Evaluation of the fertilizer and contamination potential of different broiler litter types subjected to various use cycles

Evaluación del potencial fertilizante y contaminante de diferentes camas para pollos de engorde sometidas a varios ciclos de uso

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Abstract: *The aim of this study was to evaluate two types of poultry bedding litter (wood shavings and coffee husks) with increasing use cycles, the best time to proceed with composting based on the carbon/nitrogen ratio and the ability to generate ammonia. The results obtained with the present experiment conditions indicated that the litter with wood shavings in the first cycle and the litter with coffee husks in the first and second cycles presented the best behavior in terms of the C/N ratio needed for later use as compost. In regards to the contamination potential, it was found that increasing the number of reutilizations for both the wood-shaving and coffee-husk litters resulted in a greater ammonia emission.*

Key words: Coffee husks, composting, poultry industry, wood shavings.

Resumen: *El objetivo de este estudio fue evaluar dos tipos de cama de pollo de engorde (aserrín de madera y cáscaras de café) con ciclos de uso crecientes, buscando el mejor momento para ser utilizado como compostaje en base a su relación Carbono/Nitrógeno, y conocer su capacidad de generación de amoníaco. Considerándose las condiciones experimentales en las que se llevó a cabo este estudio, se encontró que la cama de aserrín de madera del primer ciclo y la cáscara de café del primer y segundo ciclo, fueron las que presentaron mejor comportamiento en su relación C/N para su posterior utilización como compostaje. En cuanto a su capacidad contaminante, se encontró que a mayor reúso de las camas tanto de aserrín de madera como de cáscara de café, se presenta una mayor producción de amoníaco.*

Palabra claves: Cáscara de café, compostaje, industria avícola, aserrín de madera.

The continued growth of Brazilian agricultural production has resulted in activities that generate a larger amount of residues, which, due to poor management, could pollute the air, water and soil; therefore, the inclusion of sustainability concepts and environmental management is of great importance in this sector, mainly in poultry production (Avila *et al.,* 2007).

The adequate management of these residues, which have elevated contents of nutrients such as nitrogen, phosphorus, potassium and minerals, is extremely important, since they can act as important fertilizers for soil and have a minimal environmental impact on the soil, surface and groundwater (Rodrigues *et al*., 2012). However, when they are poorly managed, these residues have the potential to pollute the surface and groundwater and may also increase the content of suspended nutrients and organic substances that require oxygen and, in some cases, pathogenic microorganisms. Poor management can also affect air quality due to emissions of gases such as ammonia, odors, and dust (Singh *et al*., 2004).

In regions with a high concentration of poultry production, surplus litter is generated and disposed of in the environment, resulting in excessive nutrient levels in the soil. Since the countries of South America have a climate that allows for production in open aviaries, they offer perfect opportunities for reusing litter, which depends on the quality, volume and management (Avila *et al*., 2007). This contributes enormously to a reduction in excess litter that must be disposed of in the environment, as well as a reduction in the need to purchase other bedding materials, which are scarce in the market (Cumba, 2010).

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Various substrates are used as bedding: wood shavings, peanut and rice hulls, coffee husks, dry grass, and ground corn cobs, as well as many other materials (Grimes, 2004). Bedding composed of sawdust or wood shavings and coffee husks is the most common among farmers in many countries of South America since they provide all of the characteristics of good bedding.

The ecologically appropriate disposal of poultry residues requires studies on alternatives that address economic, technical, social and environmental aspects. Composting is included in these practices and may be employed as long as some safety parameters are adopted, i.e. without spreading disease in the region where the activity is performed (Costa *et al*., 2005), because many studies have demonstrated the feasibility of using poultry litter as fertilizer (Mello and Vitti, 2002). Font Palma (2014) reported that another alternative for the use of poultry litter is as a potential fuel candidate for thermal conversion technologies because it is an available source.

In order to obtain good compost, it is of great importance to consider the factors that influence the process. In this context, the most critical factor, besides aeration, is the C/N ratio, which should ideally be between 25/1 and 35/1. If the C/N ratio is too high, degradation may be hindered and, if it is too low, nitrogen is lost in the form of ammonia, which can be detected by its heavy odor (Kiehl, 2002; Jones *et al*., 2005).

Another important aspect regarding the contaminant potential of poultry litter is the nitrogen content, wherein ammonia and nitrates are the two chemical forms of nitrogen most common in poultry residues, which can result in poor thermal comfort conditions due to the air pollution inside facilities (Osorio *et al*., 2014; Osorio *et al*., 2009; Carvalho *et al*., 2011). Nitrates may be the compounds that most influence groundwater contamination when an excessive level of poultry litter is used as fertilizer. These nitrates are water soluble and are transported from the soil solution to the roots of the plants and also to the water table, which can contaminate underground drinking water supplies (Zhongchao and Zhang, 2004; Patterson and Adrizal, 2005), potentially causing severe environmental effects, such as soil acidification and eutrophication in water.

