

Research Article

Efficiency in the treatment of three livestock manures through a composting process with mechanized turning

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ABSTRACT

This research aimed to evaluate the efficiency of the treatment of manure from three livestock production units (cattle, swine, and poultry), through composting with mechanized turning and incorporation of natural substrate (wood sawdust) in rural properties in the municipalities of Farroupilha, Relvado, and Caxias do Sul, State of Rio Grande do Sul, Brazil. The experimental design consisted of nine treatments, three for each type of manure. These were classified as: T1 (cattle manure plus wood sawdust), T2 (swine manure plus wood sawdust), and T3 (poultry manure plus wood sawdust). The process involved the daily turning of the windrows by a mechanized process and sampling was carried out in triplicate at 60, 120, and 180 days of composting, between the months of July 2018 and July 2019. After each sampling, samples were properly stored and sent to the Chemistry Laboratory of the University of Santa Cruz do Sul for analysis of the following variables: Calcium (Ca), Cation Exchange Capacity (CTC), Phosphorus (P), Magnesium (Mg), Nitrogen (N), pH, and Potassium (K). Temperature measurements were made on the spot every 15 days. At the end of the experiment, all treatments reached the standards of humidity, temperature, pH, and NPK, established in Normative Instruction No. 25/200 for organic fertilizers, from the Ministry of Agriculture and Livestock of Brazil. Thus, the results demonstrated the efficiency of the mechanized composting process for the treatment of bovine, swine, and poultry manure, producing a high-quality organic compost.

Keywords: Bovine manure, Swine manure, Poultry manure, Composting machine, Organic fertilizer.

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INTRODUCTION

In 2015, Brazil was rated the fourth largest pork producer in the world, after China, the European Union, and the United States, producing about 3.5 million tons of meat (Guimarães *et al.*, 2017). The largest productive concentration of this activity is found in the South region (Oliveira *et al.*, 2018).

In the production of laying birds, China is also among the biggest producers, with 45% of world production, followed by the United States, India, Japan, Mexico, and Brazil. In Brazil, the State of São Paulo is the largest egg producer, responsible for 34.3% of the total production in 2014 (Delgado *et al.*, 2016).

Brazilian cattle farming also occupies an important place in food production, having the second largest herd of cattle in 2014, with 208 million head of cattle, second only to India (Brunes & Couto, 2017). In 2018, beef production grew by 3.4%, reaching 32 million head, the second consecutive increase after three years of decline. The milk production reached 24.5 billion liters, up 0.5% (IBGE, 2019). This increase in production led to high volumes of waste generated, which when handled improperly causes serious environmental impacts on water, soil, and air (Ito *et al.*, 2016).

One of the alternatives found to reduce environmental impacts is the management of waste in solid or liquid form through composting, transforming these wastes into biofertilizers that can be used as organic fertilizer in agriculture (Oliveira *et al.*, 2018). Composting is characterized by the colonization of different aerobic microorganisms in the biomass, which generate heat and release CO₂. The changes that occur in the biomass during composting are related to the respiration and the exothermic metabolism of the microorganisms, indicating the stages of the composting process (Valente *et al.*, 2016). Composting aims to accelerate the process of stabilizing organic matter, generating important components for the soil, such as mineral salts and nutrients, improving the condition of the soil, and enhancing plant development. Some of these important nutrients are assimilated in greater quantities in the roots, like phosphorus, calcium, nitrogen, potassium, magnesium, and sulfur (Pinto *et al.*, 2017).

Aiming at mechanizing the composting process, Empresa Boni e Schuster LTDA do Brasil has developed a patented machine under registration No. BR 1020150101589. The equipment was used for the first time in a composting process for pig liquid waste, licensed by the Environment Department (DEMA) of the Municipality of Capitão, RS, in 2009, based on the environmental legislation of Decree 99.274 / 90, and having been qualified for this purpose by the State Environmental Council (CONSEMA), through resolution 045/90. Although the composting system is licensed by the DEMA of the Municipality of Capitão, there is still no research to demonstrate the efficiency of the composting process carried out by the equipment. This is, therefore, the objective of this work, aiming to evaluate the efficiency of the treatment of livestock manure (cattle, pigs, and poultry) through this mechanized process, using natural substrate for composting (wood sawdust) in rural properties in the Taquari and Cai valleys, RS, Brazil.

