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Bentonite as an additive in the composting of wastewater sludge from the poultry agroindustry

Abstract – The objective of this work was to evaluate the use of bentonite as an additive in the composting of wastewater sludge from the poultry agroindustry regarding nitrogen conservation, carbon degradation, and nutrient content increase. The experimental design was completely randomized with five treatments with bentonite at 0, 0.5, 1.0, 3.0, and 6.0%, with three replicates. The organic compost used in the treatments consisted of pine sawdust and wastewater sludge from the treatment plant. During and after the composting process, the following were analyzed, respectively: pH, dry matter, temperature, and C, N, NH_4^+, NO_2^-, and NO_3^- contents; and P, K, Ca, Mg, Cu, and Zn contents and humic and fulvic acid concentrations. Bentonite at 6.0% increased C degradation, N losses, Mg content, and humification, but decreased Zn content and humidity. Bentonite, as an additive in the composting of sludge from the poultry agroindustry, promotes humification, decreases Zn content and humidity, but does not affect pH and P, K, Cu, NH_4^+, NO_2^-, and NO_3^- contents.

Index terms: organic fertilizer, sustainability, waste treatment.

Bentonita como aditivo na compostagem do lodo de efluentes da agroindústria avícola

Resumo – O objetivo deste trabalho foi avaliar o uso de bentonita como aditivo na compostagem de lodo de efluente da agroindústria avícola quanto à conservação de nitrogênio, à degradação de carbono e ao aumento no teor de nutrientes. O delineamento experimental foi inteiramente casualizado com cinco tratamentos com bentonita a 0, 0,5, 1,0, 3,0 e 6,0%, com três repetições. A compostagem orgânica utilizada nos tratamentos consistiu de serragem de pinus e lodo da estação de tratamento do efluente. Durante e após o processo de compostagem, foram analisados, respectivamente: pH, matéria seca, temperatura e teores de C, N, NH_4^+, NO_2^-e NO_3^-; e teores de P, K, Ca, Mg, Cu e Zn e concentrações dos ácidos húmico e fúlvico. A bentonita a 6,0% aumentou a degradação de C, as perdas de N, o teor de Mg e a humificação, mas diminuiu o teor de Zn e a umidade. A bentonita, como aditivo na compostagem do lodo da agroindústria avícola, promove a humificação, diminui a concentração de Zn e a umidade, mas não afeta o pH e os teores de P, K, Cu, NH_4^+, NO_2^- e NO_3^-.

Termos para indexação: adubo orgânico, sustentabilidade, tratamento de resíduos.

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Introduction

The fast growth of the poultry sector has led to an increased production, during meat processing, of wastewater with a high organic and microbiological load and, therefore, pollution potential if improperly disposed of in the environment (Sunada et al., 2015). According to the same authors, although treatment plants could minimize the problem, a proper destination for sludge, which is normally disposed of in landfills, is still required and could add value to this waste through techniques that reduce its polluting potential and guarantee its sanitary quality.

Composting is a promising alternative to treat organic waste, including sludge from wastewater treatment plants. At the end of this process, the product obtained due to the high temperatures used to stabilize organic matter is considered stable, sanitized, rich in humic substances, and without risks to the environment when applied to the soil (Orrico et al., 2012).

Therefore, composting has a positive impact on the environment, allowing of nutrient recycling through organic fertilizers, which improves crop yield and soil quality. However, it may also have negative impacts when the process is not conducted correctly, causing the emission of polluting gases and high nitrogen losses that can contribute to the increase in greenhouse gases in the atmosphere, as reported by Higarashi (2010). The author observed the emission of the following gaseous pollutants during composting: ammonia (NH_3), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and volatile organic compounds related to offensive odors, such as volatile fatty acids, aromatics, sulfur compounds, amides, and alcohols.

