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CHARACTERIZATION AND INVESTIGATION OF CHICKEN LITTER AS A SOURCE OF PHOSPHORUS FOR FERTILIZERS

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Abstract

Chicken production has been growing in Brazil due to population growth and consequently the waste generated in this process, namely chicken litter, has also increased. Currently, the main destination of chicken litter is its application to the soil in areas near to the chicken production units. The objective of this work was to characterize the chicken litter produced in the Brazilian Midwest using different techniques, in order to diversify the application of this residue and minimize the environmental impacts generated by chicken meat production. Chicken litter characterization was performed by analyses of particle size distribution, moisture content, pH, water activity, proximate composition, total nitrogen, protein and non-protein nitrogen, and pyrolysis and thermogravimetric analysis. In addition, a greenhouse experiment was carried out to evaluate the agronomic efficiency of chicken litter compared to mineral fertilizer. Mass balance of chicken litter pyrolysis showed that it kept 50% solid mass and the first most significant mass loss of chicken litter occurs between 250 and 350 °C from the thermogravimetric analysis. Chicken litter was less efficient than mineral fertilizer. However, the great improvement in shoot dry matter yield compared to control showed the potentiality of this residue as a nutrient source when properly used.

Key words: nutrient resource, organic fertilizer, plant nutrition, poultry waste

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1. Introduction

Chicken litter is a waste generated from the chicken production. To reduce the environmental impacts of poultry industry and to avoid the leachate leakage, a layer of material, usually wood sawdust, between 5 and 10 cm thick is spread over the floor (Angelo et al., 1997). Over time, this material is mixed with remaining animal feed, excretions, feathers and skin scales, making it a nutrient-rich material (Chen and Jiang, 2014; Wilkinson et al., 2011).

Characterization of the chicken litter is necessary because with a knowledge of its physicochemical characteristics it is possible to identify the best applications of this waste. In the literature, there are some publications which characterize chicken litter. Performing some analyses such as moisture content, pH, water activity, proximate composition, pyrolysis and thermogravimetric analyses can better determine waste characteristics. Moisture content and water activity are analyses that help to understand absorption capacity of water. The removal of moisture from the material causes a decrease in the water activity inhibiting the development of microorganisms and delaying biodegradation of various compounds (Cano-Chauca et al., 2004). The physical-chemistry composition can identify the content of crude fiber,

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protein, lipids, ashes, and total carbohydrates (Ferreira et al., 2008).

The pyrolysis of chicken litter can be an alternative to waste disposal, and this process can allow the use of some subproducts, such as pyrolysis oil (Kim and Agblevor, 2007). Thermogravimetric analysis is a technique of thermal analysis in which the variation in the sample mass with the change in temperature and time is controlled. This technique determines the thermal degradation behavior of chicken litter (Damartzis et al., 2011). The pH analysis for chicken litter is also important depending on the application as it may be necessary to correct the pH and provide instructions about its use (Oliveira et al., 2003). Analysis of the mineral composition of the chicken litter may show considerable nutrient contents that plants need (Rogeri et al., 2016). Nutrients in the dry matter of chicken litter such as Nitrogen (N), phosphorus (P) and potassium (K) are found in average concentrations of 3.5%, 1.6% and 1.8% respectively (Keating, 2000). It is important to emphasize that the concentration of these nutrients will depend on the method of broiler production and the type of absorbent material used in the litter (Souza et al., 2012).

Most chicken litter is directly applied to the soil, with or without incorporation in areas around the plant. The use of chicken litter as a fertilizer can be justified because of the large amount of nitrogen from high levels of protein and amino acids that it contains, making it one of the most valuable animal wastes as organic fertilizer (Chen and Jiang, 2014). Also, the considerable amount of P in chicken litter (Rogeri et al., 2016; Souza et al., 2012) and in its ash (Codling et al., 2002) mean that this material can be used as a phosphate fertilizer for Brazilian croplands due to the high phosphorus demand. However, its use as a fertilizer has been threatened because of the potential of pollution of water resources due to losses from runoff (Kibet et al., 2011).