MATERIALS AND METHODS

Study area and sampling

The experiments were conducted during the period from July 2018 to July 2019, in the municipalities of Farroupilha, Relvado, and Caxias do Sul, RS, Brazil (Figure 1). The organic

compost was collected from three production units: dairy cattle in a confined system; swine in a finishing system; and poultry farming in a confined system. The compost was collected directly from the compost pans, with the aid of a shovel and stored in plastic containers, which were subsequently sent to the UNISC chemical analysis laboratory.

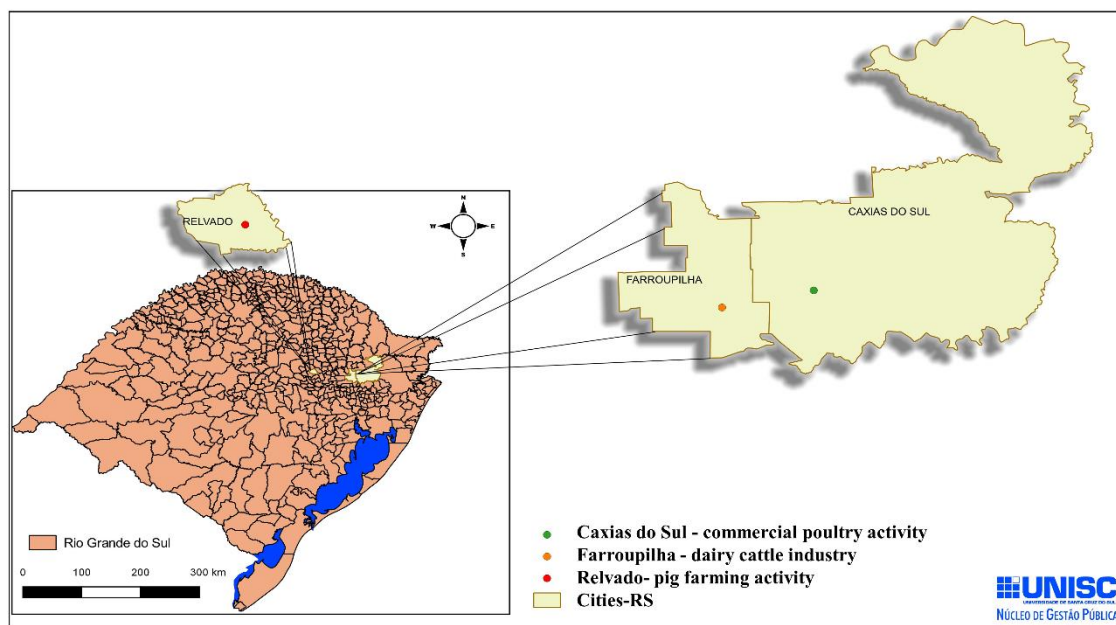


Figure 1. Map of the study area, showing the location of the municipalities of Farroupilha, Relvado, and Caxias do Sul, RS, Brazil.

Experimental design

The internal temperature of the windrows for each experiment was measured every 15 days, with a total of 9 samples (3 samples from manure type) being collected, during the 180-day period, with one collection every 60 days of composting. The collected samples were submitted to three treatments: T1: containing dairy cattle manure and untreated wood sawdust; T2: containing swine manure and untreated wood sawdust; T3: containing poultry manure and untreated wood sawdust. The volume of substrate (untreated sawdust) had a maximum height of one meter in the windrows in all experiments, since it corresponds to the maximum height allowed by the equipment's helicoids, and for each m^3 of substrate, a volume of $0.021 m^3$ of livestock waste per day was applied.

For the performance of chemical analyses, the following parameters were adopted: Calcium (Ca), cation exchange capacity (CTC), Total Phosphorus, Magnesium (Mg), Total Nitrogen (N), pH, and Potassium (K). The interpretation of the results was based on norm no. 25 of July 2009, of the Ministry of Agriculture, Livestock and Supply (Brazil, 2009), for Class “A” Compound Organic Fertilizers.

Description of the equipment to be used in the evaluation of the composting processes

The “Composting Machine” to be used in this research is mechanical equipment intended for the composting process in agriculture developed by the company Boni e Schuster LTDA do Brazil (Fig. 2). The equipment is patented under Patent Registration No. BR 1020150101589.

The equipment has a maximum capacity of turning a volume of $35 m^3$ of waste per day, amounting to $0.021 m^3$ of liquid material per m^3 of sawdust, using sawdust levels according to the orientation and size of the equipment indicated by the equipment manufacturer. Every day,

all the windrows were turned by the machine equipped with helicoids that transfer residues and substrates from the bottom upwards.