In this scenario, bentonite has been recommended as an additive to reduce N losses during composting (Zhang & Sun, 2017; Guo et al., 2020; Li et al., 2020a), as well as to increase humic substances and water retention capacity (Teixeira-Neto & Teixeira-Neto, 2009). Bentonite is a clay, belonging to the smectite group, with a high content of montmorillonite and a 2:1 crystal structure, composed of two silicon-oxygen tetrahedra sandwiched between two layers of aluminum-oxygen octahedrons (Li et al., 2020b). According to these authors, although the presence of copper, magnesium, calcium, and other cations in the layered structure may make the interaction with the crystal very unstable, bentonite has a high cation exchange capacity.

Compared with other commercially available materials, bentonite also shows several advantages related to its cost, availability, adsorption properties, and non-toxicity, for example (Bhattacharyya & Gupta, 2008). However, there is still a lack of studies on the use of this clay in the composting of wastewater sludge from treatment plants and on the best concentration for a better quality of the produced compost.

The objective of this work was to evaluate the use of bentonite as an additive in the composting of wastewater sludge from the poultry agroindustry regarding N conservation, C degradation, and nutrient content increase.

Materials and Methods

The experiment was conducted on a pilot scale, during 152 days, at the Vossko do Brasil Alimentos Congelados Ltda. company, located in the municipality of Lages, in the state of Santa Catarina, Brazil (27°45'03.40"S, 50°20'27.99"W).

The experimental design was completely randomized with five treatments consisting of bentonite at the concentrations of 0, 0.5, 1.0, 3.0, and 6.0%, with three replicates. Each treatment was carried out inside a polypropylene box with a volume of 0.594 m^3 (0.6 m in height, 0.9 m in width, and 1.10 m in length), which was kept in a covered area, without ambient temperature control.

Each box was filled with 100 kg freshly cut pine sawdust, with 50.24% humidity, and 500 kg sludge, which were the feedstocks used for composting. Since sludge has a high water content, different percentages of its total volume were added to the sawdust on three different days to avoid compromising the aeration of the composting process (Sardá et al., 2010): 40% (200 kg), with 80.6% humidity, on the first day; 30% (150 kg), with 78.18% humidity, on the thirtieth day; and 30% (150 kg), with 81.04% humidity, on the eighty-eighth day. Before each of these three sludge applications, T-Cond QB41 bentonite (T-Minas Bentonitas Industriais Ltda, Quatro Barras, PR, Brazil) was added at 0, 0.5, 1.0, 3.0, and 6.0% (w/w sludge). The characteristics of the used sawdust and sludge (sampled each time before it was added) are shown in Table 1.

The PSL-517 gas-powered drill (Lynus, Araquari, SC, Brazil) was used to incorporate the sludge into the

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sawdust and turn the compost, aiming to reproduce, on a pilot scale, the processes used in the automatic composting machine installed in the industry where the present study was conducted. The operating protocol adopted for the composting plant was the one described by Oliveira et al. (2017), consisting of biomass turning once a day in the first three days after each sludge application to homogenize and incorporate oxygen into the mixture and, then, twice a week until the end of the experiment.

Composting temperature was measured using the HI935005 digital thermocouple thermometer (HANNA Instruments, Smithfield, RI, USA) once a day in the middle of the polypropylene box and of the compost bed height.

For compost analysis, approximately 300 g of the material were collected from each corner and the middle of the box, totaling five different sampling points; this was done right after turning using a gardener's shovel.

Compost moisture was determined using the equation: M = 100 - DM (M), where M is moisture; and DM is dry mass, obtained through gravimetry by heating the samples at 105ºC for 24 hours.

pH was measured in an aqueous extract of distilled water (ratio of 1.0:2.5 w/v and contact time of 120 min) using the SevenGo SG23 digital pH meter (Mettler-Toledo GmbH, Greifensee, Switzerland), previously calibrated with standard buffer solutions with pH values of 4, 7, and 10. After the pH analysis, the used samples were frozen and sent to the laboratory of physicochemical analysis of Embrapa Suínos e Aves, located in the municipality of Concórdia, also in the state of Santa Catarina. There, N, total organic carbon (TOC), DM, P, K, Ca, Mg, Cu, Zn, NH_4-N, NO_3-N, and nitrite (NO_2-N) contents, as well as humic (HA) and fulvic (FA) acids, were analyzed.