Thus, sustainable strategies for the correct disposition of chicken litter are required (Keating, 2000). Therefore, the objective of this study was to characterize chicken litter from Center-West of Brazil physiochemically, and to suggest alternatives for the destination of this residue as a phosphate fertilizer for plant nutrition.

2. Material and methods

2.1. Chicken litter characterization

The characterization of chicken litter was carried out at the Federal University of Bahia, Salvador, and at the Federal University of Rio de Janeiro, Rio de Janeiro. The industrial chicken litter used was from the BRF SA Integration System located in the Brazilian Mid-West, where the litter is changed after 8 lots (~ 1.5 years). At each batch change, CaO is applied per farm. For this study, the chicken litter was previously sieved through sieves and the material less than 2 mm was characterized. All the characterization methods used ran in triplicate samples.

Particle size distribution was also analyzed. This analysis was carried out on a sieve shaker set with five sieves of 10, 24, 32, 200 and 400 mesh. The analysis ran for 5 minutes at vibration intensity of "3".

Moisture content, pH and water activity were analyzed from the chicken litter. The moisture content was determined by the thermogravimetric method, after drying the sample in an oven at 105 °C for 12 hours. The pH was measured by potentiometric method by combined electrode in the suspension of chicken litter and distilled water (10 g: 75 mL relationship) after 30 minutes of the equilibrium and fresh shaking. Water activity analysis was done in triplicate samples by the method described in AOAC (2000) using the Aqua lab LITE® Decagon Devices (Washington, USA) equipment.

The proximate composition, total nitrogen, protein and non-protein nitrogen, pyrolysis and thermogravimetric analysis also were determined in the samples. The analysis of the proximate composition determined the contents of volatile substances at 105°C, total protein by Kjeldahl method using the value 6.25 as nitrogen conversion factor, crude fiber by acid digestion (1.3% sulfuric acid) and alkaline (1.3% sodium hydrogen), and total carbohydrates (by difference) according to the methodology described in AOAC (2000). Total lipids were quantified using the method of Bligh and Dyer (1959).

The pyrolysis was done at a temperature of 500°C, nitrogen flow rate of 80.21 mL min^{-1}, and reaction time of 60 minutes. After the oven reached the process temperature, 5 g of sample was added and the reaction was started. Gas chromatography / mass spectrometry (GC/MS) analyses were performed to determine the composition of the condensate collected during the chicken litter pyrolysis process. A gas chromatograph connected to a DANI Instruments mass spectrometer, Milan, Italy model MÁSTER, equipped with a DN-wax DANI capillary column, with a length of 30 m, internal diameter 0.32 mm and thickness of the 1.0 µm film. The equipment was coupled to a thermal conductivity detector.

The thermogravimetric analysis (TGA) of the thermal degradation of the material as a function of temperature was carried out using the equipment Perkin-Elmer TGA-7 model. The samples were subjected to increasing temperature values, ranging from 50 °C to 700 °C, at a constant heating rate of 10°C/min and under an inert nitrogen atmosphere. This characterization was performed from a crude sample, without drying.

2.2. Agronomy efficiency

The experiments were carried out in greenhouses with controlled temperatures. The soil, a Latossolo Vermelho type (Santos et al., 2018), was collected from the soil layer depth from 0 to 20 cm at the UniRV experimental farm in Rio Verde city, Goiás. It was air dried, sieved in size lower than 4 mm and stored until use. It had a pH ($CaCl_2$ 0.01 mol L^{-1}) of 5.2, a content of 15.3 g kg^{-1} organic matter, 540 g kg^{-1} clay, 0.3 mg kg^{-1} phosphorous (Mehlich-1) and 4.6 $cmol_c$ kg^{-1} of CEC (at current soil pH).