Figure 2. Composting machine

Operation of the composting system

The equipment was used for the first time in a composting process for pig liquid waste, licensed by the Department of Environment (DEMA) of the Municipality of Capitão, RS, in 2009, based on the environmental legislation of Decree 99.274 / 90, and having been qualified for this purpose by the State Environmental Council (CONSEMA), through resolution 045/90. The licensing process was based on the premise that the composting process offers a promising alternative for the management of cattle, swine, and poultry waste, transforming waste into biological organic compost. In this context, although the composting system is licensed by DEMA in the municipality of Capitão, there is still no research that demonstrates the efficiency of the composting process carried out by the equipment, thus this is the objective of the current work.

Characteristics of the dairy cattle industry

The project is located on the Nova Milano Line, Município de Farroupilha, RS, where the activity of dairy cattle farming takes place with a capacity for 120 dairy cows. For the treatment of waste in the composting system a masonry shed was used, with a wooden and concrete waterproof floor, with the following dimensions: 45.0 m x 19.8 m, divided into 6 rows of 3.3 m wide and 1.3 m high (only 4 windrows are used for composting and 2 are used for storing compost available for sale).

The collected samples were submitted to Treatment 1 (T1): cattle manure and untreated wood sawdust. The composting system is managed daily with the application of 7.2 m³ of bovine manure per windrow. The waste is deposited in a single row, while the other three rows are turned.

Characteristics of the pig farming activity

The project is located on the Cruzeiro Line, Municipality of Relvado, RS, where the pig farming activity is carried out in a finishing system with a capacity for 2,000 pigs. For the treatment of waste in a composting system, a masonry shed, with wood and concrete-proofed floor was used, with the following dimensioning: 55 m x 13 m, divided into four rows of 3.3 m and height of 1.3 m. The collected samples were submitted to Treatment 2 (T2): swine manure and untreated wood sawdust. The composting system was managed daily with the application of 14 m³ of swine manure per windrow, that is, while waste was added to one windrow, the others were turned by the composting machine.

Characteristics of the commercial poultry activity

The project is located on the Feijó Line, Municipality of Caxias do Sul, RS, where commercial poultry farming is carried out in a confined system with a capacity for 30,000 birds. For the treatment of waste in a composting system, a masonry shed, with wood and concrete-proofed floor was used, with the following dimensions: 40.0 m x 6.5 m, divided into two rows of 3.3 m wide and 1.3 m high. The collected samples were submitted to Treatment 3 (T3): poultry waste and untreated sawdust. The composting system was managed with the daily application of 3.1 m³ of poultry manure per windrow. The waste is deposited on a single windrow, while the other is turned.

Data analysis

In the information processing, descriptive statistics were used (mean \pm standard deviation, Coefficient of Variation, CV). Statistical differences between the means of the physical and chemical parameters were established using the Kruskal-Wallis non-parametric statistical test, followed by the Mann-Whitney test for multiple comparisons. The analyses were processed using PAST software version 2.15 (Hammer *et al.*, 2001). We worked with significance levels of 5% ($\alpha = 0.05$).

RESULTS AND DISCUSSION

The results of measurements of physical and chemical parameters in samples 1, 2, and 3 over periods of 60, 120, and 180 days, with Treatments T1, T2, and T3, corresponding to manure from dairy cattle, swine, and poultry, respectively, are shown in Tables 1-3, and in Figures 3-5.

Table 1. Values of parameters measured in samples 1, 2, and 3 with Treatment 1, corresponding to manure from dairy cattle and sawdust from untreated wood.

Parameter / Sample	Sample 1 (60 days)	Sample 2 (120 days)	Sample 3 (180 days)	Unit	Methodology
Humidity	69.9	58.6	26.4	%	IN 03/2015 Cap. III D
Calcium	0.6	1.2	3.6	%	IN 03/2015 Cap. III E 7
CTC	921	848	863	Mmol kg ⁻¹	IN 03/2015 Cap. III E 15
Total Phosphorus	0.4	1.14	3.10	%	IN 03/2015 Cap. III E 2
Magnesium	0.2	0.5	1.6	%	IN 03/2015 Cap. III E 7
Total Nitrogen	0.6	0.9	1.9	%	IN 03/2015 Cap. III D 1,2
<i>pH</i>	7.5	8.4	8.3	-	IN 03/2015 Cap. III D
Water Soluble Potassium	0.6	1.0	1.2	%	IN 03/2015 Cap. III E 6