Table 1. Characterization of the sludge and sawdust used as feedstocks (natural base) for composting.

Parameter	Sludge	Sawdust
Total organic carbon (%)	9.38	24.19
Total nitrogen (%)	1.53	0.11
Carbon/nitrogen ratio	6.13	219.91
Dry matter (%)	20.06	49.76
pH	5.79	5.12

All analyses were performed using the standard methods adopted from American Public Health Association (Clesceri et al., 1998), except those of HA and FA, adapted from Sánchez-Monedero et al. (1996) and Benites et al. (2003). Specifically, TOC and N were determined using the Flash 2000 CHNS/O elemental analyzer (Thermo Fischer Scientific, Waltham, MA, USA), NO_2-N and NO_3-N were evaluated by an automated flow analysis system using the FIAlab-2500 UV-vis spectrophotometer detector (FIAlab Instruments, Inc., Seattle, WA, USA), and NH_4-N was obtained by the volumetric method. In addition, P was determined by UV-vis spectrophotometry using the molybdovanadate reagent according to method 958.01 of AOAC International (Helrich, 1990), whereas Ca, Mg, Cu, and Zn were analyzed by atomic absorption spectrometry and K by inductively coupled plasma optical emission spectrometry (ICP-OES), all using the Optima 4300 DV simultaneous spectrometer (PerkinElmer, Inc., Waltham, MA, USA).

To evaluate decreases in C and N contents during composting and to eliminate the dilution effect caused by bentonite, which was previously reported by Wong et al. (2009), a mass balance was conducted. For this, the difference between the total C and N added during composting and the C and N that remained in the final compost was calculated using the formula: %decrease = ((Cs×p) + (Cl1×p) + (Cl2×p) + (Cl3×p) - (Ccf×p)) × 100/((Cs×p) + (Cl1×p) + (Cl2×p) + (Cl3×p), where Cs, Cl1, Cl2, Cl3, and Ccf are the contents of the element, respectively, in the sawdust, in the first sludge application, in the second sludge application, in the third sludge application, and in the final compound; and p is the weight of the material.

The data were subjected to the analysis of variance, and the effects of concentrations and treatments were evaluated by Tukey's test, at 5% probability. All analyzes were performed with the Past, version 4.03, software (Hammer, 2022).

Results and Discussion

The composting temperatures of all treatments increased after the first sludge application with different percentages of bentonite (Figure 1). The value for the thermophilic stage was reached in two days and maintained until the second sludge application on the thirtieth day, when temperatures dropped to close to

30°C, but increased to over 45°C after a week. However, temperatures did not reach the thermophilic stage with the third sludge application on the eighty-eighth day, which coincided with the winter period when the daily average ambient temperatures were close to 10°C. This combination increased humidity and reduced the temperature in the compost bed, not only delaying the composting process, but preventing the sanitization of the compost as recommended by Resolution 481/2017 of Conselho Nacional do Meio Ambiente (Conama, 2017). After 138 days of composting, temperatures dropped steadily, tending to an equilibrium with ambient temperature in all treatments, suggesting that the readily available organic matter was running out and composting was coming to an end.