The treatments were performed on the chicken litter (described above); triple superphosphate (TSP) and a control without the addition of P. The total P (nitric acid digestion) in the fertilizers was 1.22 and 19.65 for chicken litter and TSP respectively. TSP was chosen as the soluble P source due to its wide usage in Brazilian farmlands. All fertilizers were applied at rate of 100 mg of P per pot due to the estimated P adsorptive capacity of the soil defined in a previous study conducted (data not shown). Each pot was filled with 2 kg of soil (dry base). A randomized block design with four replications was used.

Five corn seeds were planted and after five days these were thinned to two plants per pot. A nutrient solution, without P, was applied to all pots. For each kilogram of the soil N 100 mg, 80 mg K, 80 mg Ca, 80 mg Mg, 80 mg S B, 1 mg, Cu 4 mg, Mn 8 mg and Zn 8 mg in the nutrient solution was applied. The wetting of the soil was controlled by pot weighing every two days to keep the humidity between 60 and 70% of the field capacity. Complementary N applications were performed at rate of 150 mg per kg of soil split at three times sowing. The plants grew in a greenhouse for 45 days.

The plant shoots were cut out at ground level at the end of the experiment. These were dried in an oven until constant mass and the shoot dry mass was measured. After the nitroperchloric digestion, the P content in the shoot tissue was determined. The P content in samples was determined by molecular absorption spectrometry (Teixeira et al., 2017). The dry mass yield, P uptake and relative agronomic efficiency were calculated using the soluble source (TSP) as reference.

The ANOVA Test ($P \leq 0.05$) was applied to the data and the Tukey test was applied ($P \leq 0.05$).

3. Results and discussion

3.1. Characterization of chicken litter

Particle size distribution was determined as shown in Table 1 and most of the material was retained in the 200 mesh screen, representing 43.1% of the material. It was also noted that 35.1% of the material was retained in the 24 mesh screen. In a study by Whitely et al. (2006), although the set of screens used were different, most of the chicken litter was retained in the 140 mesh screen. This is similar to the result of the present study and the screen that best comes close to this is 200 mesh. The portion that was retained in the 10 mesh screen can be associated with the crowded manure as well as feathers and shavings used in the initial floor covering of the aviary. Studying the size of the particles is important, as it influences the moisture absorption and compacting capacity of the chicken litter. When the litter is very humid, the trampling of the chickens, the dripping or draining of water due to problems in the drinking fountains, waste of feed from the feeders, among other factors, can compact the chicken litter, leading to the formation of blocks that can damage the lot, affecting the quality of the meat produced due to lesions on the feet of the confined chickens.

The water activity analysis which examines the relationship between the water vapor pressure of the evaluated material and the pure water vapor pressure at the same temperature, is verified on a scale of 0 to 1, where 1 represents the pure water. The water activity of the chicken litter was 0.702, the pH was 8.29 and the moisture content was 9.5% (see Table 1). Water activity and moisture content are important because the humidity present in the chicken litter increases the cost of transportation as this is based on the weight of the load. The moisture content of chicken litter evaluated in this work is similar to the values found in the literature (Whitely et al., 2006). The pH analysis showed similar results to other studies reported in the literature (Petkova et al., 2013; Do et al., 2005). Knowing the characteristics of chicken litter is important for a better understanding of its nutritional value so that it can be properly applied in agriculture, or even for other functions that may be affected by these indicators.

The proximate composition analysis of the chicken litter was carried out, and results can be seen in Table 3. The quantity of volatile substances at 105°C was 95 g kg^{-1}, and among these substances is ammonia. This high result had already been expected, given that the pH was above 7 (8.29). According to Reece et al. (1979), the pH of the chicken litter has a direct influence on ammonia levels. Ammonia volatilization is low when the pH is less than 7 and increases as the pH rises. The pH below 7 and H^+ ions in the chicken litter increase the ammonium: ammonia ratio, in other words, more ammonia will be converted to non-volatile ammonium ions. Ammonia volatilizes because it has no electric charge (Moore Jr. et al., 2000).