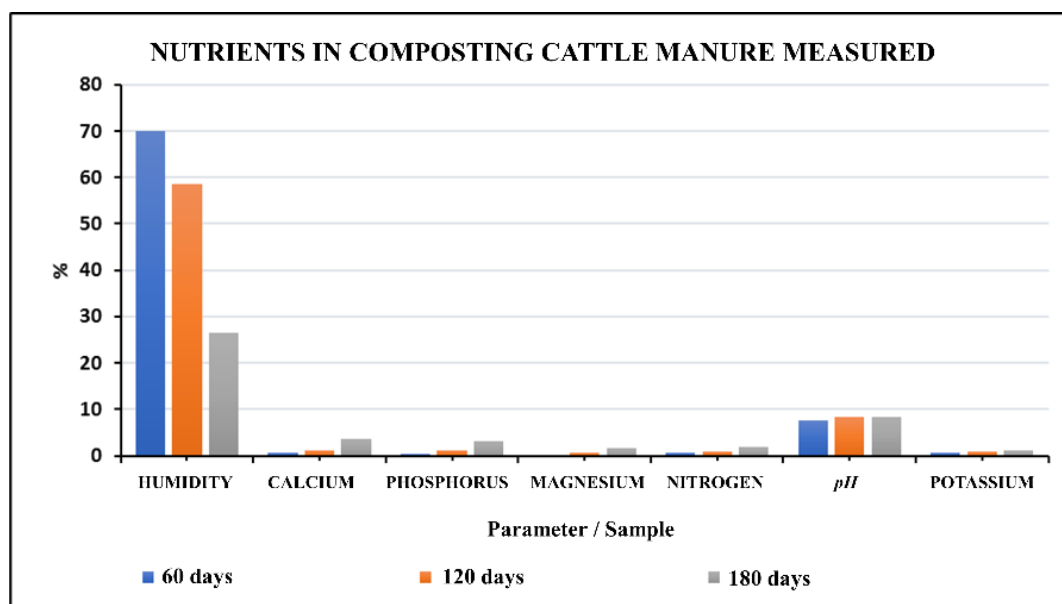


Figure 3. Values of nutrients in composting cattle manure measured at 60, 120, and 180 days.

Table 2. Values of parameters measured in samples 1, 2, and 3 for Treatment 2, swine manure and untreated wood sawdust.

Parameter / Sample	Sample 1 (60 days)	Sample 2 (120 days)	Sample 3 (180 days)	Unit	Methodology
Humidity	76.7	60.1	25.3	%	IN 03/2015 Cap. III D
Calcium	0.4	1.4	3.1	%	IN 03/2015 Cap. III E 7
CTC	374	892	756	Mmol kg ⁻¹	IN 03/2015 Cap. III E 15
Total Phosphorus	0.4	1.4	2.8	%	IN 03/2015 Cap. III E 2
Magnesium	0.1	0.6	1.0	%	IN 03/2015 Cap. III E 7
Total Nitrogen	0.4	0.9	2.0	%	IN 03/2015 Cap. III D 1,2
pH	7.0	8.5	7.9	-	IN 03/2015 Cap. III D
Water Soluble Potassium	<1.0	1.9	1.1	%	IN 03/2015 Cap. III E 6

Table 3. Values of parameters measured in samples 1, 2, and 3 for Treatment 3, manure from commercial laying birds and untreated wood sawdust.

Parameter / Sample	Sample 1 (60 days)	Sample 2 (120 days)	Sample 3 (180 days)	Unit	Methodology
Humidity	36,1	35,8	20,2	%	IN 03/2015 Cap. III D
Calcium	4,4	2,6	4,0	%	IN 03/2015 Cap. III E 7
CTC	413	851	658	Mmol kg ⁻¹	IN 03/2015 Cap. III E 15
Total Phosphorus	2,8	2,8	3,5	%	IN 03/2015 Cap. III E 2
Magnesium	0,6	1,0	1,4	%	IN 03/2015 Cap. III E 7
Total Nitrogen	0,9	1,6	2,2	%	IN 03/2015 Cap. III D 1,2
pH	8,8	8,5	8,2	-	IN 03/2015 Cap. III D
Water Soluble Potassium	1,2	2,0	1,3	%	IN 03/2015 Cap. III E 6