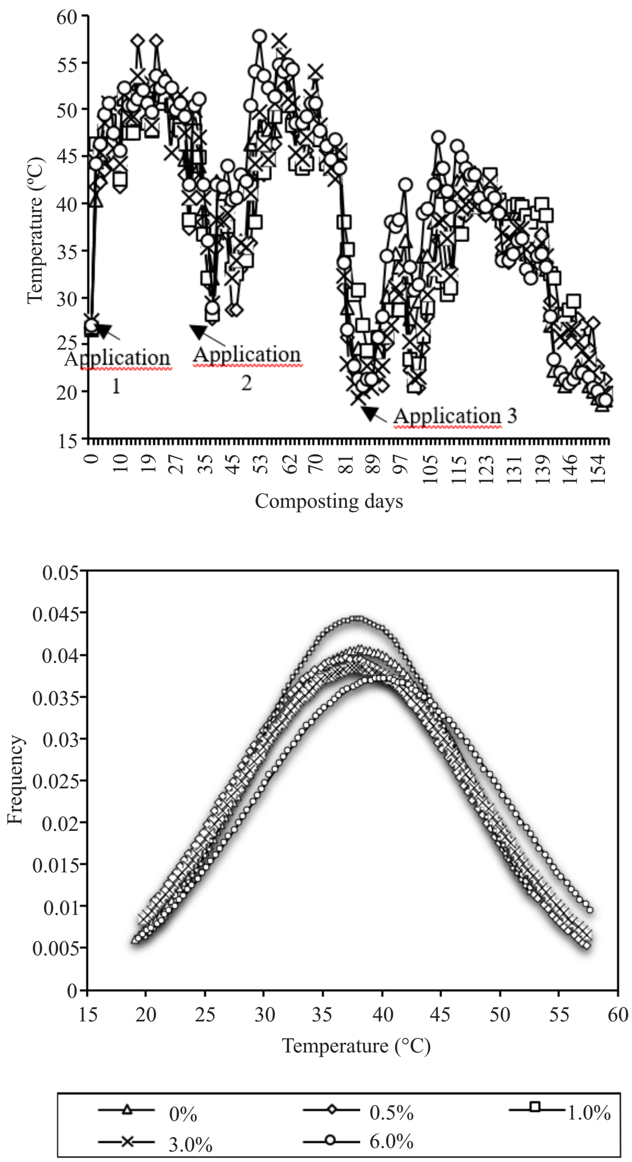

Figure 1. Temperature and temperature frequency of compost from poultry industry sludge during treatments with the application of bentonite, as an additive for composting, at the concentrations of 0, 0.5, 1.0, 3.0, and 6.0%.

During the 152 days of composting, temperature frequency had a normal distribution. Although the recorded temperatures were frequently 40°C in the treatment with bentonite at 6.0%, no significant differences were observed among treatments (Figure 1). Likewise, Li et al. (2012) did not report effects of bentonite on temperature when studying nutrient transformation during the composting of swine manure using bentonite. Ren et al. (2018), however, concluded that the additive might have prolonged the thermophilic stage of the process for chicken manure compost.

In all treatments, moisture reached values above the recommended due to the high moisture content of the applied sludge; however, as the composting process progressed, moisture decreased due to the heating caused by microbiological activity (Figure 2). In the case of the third sludge application, temperature did not increase afterwards and the compost remained for a longer time with a humidity above the ideal range, which could be explained by the greater heat loss by diffusion due to the low ambient temperatures and consequent reduction in microbiological activities. At the end of the composting process, humidity was 60.87, 60.67, 60.57, 58.8, and 54.23% for the treatments with bentonite at 0, 0.5, 1.0, 3.0, and 6.0%, respectively, which is an indicative that the decrease in moisture in the final compost is directly related to the concentration of the clay.

The highest moisture content was observed in the treatment with bentonite at 6.0%, which may have been due to the synergistic effect of the water absorption capacity and porous structure of the clay (Bhattacharyya & Gupta, 2008). This caused a decrease in the amount of free water, allowing of a better aeration and favoring the development of microorganisms, which led to an increased biological activity, biomass heating, and gaseous exchange. Similarly, Li et al. (2012) found that compost moisture was reduced when bentonite was used during swine manure composting, which is particularly interesting for the co-composting of residues with high water contents, such as swine manure and the sludge used in the present study.