The ash in the chicken litter was 40%, this result is confirmed by the TGA analysis that will be presented later. This is where most of the nutrients that will be supplied to the soil and plants are concentrated. The high ash content can be explained by the presence of impurities, because it is a warehouse with windows for ventilation that allows the entry of dust and also by the addition of CaO in the chicken litter between batch changes. The use of CaO in the treatment of litter between batches also results in the high content of Ca in the chicken litter. In the studies by Font-Palma (2012) and Lynch et al. (2013), the authors present the nutrients present in chicken litter ashes and the quantities of phosphorus, potassium, calcium, iron, magnesium and sodium. While in the work of Lynch et al. (2013), in addition to these nutrients they also found amounts of boron, selenium, cobalt, manganese, molybdenum, copper and zinc. This reinforces the hypothesis that it is in the ashes there are the nutrients needed for agriculture. Dalólio et al. (2017) points out that the mineral nutrients present in natural chicken litter have less stability and availability than those offered by ash. Thus, the use of the ash can increase the efficiency in organic fertilization and reduces the environmental impact.

Table 1 also showed the protein, crude fiber, lipid and carbohydrate contents found in chicken litter. The results show that the amount of protein (%N 6.25) was 105 g kg^{-1}, total lipids 28 g kg^{-1}, raw fiber was 127 g kg^{-1} and total carbohydrates was 366 g kg^{-1}. The carbohydrate content found in the present study was similar to that found by Ghaly and McDonald (2012) namely 330g kg-1. The other nutrients presented different values, the protein, lipid and fiber contents were 422, 63 and 65 g kg^{-1}, respectively. These levels may differ between the types of chicken litter, as they depend directly on the diet used for the confined chicken (Keating, 2000), as well as on the material used for poultry floor lining. This is important so as to identify the amount of supplementation that will be required for chicken litter fertilizer formulation.

The mass balance results are presented in Table 1. During the pyrolysis fractions of 51% solid, 37.7% liquid and 11.2% gas were generated. The liquid fraction result approximates the value found by Weldekidan et al. (2019), in which 39% of mass was identified, however, the solid and gas fraction results differ slightly. This difference may be related to the material used for floor covering, which in that case was rice husks, while the material used in the present work was wood shavings. However, the result of the TGA analysis of this work shows that the solid fraction was approximately 40%, which coincides with the comparative work that found 42% of solid mass. Throughout the pyrolysis process, water vapor derives from thermochemical reactions and also from wet raw material. Thus, at the end of the reaction there is a liquid fraction, which is the junction of water and bio-oil (Simbolon et al., 2019). The bio-oil compounds identified in the GC/MS analysis are presented in Table 2. Among the volatile substances found in the chicken litter were ammonia, acetic acid, and others. Pyrolysis of chicken litter is important as it would solve problems of disposal of this waste and pollution of water resources. In addition, it adds value to the product by using the pyrolysis oil for power generation and also using ash as a source of nutrients free from microorganisms that often affect the health of the producer by releasing ammonia into the air (Kim and Agblevor, 2007).

The results of thermogravimetric analysis (TGA) presented in Fig. 1 shows that most of the chicken litter decomposed between 270 °C and 600 °C at each heating rate. This large amount pyrolyzed was attributed to the decomposition of hemicellulose and cellulose (Kim and Agblevor, 2007). Based on the Cao et al. (2004) method, the curve was separated into four temperature ranges for a better understanding of chicken litter mass loss. Range I comprising the room temperature up to 150 °C; range II between 150 °C and 350 °C; range III between 350 °C and 500 °C; and range IV between 500 °C and 650 °C. The residue found at temperatures more than 600 °C is attributed to mineral decomposition, part of which contains the main nutrients to be supplied to plants. The mass loss in region I is approximately 10%, which is related to moisture and volatile gases that evaporate (Whitely et al., 2006). The lowest mass observed at the end of the TGA analysis was 39.8%, which coincides with the ash content (40.6%) quantified in the proximate composition analysis. In region II it is assumed that pyrolysis and oxidation occur simultaneously, as rapid devolatilization and subsequent oxidation is observed (Whitely et al., 2006). In temperature region III the reaction rate is constant, which can be attributed to the initial diffusion and combustion of coal. This process can be considered preparation for combustion that occurs in the temperature region IV (Chen et al., 1995).