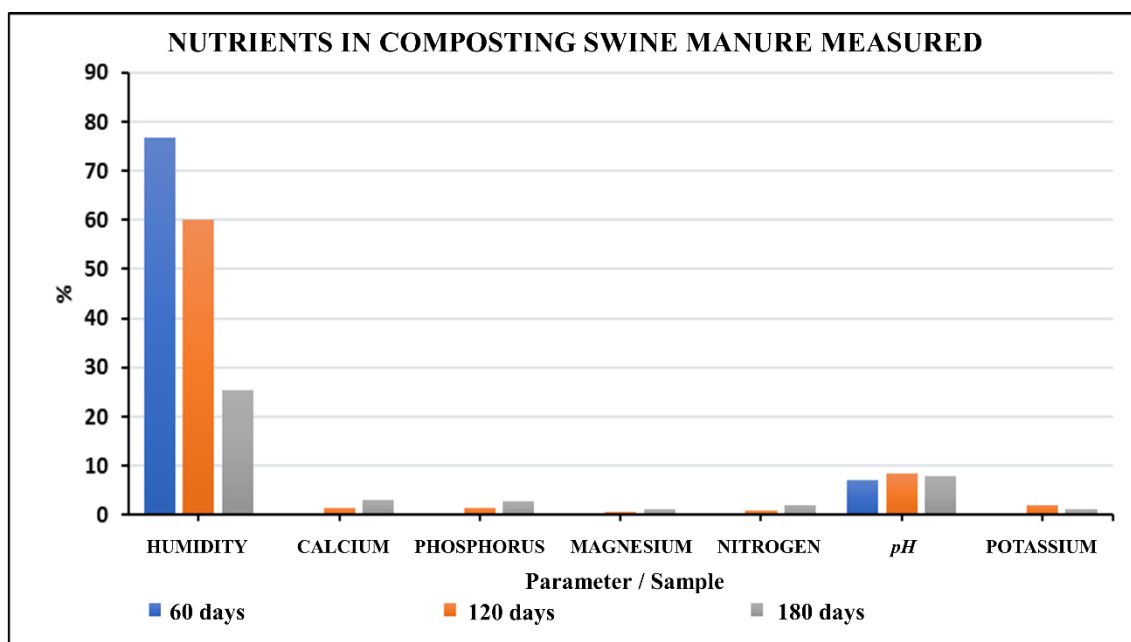


Figure 4. Values of nutrients in composting swine manure measured at 60, 120, and 180 days.

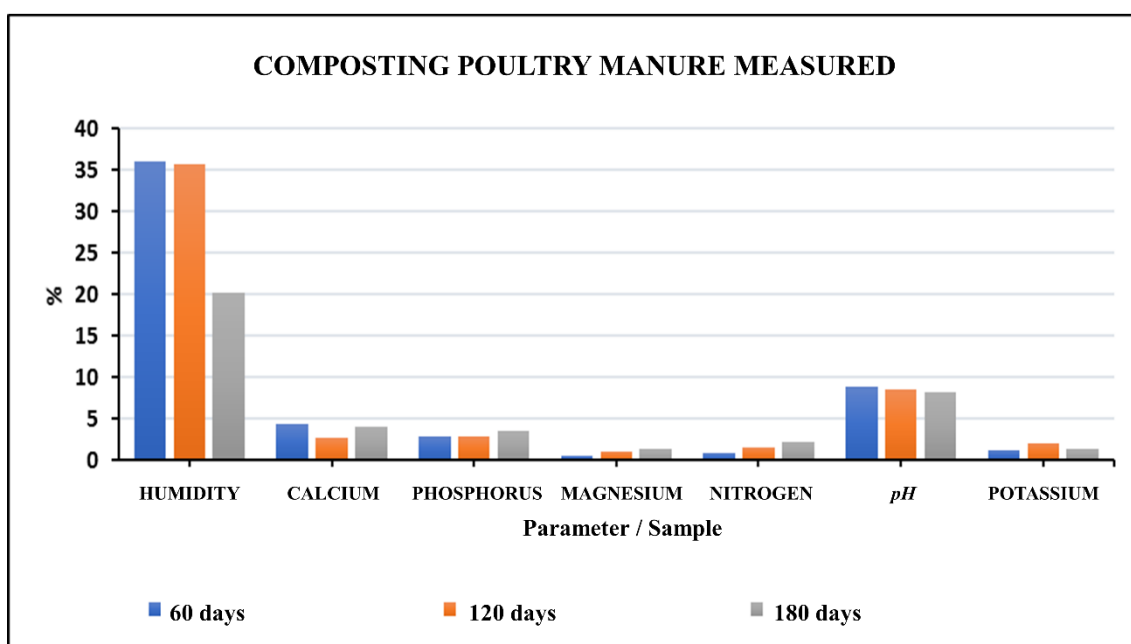


Figure 5. Nutrient values of composting poultry manure measured at 60, 120, and 180 days.