The pH values of the sludge were 6.09, 5.49, and 5.81 in the first, second, and third applications, respectively. After each application, the pH curves of all treatments showed sudden drops followed by sharp increases (Figure 2). In the first sludge application, initially, pH was close to 5.5, reaching values above 8.0 after one week. The low pH observed at the beginning of composting can be explained by the low pH of the sludge and sawdust used in the experiment, with values of 6.09 and 5.12, respectively. In the second and third sludge applications, the low pH of the treatments was exclusively attributed to the low pH of the sludge, whereas the increase in pH a few days after sludge application (Figure 2) was probably due to the biodegradation of organic acids and mainly to N ammonification (Li et al., 2020a).

After 147 days of composting, pH stabilized at values close to 6.0. Therefore, pH values were similar among all treatments, which is an indicative that bentonite did not affect composting. Li et al. (2012) and Yang et al. (2019), evaluating pig manure and animal carcass for composting, respectively, credited the reduction of pH at the end of the process to other factors such as nitrate production, H^+ release during nitrification, and the formation of low molecular weight fatty acids and CO_2.

The C/N ratio of the biomass at the beginning of composting showed values close to 10 (Figure 3), which were below the initial ratio of 25–30, considered ideal for the process. However, according to Guo et al. (2012), composting at lower initial C/N ratios is possible and can increase the amount of waste treated. In the present study, this was confirmed by the successful implementation of the composting process using sludge and sawdust at a ratio of 5:1 (w/w).

The behavior of the C/N ratio was similar throughout the composting process. As soon as the thermophilic stage began, N losses in the form of NH_3 and N_2O were favored, increasing the values of the C/N ratio until the second sludge application, after which they decreased again due to the high N content of the applied sludge (1.52% on a wet basis). However, after the forty-sixth day, decreases in C were more pronounced than N losses, which decreased the C/N ratio (Figure 3). From the third application of the sludge onwards, the composting process no longer reached the thermophilic stage, causing a reduction in N losses in the form of NH_3 and leading to the low C/N ratio observed until the end of the experiment.

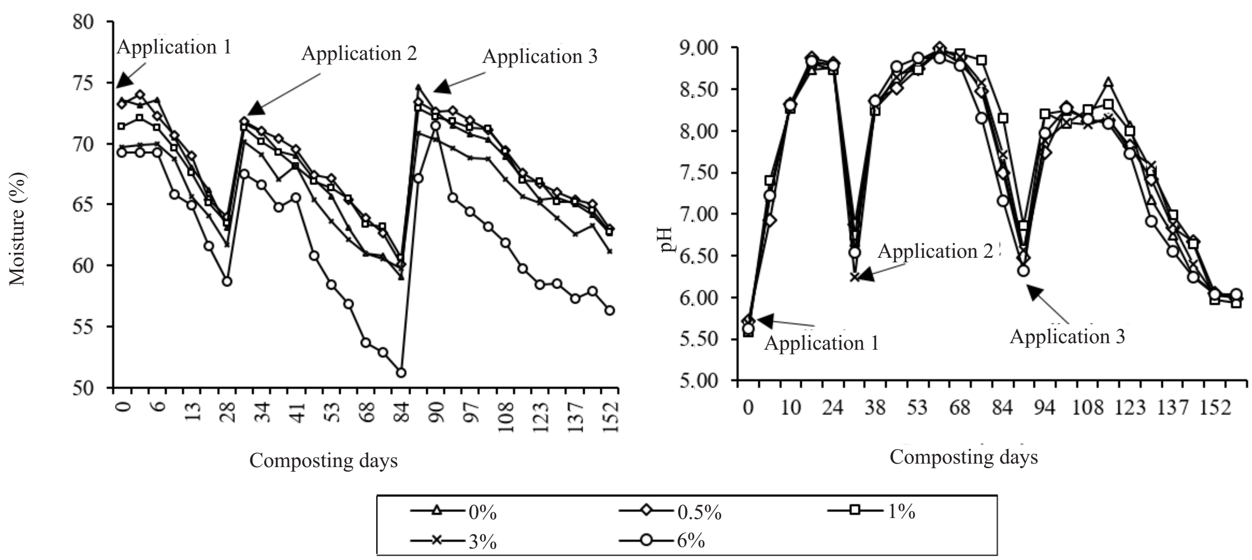

Figure 2. Moisture and pH of poultry industry sludge during treatments with the application of bentonite, as an additive for composting, at the concentrations of 0, 0.5, 1.0, 3.0, and 6.0%.