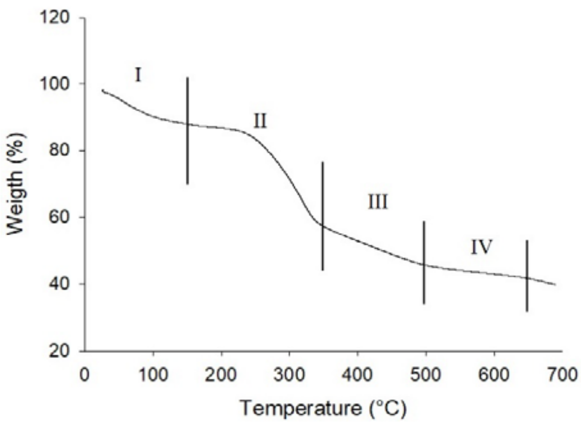

Fig. 1. TGA of raw chicken litter

Table 1. Particle size analysis, pyrolysis mass balance and physical-chemistry of chicken litter

Particle size					*Pyrolysis mass balance*			*Physical-chemistry*		
Mesh										
10	*24*	*32*	*200*	*400*	*Solid*	*Liquid*	*Gas*	*Water activity*	*pH*	*Moisture content*
----------------------------------- % -----------------------------------										%
2.7	35.1	12	43.1	7.1	51	37.7	11.2	0.702 ± 0.004	8.29 ± 0.03	9.50
mineral waste *										
Volatile substances at 105 ºC		FMW¹		Protein (%N 6.25)		Total lipids		Raw fiber	Total Carbohydrates	
-- g kg^{-1} --										
95 ± 0.15		406 ± 1.56		105 ± 0.25		28 ± 0.11		127 ± 0.35	366 ± 1.24	

** Results expressed as mean and standard deviation of triplicate analysis. [1] Fixed mineral waste (total ashes).*

3.2. Agronomic efficiency

The results for the planted corn showed that shoot dry mass of the samples using chicken litter was higher than control, and also the P content in corn shoot tissue and P uptake (Fig. 2A, B and C). Only in corn shoot dry mass, chicken litter was lower than triple superphosphate (TSP) (Fig. 2A). The yield of shoot dry mass for chicken litter was 7.85 g pot^{-1} in average and 12.39 g pot^{-1} for TSP. The relative agronomic efficiency to TSP of chicken litter was 60.7 %. Chicken litter had the higher P content in corn shoot tissue (Fig. 2B). Although it is expected that TSP had the higher P content due to the high solubility, in this case, the high yield in shoot mass (Fig. 2A) causes the dilution of the P in shoot tissue. Thus, the chicken litter with the lower yield than TSP with good P availability had the greater P content in shoot tissue. TSP and chicken litter were higher than control and similar in P uptake (Fig. 2C). This similarity is due to the compensation of the high content P in shoot tissue (Fig. 2B) for chicken litter despite the lower yield (Fig. 2A).

The majority of P in chicken litter is the form of inorganic phosphate (Mackay et al., 2017; Souza et al., 2012). This is more soluble than some organic P forms that make P more available to plants (Schmitt et al., 2018). The P from organic fertilizers is released lower than soluble sources such as TSP. This P will be released over the crop grown or for the next crop (Pitta et al., 2012). In cases of lower P availability in soil the soluble source is more efficient due to the fast release of P, however, in cases of P soil content near of the sufficient level, chicken litter is a great P source for replacement fertilizers. In addition, it is important to emphasize that chicken litter is also a great source of the other nutrients (Rogeri et al., 2016) not evaluated in this study.