In T1, to the composting of bovine waste, humidity reached 26.4% after 180 days of composting, for T2, to the composting of swine manure, it reached 25.3% and in T3, poultry waste, 20.2% (Tables 1, 2, and 3), meeting the required parameters of Normative Instruction No. 25 of July 2009 (MAPA, 2009), which requires a maximum humidity of 50%. The T1 and T2 treatments showed high humidity up to 120 days, which was controlled by regularly turning

the organic matter, contributing to aeration, and preventing anaerobic degradation. In the three treatments, there is a reduction in moisture as soon as the maturation stage is completed.

Cavaletti (2014), analyzing mechanized composting of swine manure, found humidity results of around 69.1%. Despite the high moisture content, the reduction in waste generated was 85.5% through evaporation of water from the biomass. These results are similar to those of Bittencourt (2015), who analyzed the composting of manure and litter from dairy cattle, where the humidity values remained high throughout the process. According to the author, the saturation of the windrows may have occurred because they are open to the sky, subject to bad weather, causing the leaching of excess water from the windrows, losing nutrients and decreasing the efficiency of the process.

The percentage of nitrogen was above the minimum required ($N > 0.5\%$) by IN n° 25/2009, in all treatments, 1.9% in T1, 2.0% in T2, and 2.2% in T3. Total nitrogen increased after 180 days in the three treatments performed. According to Kiehl (2004), this occurs due to the loss of other components through volatilization, while the nitrogen is maintained. At the end of the process, bacteria present in the compost can fix nitrogen from the atmosphere.

In recent years, studies have been conducted in relation to nitrogen, as it is a vital component in the development of the quality of the final product. For example, Sun *et al.* (2019) used bovine manure with rice straw to study the alpha diversity of bacteria and to evaluate the effects of N. The results showed a gradual increase in the total N content during the composting process. This phenomenon can be attributed to the fact that the compost mass was reduced more quickly than nitrogen, causing an increase in total N due to the concentration effect.

Jiang *et al.* (2018), who used pig manure with wheat straw, in the study of the alpha diversity of bacteria and in the evaluation of the effects on N loss, suggest that the late addition of animal manure and acid substrates may prevent the loss of N during composting and improve the quality of the compost. This condition was not observed in this research since significant values were obtained at the end of the maturation process.

After 180 days of composting, the pH of T1 was 8.3; 7.9 for T2; and 8.2 for T3, complying with IN n° 25/2009, which establishes a minimum pH value of 6.0. We observed in the treatments that there was an increase in the volume of the compost due to bacterial activity, with a pH between 6.7 and 9.0, thus avoiding nitrogen losses through ammonification (Bernal *et al.*, 2009; Choinska-Pulit *et al.*, 2019).

The treatments performed presented favorable conditions of pH, nutrients, temperature, and humidity, which support life for bacteria and fungi to digest organic matter, releasing organic acids for compounds of alkaline reactions (Bernal *et al.*, 2009). Works such as Wu *et al.* (2019), Duan *et al.* (2019), and Jiang *et al.* (2018) highlight the importance of monitoring pH values, with a low pH delaying the increase in temperature, prolonging the composting process, and stimulating the growth of fungi that aid in the decomposition of lignin and cellulose found in sawdust. Vione *et al.* (2018) obtained pH values that ranged from 6.5 to 8.2, in compost s matured from bovine, swine, and poultry manure. According to the authors, the ideal pH should be slightly acidic to neutral, since values greater than 8.4 can be harmful to plants, especially if associated with odors and the loss of ammonia. The pH results found in this research, in the three treatments used, were between 7.9 and 8.3, similar to the results of the mentioned works, achieving the values that best assist in the composting process without harming the plants.

We observed that the parameter Cation Exchange Capacity (CTC) in the swine and poultry compost shows an increase in values of 374 to 892 Mmol Kg⁻¹ and 413 to 851 Mmol Kg⁻¹,

from 60 to 120 days, respectively, undergoing a stabilization process at 180 days. This increase is due to the possible accumulation of positively charged materials, due to products derived from lignin found in sawdust, or the increase in carboxyl and / or hydroxyl groups (GAO *et al.*, 2010).