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Carbon contents decreased in all treatments, with values of 34.89, 33.72, 33.48, 28.56, and 25.27% after 147 days of composting with bentonite at 0, 0.5, 1.0, 3.0, and 6.0%, respectively (Figure 4). This decrease can be attributed to the decomposition of organic matter mediated by the combination between microbial activity and CO_2 emission (Wang et al., 2017). In the present study, the decrease in C content was proportional to the amount of applied bentonite, which causes dilution, an effect that tends to be intensified as the composting process advances and the mass of the compost is lost.

In all treatments, N contents increased soon after each application of sludge and bentonite due to the high N content present in the sludge; however, as composting progressed, these contents decreased (Figure 5). In the final composts, N contents (on a dry basis) were 3.09, 3.02, 2.86, 2.69, and 2.35% with bentonite at 0, 0.5, 1.0, 3.0, and 6.0%, respectively. Regarding differences between treatments, N content was up to 23.91% lower in that with bentonite at 6.0%, compared with those with concentrations of 0, 0.5, and 1.0%, but 13.09% lower with bentonite at 3.0%, which only differed from the concentration of 0%.

At the beginning of the composting process, the dilution effect of bentonite resulted in lower C and N contents at higher concentrations of the clay. According to mass balance, the highest bentonite concentration caused C degradation and N losses, showing decreased C contents when compared with the treatments with 0 and 1.0% of the clay and higher N losses throughout composting than the treatment with 0% bentonite (Figure 6), which may be related to the higher consumption of N due to the higher microbial activity for C degradation.

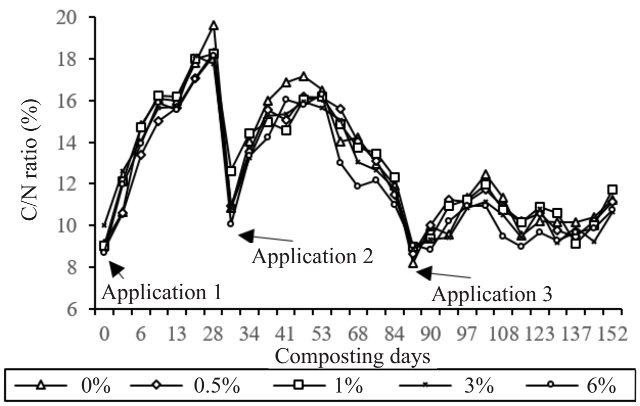

Figure 3. Carbon/nitrogen ratio of poultry industry sludge during treatments with the application of bentonite, as an additive for composting, at the concentrations of 0, 0.5, 1.0, 3.0, and 6.0%.

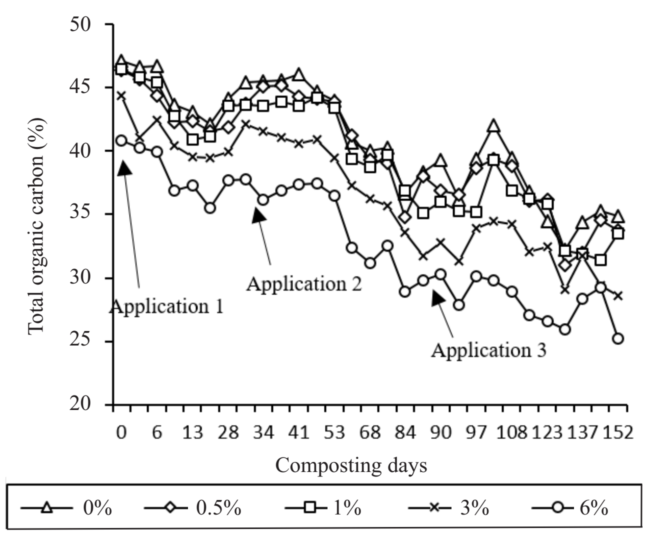

Figure 4. Changes in organic carbon from poultry industry sludge during treatments with the application of bentonite, as an additive for composting, at the concentrations of 0, 0.5, 1.0, 3.0, and 6.0%.

