of secondary treatment. E.C.= Electrical conductivity. [1]Different letters in columns are statistically different according to Tukey's test ($p<0.05$). [£]Equations in relation to time: N: $y = -0.000509x^2 + 0.111x + 17.93$; $R^2 = 0.81$*; P: $y = -0.000089x^2 + 0.011x + 5.180$; $R^2 = 0.95$**; Ca; $y = 0.023x + 15.66$; $R^2 = 0.93$**; Mg: $y = 0.008x + 5.76$; $R^2 = 0.90$*; S: $y = 0.017x + 0.3$; $R^2 = 0.83$*; B: $y = -0.0018x^2 + 0.187x + 26.72$; $R^2 = 0.98$**; Cu: $y = 0.070x + 26.8$; $R^2 = 0.95$**; Fe: $y = 12.15x + 2929.0$; $R^2 = 0.97$**; Mn: $y = -0.003x^2 + 0.795x + 171.7$; $R^2 = 0.99$**; Zn: $y = 0.329x + 134.2$; $R^2 = 0.97$**; pH: $y = 0.004x + 2.97$; $R^2 = 0.87$*; EC: $y = 0.000052x^2 - 0.011x + 6.815$; $R^2 = 0.70$*; Lignin: $y = 0.004x^2 - 0.802x + 141.9$; $R^2 = 0.84$*; Lignin/N: $y = 0.000442x^2 - 0.081x + 8.078$; $R^2 = 0.84$*

For the sampling time factor, significant results were obtained for all variables except potassium (Table 2). The maximum availability of the nutrients N, P, and B occurred at 111, 61, and 94 days after the start of composting, respectively. In turn, the concentrations of Ca, Mg, S, Cu, Fe, Mn, and Zn increased with time, as did the electrical conductivity. In contrast, the pH, lignin, and lignin/N ratio decreased with the length of the composting period.

For N, P, Ca, Mg, S, B, Cu, Fe, Mn, Zn, and E.C., the maximum values were 23.99 g kg^{-1}, 5.51 g kg^{-1}, 18.4 g kg^{-1}, 6.7 g kg^{-1}, 2.3 g kg^{-1}, 32.6 mg kg^{-1}, 35.2 mg kg^{-1}, 4387.0 mg kg^{-1}, 223.9 mg kg^{-1}, 173.6 mg kg^{-1}, and 3.45 mS cm^{-1}, respectively, showing increases of 33.7, 6.3, 17.5, 16.3, 666.0, 22.0, 31.3, 49.7, 30.4, 29.4, and 16.1%, respectively (Table 2). However, for pH, lignin, and lignin/N ratio the minimum values were 6.24, 103.2 g kg^{-1}, and 4.7, respectively, with decreases of 8.4, 27.2, and 41.5%, respectively (Table 2).

Thus, for N, P, and B the superior model was the second level, and the maximum values occurred prior to 120 days, whereby the concentrations in the final of composting process were 23.92 g kg^{-1}, 5.69 g kg^{-1}, and 23.24 mg kg^{-1}, respectively, with an increase of 33.4 and 9.84% and a decrease of -13.1%, respectively.

Discussion

Composting is the process of biological decomposition and stabilization of

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organic substrates through the action of various microorganisms. It has the advantage of producing fertilizer and promoting treatment of organic material (Costa et al., 2015; Cotta et al., 2015; Sena et al., 2019; Lacerda et al., 2020), and the livestock residues can be recycled and returned to production systems through the composting process (Valente et al., 2014; Sunada et al., 2015; Rodrigues et al., 2016). Composting has proven to be important in the development of sustainability education and awareness (Lima et al., 2016; Barbosa et al. 2019; Eloy et al., 2019).

The results shown in Table 1 reveal that the temperature oscillations depicted were influenced by the moisture level, corroborating Souza et al. (2019), whereby the addition of less water lowered the temperature variables that determine the optimal conditions for the activity of microorganisms (Valente et al., 2009). This was observed for the value of kmax, which represents the relationship between temperature and the consumption of O_2 (Table 1). Thus, the addition of water is important for the multiplication of microorganisms and decomposition of organic matter, and low values can change the temperature of the composted material and reduce the microbiological activity (Costa et al., 2018). Some authors mention that the temperature remains in the thermophilic range due to the degradation of organic matter, which can be considered essential for waste treatment (Valente et al., 2009). In a review article on the composting of organic wastes, Valente et al. (2009) reported that temperatures above 50 °C are unfavorable to the survival and development of pathogenic microorganisms.