In the composting of the bovine manure, there was a decrease in the parameter for Cation Exchange Capacity from 60 to 120 days, from 921 to 848 Mmol Kg⁻¹, stabilizing at 863 Mmol Kg⁻¹ at 180 days, reaching the desired degree of maturity. During the process of the biodegradation of organic residues until the degree of maturation, the factors of humidity, oxygenation, and temperature could be controlled by periodically turning the composting rows, as well as an increase in the CTC due to the functional groups of the humic substances that were observed (Maragno *et al.*, 2007; Valente *et al.*, 2016).

It should be noted that CTC is an important factor for the monitoring and maturation of the compost, which increases with the decomposition of organic matter as it forms the humus, responsible for the adsorption of cationic nutrients (ammoniacal nitrogen, potassium, calcium, magnesium, iron, zinc, manganese, and copper), since humus is a negative colloid that is balanced by positively charged cations (Kiehl, 2004).

The biodegradation performance of aerobic composting at any time depends on the physical conditions (temperature, humidity, size, and degree of mixing of the raw materials), and chemical (O₂ in the air) and nutritional conditions, such as N, P, K, and C bioavailability in the material (Khan *et al.*, 2014). In this sense, throughout the fermentation period it was observed that there was an increase in the content of nutrients N, P, K, Ca, and Mg with increasing fermentation time, presenting satisfactory levels for improved quality at the end of the maturation phase, meeting Normative Instruction No. 25 of July 2009 (MAPA, 2009). The parameters increased between 60 and 180 days of maturation in the three composts, such as for phosphorus, from 0.4% to 3.1% (bovine compost), 0.4% to 2.8% (swine compost), and 2.8% to 3.5% (poultry compost). For magnesium, values were observed from 0.2% to 1.6%; 0.1% to 1.0%; and 0.6% to 1.4%, respectively.

Being a biological process, the compost needs nutrients for microbial growth and process development. Carbon is the main source of energy, and nitrogen is needed for cell synthesis; phosphorus and sulfur are also important, however, their role in the process is less known (Fernandes, 1999).

For the composting carried out in this research, sawdust was used along with the selected waste as a volume agent to optimize the substrate properties such as air space, moisture content, C / N ratio, particle density, pH, and mechanical structure, positively affecting the decomposition rate. This choice is also related to studies where sawdust has shown better results together with animal waste (Bernal *et al.*, 2009).

Table 4 and Figure 6 show the values observed in the temperature measurements of treatments T1, T2, and T3, during the period of 120 days, with intervals of 15 days. It is observed that the temperature showed a gradual increase as a function of the composting age for T1, T2, and T3, corresponding to cattle, swine, and poultry waste, respectively, reaching an average for T1 of 61.2 ± 12.5 °C (CV = 20.5%), 61.0 ± 12.1 °C (CV = 19.5%) for T2, and 61.0 ± 13.7 °C (CV = 22.6%) for T3, with no significant differences between these averages (p > 0.05). After 150 days of composting, there was a drop in temperature, reaching an average of 35°C for the three treatments. (39.2 ± 4.7 °C; CV = 12.0%).

The three substrates achieved favorable development conditions in the composting process, balancing favorable conditions for the efficiency of the actions of microorganisms (bacteria, fungi, and actinomycetes), highlighting the temperature, humidity, aeration, pH, type of existing organic compounds, carbon / nitrogen (C / N), granulometry of the material, and windrow dimensions. Temperature control is essential for the performance of the degradation process, being a factor indicating the biological balance in the composting mass, which reflects the efficiency of the process (Bidone, 2001).

We found that in all three treatments, the mesophilic, thermophilic and maturation stages occurred. The first is observed in the first 15 days, where the mesophilic microorganisms break the soluble and rapidly degradable compounds, thus raising the temperature, until reaching 40 °C and starting the thermophilic phase. This phase begins after 45 days, with organisms that have ecological preferences for high temperatures, reaching high temperatures, as observed from 90 to 105 days of maturation. According to Meng *et al.* (2018), microbial respiration and the consumption of organic matter cause the accumulation of heat, resulting in an increase in temperature during composting, the destruction of pathogenic organisms, microbes, and fats, in addition to complex proteins and carbohydrates, such as cellulose and hemicellulose present in the sawdust.

Table 4. Measurement of temperature (°C) at intervals of 15 days for T1, T2, and T3, in manure from dairy cattle, swine, and poultry, respectively, in a period of 120 days.