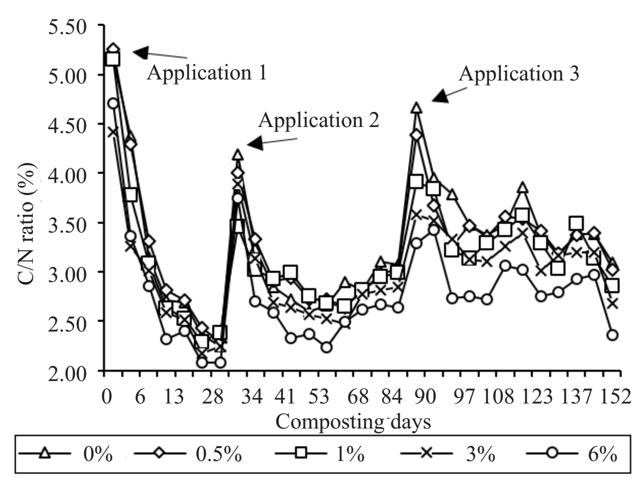

Figure 5. Total nitrogen of poultry industry sludge during treatments with the application of bentonite, as an additive for composting, at the concentrations of 0, 0.5, 1.0, 3.0, and 6.0%.

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Wang et al. (2016a) found that the addition of bentonite to swine manure compost resulted in higher degradation rates of organic matter and dissolved organic carbon. Likewise, Ren et al. (2019) observed that adding tertiary amine bentonite at different concentrations to poultry manure compost caused the degradation of TOC. Such effect of bentonite is probably due to its large specific area and porosity that cause a greater bacterial development (Külcü & Yaldiz, 2014).

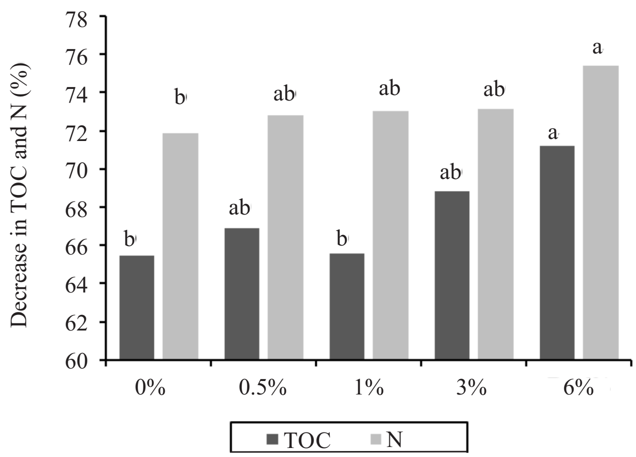

Figure 6. Average decrease in carbon and nitrogen contents in poultry industry sludge during treatments with the application of bentonite, as an additive for composting, at the concentrations of 0, 0.5, 1.0, 3.0, and 6.0%. Means followed by equal lowercase letters do not differ among treatments by Tukey's test, at 5% probability. TOC, total organic carbon.

Regarding other nutrient contents, those of P, K, and Cu were not affected by the treatments, whereas that of Mg differed between the treatments with bentonite at 1.0, 3.0, and 6.0%. At the highest bentonite concentration, Mg showed the highest content of 3,358.76 mg kg^{-1} and Zn the lowest of 137.58 mg kg^{-1} (Table 2). These results may be explained both by the high content of MgO (1.93%) in bentonite, which possibly proportionately increased Mg content in the compost, and to the ability of the clay to immobilize Zn, as reported by Wang et al. (2016a) when evaluating the use of calcium bentonite as an additive in the composting of swine manure.