In a comparison of techniques to verify the stability of the composting process, Lasaridi & Stentiford (1998) observed maximum rates of oxygen consumption in composting of sewage sludges of 19.8 mg O_2 g^{-1} VS h^{-1} when wet and 2.5 mg O_2 g^{-1} VS h^{-1} when dry, and values below 1.0 mg O_2 g^{-1} VS h^{-1} were obtained at the end of the composting period, indicating the maturation of the material. Therefore, the concentrations found by these authors for a dry base are similar to those found here (Table 1), although the composting system used in this experiment did not involve rotation of the compost piles.

Furthermore, the maximum oxygen consumption is related to the concentration of organic compounds, which serve as an immediate source of carbon and energy for the microbial biomass present in the soluble fraction of the organic matter (Said-Pullicino et al., 2007).

The increase in nutrients can be linked to the mineralization of organic matter, along with the reduction in pH, which can be explained by the release of organic acids and transformation of ammonium into nitrate (Li et al., 2012). This also applies to the increase in salts (electrical conductivity), which is explained by the mineralization of nutrients and production of nitrogen in the form of nitrate (Li et al., 2012). Although the electrical conductivity increased, it remained below 4 mS cm^{-1}, which is considered critical for the use of organic materials (Li et al., 2012).

The results for N, P, and B during the composting period show that the maximum point for these nutrients is achieved through mineralization (organic matter is the source of N, P, and B). The decrease in phosphorus relates to

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the results of Wei et al. (2015), who found a positive and significant correlation between phosphorus content and pH in the composting of various organic wastes, corroborating the findings of the present study, with a decline in pH during composting of residues from the production and slaughter of small ruminants and lower availability of P. For B, the mineralization of organic matter could be decreased as pH declined, causing the available B to be lowered. The increase phosphorus could be explained by an increase in solubilization that was immobilized by microbial cells (Valente et al., 2016).

Furthermore, composting processes with low lignin/N and C/N ratios can induce nitrogen loss by volatilization (Tuomela et al., 2000). In addition, the mineralization of organic matter is influenced by changes in pH, temperature, and humidity, resulting in changes to the concentrations of N, P, and B, since organic matter is the source of these nutrients. The sulfur level was not expected to change substantially (Valente et al., 2016).

The decline in the lignin content can be explained by the degradation of the composted material, and the increase in nitrogen, which is essential for lignin degradation (Tuomela et al., 2000), and combined, these factors explain the reduction of the average lignin content (of 22%) between the start and end of the composting process and the consequent decline of the lignin/N ratio.

Another explanation for the decrease in lignin content is the optimal value of manganese. According to Perez & Jeffries (1992), manganese plays a role in lignin degradation in the form of Mn-peroxidase which is the enzyme responsible for lignin degradation.

The 70% moisture level produced the highest concentration of N and the lowest lignin/N ratio; therefore, the lignin content influences the process of composting (Orrico Júnior et al., 2012).

The increase in Ca and Mg concentrations could be related to the decrease in lignin (Valente et al., 2016). For Cu, Fe, Mn, and Zn, the composting source is carcass and manure, because these nutrients are present in the diets of small ruminants (Silva et al., 2017).

The results shown in Table 1 characterize the transformations of the materials used in the composting process and the relative richness of nutrients in the organic compost that could be used for fertilization, thereby contributing to nutrient cycling in livestock systems.

Independent of moisture level (30, 50, or 70%), at the end of the composting process (120 days), the contents of N, P, Ca, Mg, S, B, Cu, Fe, Mn, Zn, and electrical conductivity increased, while pH and lignin values decreased. Thus, under the conditions of this experiment, it is possible to conclude that 120 days is the most effective time to end the composting process.

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