Composting age	Cattle (°C)	Pigs (°C)	Poultry (°C)
15 days	38	39	35
30 days	47	48	44
45 days	58	55	62
60 days	69	68	71
75 days	67	69	68
90 days	70	71	69
105 days	72	70	69
120 days	69	68	70
135 days	70	69	68
150 days	68	67	69
165 days	45	43	42
180 days	36	34	35

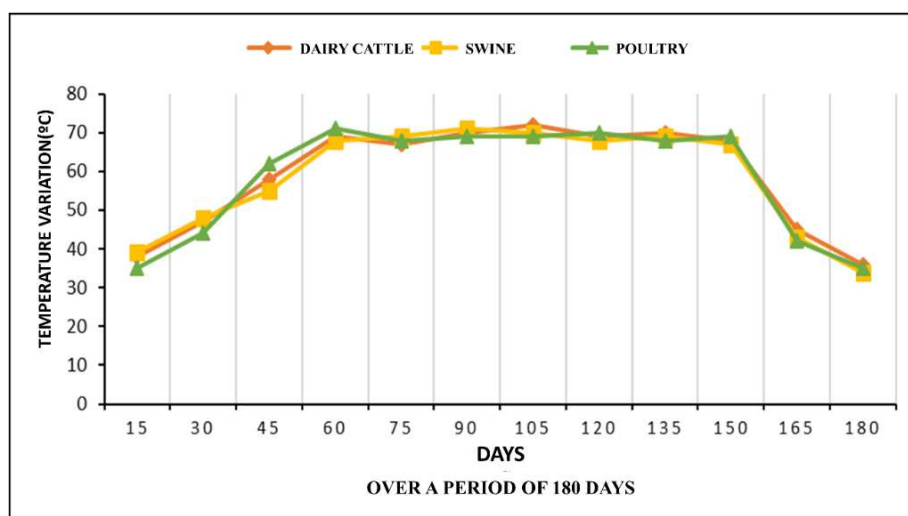


Figure 6. Temperature variation in samples T1, T2, and T3, in manure from dairy cattle, swine, and poultry, respectively, over a period of 180 days.

With the decreasing temperature, the maturation phase begins, around 120 to 135 days of the process, reaching room temperature, and completing the cycle, where the microbial activity is responsible for the degradation of organic wastes, transforming them into organic humus (Awasthi *et al.*, 2020). The same temperature fluctuations were observed in the studies by Maragno *et al.* (2007) and Kunz *et al.* (2008), obtaining a gradual increase in temperature, and decreasing after the maturation phase. However, it is important to highlight that the local climate can influence the results, as in the work of Gao *et al.* (2010) in Jiaozhou district, Qingdao, China, where the temperature of the batteries increased rapidly, between 5 and 20 days, or the research by Khan *et al.* (2014), obtaining a maximum peak in the first 14 days, in the laboratory.

According to Bernal *et al.* (2009), the composting system, the conditions and characteristics of the bedding material, the volume of the added agent for fermentation, and the environmental conditions for the season (winter / summer) have a great influence on the mineralization of organic matter during composting. Liquid waste always needs a structuring agent for composting, such as poultry litter, rice husks, sawdust, or shavings (Valente *et al.*, 2009).

CONCLUSION

The results demonstrated that the use of composting using an automated machine (composting machine), with the addition of sawdust for the treatment of cattle, pig, and poultry manure, is efficient, since it significantly reduces the volume of manure with the use of cheap and abundant substrates available in the region, benefiting the small rural producer through the reduction of the volume of waste and, consequently, the potential impact caused on water, soil, and air resources.

The composting machine offers an alternative composting process, using aerobic fermentation, that significantly reduces the volume of waste, changing its physical characteristics, and concentrating nutrients. In addition, it provides a good quality organic fertilizer with high agronomic value for use in diverse vegetable crops in accordance with the specifications of the Brazilian legislation in force, IN 25/2009 (BRASIL, 2009), for humidity, nitrogen, pH, and temperature.

We conclude that the treatment of manure from dairy cattle, pigs, and commercial laying birds with the use of sawdust substrate, carried out by the composting machine, demonstrated efficiency in the composting process, since it provides a final product within the standards established by IN n° 25/2009, thus allowing the indication of this equipment for the production of organic fertilizer.

Authors' Contributions

Ari J. Strapazzon and Fernanda A. B. Theves, field work, sample collection, data analysis and initial writing. Patrik G. Wiesel, writing, translation, and formatting. Eduardo A. Lobo, supervision of works, guidelines, corrections, and revisions of writing. All authors know and agree with the final version of the article and its submission.

Conflicts of Interest

The authors declare that there is no conflict of interest for the publication of the manuscript.

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