Table 2. Identified bio-oil compounds from the pyrolysis of chicken litter

Compounds Name	***%***
Carbon dioxide/ Carbamic acid/ Monoammonium salt/ ethanedial/ dioxime	0.02
Ammonia/ water	0.03
Acetic acid	0.15
2-Propanone, 1-hydroxy-	0.05
2-Furanmethanol	0.05
Ethanone, 1-(2-furanyl)-/Butyrolactone/2(1H)-Pyridinone	0.03
2-Cyclopenten-1-one, 2-hydroxy-3-methyl-	0.04
n-Hexadecanoic acid	0.04

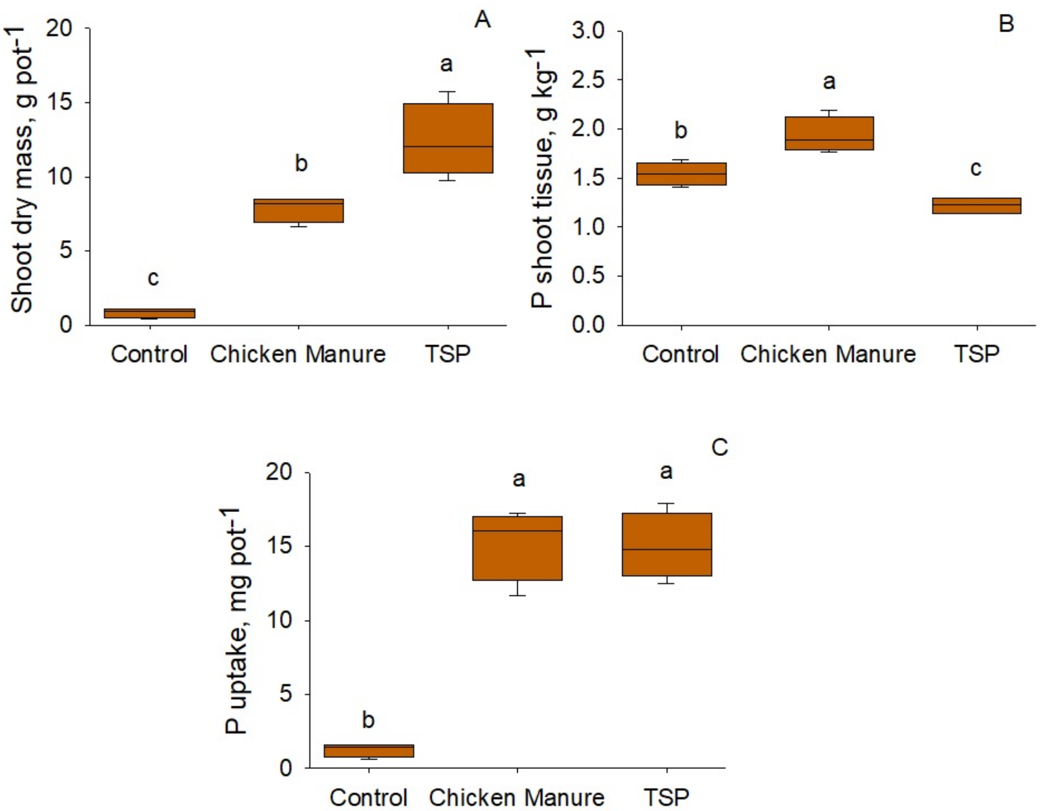

Fig. 2. Corn shoot dry mass (A), phosphorus in plant tissue (B), and phosphorus uptake (C).
Triple Superphosphate=TSP.
Same letters do not differ according to Tukey test (P≤0.05)

4. Conclusions

The characterization of chicken litter made it possible to better understand what the main characteristics of this material are and consequently how to expand the possibilities of the application of this waste. It is important to note that the generation of this waste is an environmental problem and knowing the thermal characteristics and by-products generated in the pyrolysis of chicken litter, it is possible that other researchers have ideas for new applications of this waste and thus reduce the environmental impacts caused by it.

Chicken litter can be use as phosphate fertilizers for plant nutrition, however, it has a lower shoot yield than soluble inorganic phosphate in soil with low P availability.

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