The concentrations of humic and fulvic acids, considered the main components of the humic fractions of composts, are important parameters to evaluate the maturity and stabilization of an organic fertilizer (Dias et al., 2010). According to Wang et al. (2017), generally, mature compost has a high concentration of humic acid and a low one of fulvic acid. In the present study, the treatments with bentonite at 3.0 and 0% differed for humic acid, but not for fulvic acid (Table 2). Moreover, the concentration of 3.0% bentonite affected the production of total

Table 2. Chemical properties of the compost obtained at the end of the composting process (on a dry basis) of poultry industry sludge treated with five concentrations of bentonite[(1)].

Parameter	Bentonite concentration				
	0%	0.5%	1.0%	3.0%	6.0%
Dry matter (DM, %)	37.37 (0.05)a	36.95 (0.004)a	37.24 (0.005)a	38.85 (0.02)a	43.70 (0.03)b
Ca (mg kg^{-1})	7850.52 (0.02)ab	7613.89 (0.03)ab	8361.83 (0.05)a	7625.91 (0.1)ab	6684.72 (0.07)b
Mg (mg kg^{-1})	1501.07 (0.02)d	1670.73 (0.04)d	2015.04 (0.05)c	2595.45 (0.06)b	3358.76 (0.04)a
Cu (mg kg^{-1})	17.70 (0.09)a	17.65 (0.07)a	17.40 (0.03)a	17.35 (0.07)a	15.62 (0.03)a
Zn (mg kg^{-1})	161.21 (0.05)a	161.70 (0.08)a	159.74 (0.06)a	158.57 (0.06)ab	137.58 (0.04)b
K (mg kg^{-1})	3828.04 (0.06)a	3801.53 (0.03)a	4246.71 (0.06)a	4148.43 (0.12)a	4043.02 (0.13)a
P (mg kg^{-1})	21616.13 (0.15)a	22490.75 (0.07)a	20908.60 (0.07)a	20429.00 (0.20)a	16047.75 (0.02)a
NO_2-N (mg kg^{-1})	0 (0)a	0 (0)a	0 (0)a	0 (0)a	0 (0)a
NO_3-N (mg kg^{-1})	208.58 (0.67)a	123.29 (0.86)a	115.41 (0.19)a	80.067 (0.38)a	172.60 (0.07)a
NH^4-N (%)	0.94 (0.18)a	0.99 (0.12)a	0.87 (0.08)a	0.81 (0.04)a	0.78 (0.11)a
N (%)	3.09 (0.03)a	3.02 (0.07)a	2.86 (0.05)ab	2.69 (0.02)ab	2.35 (0.06)b
C (%)	34.85 (0.04)a	33.72 (0.03)a	33.48 (0.04)a	28.57 (0.02)b	25.26 (0.05)c
C-N (%)	11.26 (0.08)a	11.16 (0.1)a	11.71 (0.09)a	10.64 (0.06)a	10.72 (0.09)a
Humic acid (HA, %)	0.7 (0.06)b	1.0 (0.11)ab	0.9 (0.13) ab	1.1 (0.12)a	1.0 (0.32)ab
Fulvic acid (FA, %)	5.1 (0.02)a	5.8 (0.04)a	5.5 (0.05) a	6.0 (0.09)a	5.7 (0.09)a
pH	6.05 (0.02)a	6.05 (0.02)a	5.97 (0.01)a	6.02 (0.02)a	6.04 (0.01)a

[(1)]Means followed by equal letters, in the columns, do not differ from each other by Tukey's test, at 5% probability. Numbers between parentheses are the coefficient of variation.

humic substances (humic acid+fulvic acid), which may be attributed to the favorable conditions created by bentonite for the degradation of the organic matter present in the compost.

Conclusions

1. Bentonite, as an additive in the composting of sludge from the poultry agroindustry, promotes humification, decreases Zn content and humidity, but does not affect pH and P, K, Cu, NH_4^+, NO_2^-, and NO_3^- contents.
2. The use of bentonite at the highest concentration of 6.0% promotes C degradation, N losses, an increased Mg content, and a decreased Zn content.

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