When nitrogen fertilizers, whether ammonia-based, resulting from a rapid conversion into other forms of ammonia or organic residues rich in ammonia, are applied to the surface of soils with a basic pH (alkaline or limed), a chemical reaction can cause the loss of nitrogen as NH_3 gas in a process called volatilization (equation 1). Also, the ammonium ion (NH_4^+) may be converted to nitrous oxide through processes of nitrification and denitrification, which is an important greenhouse gas (Blake and Hess, 2001).

$$NH_4^+ + H_2O + OH \longrightarrow NH_3(g) + 2H_2O \qquad (1)$$

Thus, with an increase in the number of cycles in which the poultry litter is utilized, a greater ammonia concentration capable of being volatilized is expected; however, no method is known for understanding its potential capacity in function of material and number of cycles of reutilization, resulting in a lack of studies in this field.

Based on the above information, the objective of this study was to assess two types of poultry bedding litter, wood shavings and coffee husks, and their quality as a function of increasing use cycles, along with the best time to proceed with composting based on the carbon/nitrogen ratio and understanding the ability to generate ammonia.

MATERIALS AND METHODS

This study was conducted on the Laboratory of Solid Residues and Rural Construction at the Department of Agricultural Engineering of the Federal University of Viçosa - Brazil, and the litter resulted from conventional commercial broiler production facilities in the integrated network from the companies Pif – Paf Alimentos S/A and Nogueira Rivelli Ltda. These facilities are located in the Zona da Mata region of Minas Gerais - Brazil, in the municipalities of Viçosa, Ubá, Barbacena, São Miguel do Anta, Canaã, Ubá, Rio Pomba and Rio Branco.

Samples of poultry litter were collected from 32 aviaries that were typologically representative of the companies during the summer and winter periods, between April and June (12 with natural ventilation, 10 with mechanical ventilation "negative pressure" type tunnels, and 10 with lateral pressure and natural ventilation); they are located in the Zona da Mata region of the state of Minas Gerais, which in turn is representative of the entire state and most Brazilian and South American poultry production, with densities of up to 13 female birds m^{-2} and 11 male birds m^{-2}.

Two types of the most commonly used bedding in these animal production installations were evaluated, wood shavings and coffee husks. Samples were collected in the last week of bird production in installations managed under the same working and climate conditions in order to obtain homogeneous and representative samples. For sample acquisition in evaluating the chemical and physical properties, 16 sampling points were selected in each of the 32 aviaries (Figure 1); sampling in areas near the feeders and waterers was avoided according to the methodology used by Singh *et al.* (2004).

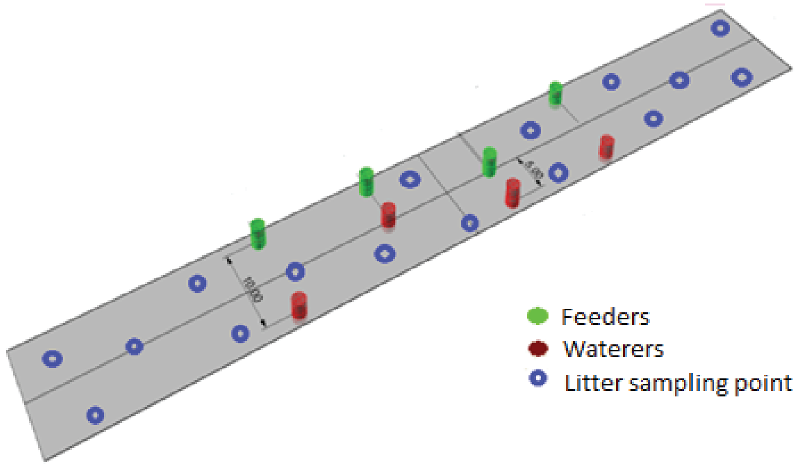

Figure 1. Points selected for litter sampling.

Evaluation of the chemical and physical properties. Each sample was homogenized, packaged and hermetically sealed to prevent moisture loss. The evaluation of the chemical and physical properties of each sample included: determination of moisture content and pH, quantification of compostable organic carbon, total nitrogen and ammonia.

To determine the pH and moisture content of the litter, the method recommended by the Brazilian Agricultural Research Corporation (2006) was used with the following equation to determine the moisture content:

$$U_{(w.b)} = \frac{(M_u - M_s)}{(M_u - M_r)} \times 100 \qquad (2)$$

$$U_{(d.b)} = \frac{(M_u - M_s)}{(M_s - M_r)} \times 100 \qquad (3)$$

where,

$U_{(w.b)}$ Moisture content (wet basis)
M_u Mass of moist material + M_r (g)
M_s Mass of dry material at 65°C + M_r (g)
M_r Mass of the recipient (g)
$U_{(d.b)}$ Moisture content (dry basis)

In order to determine the compostable organic carbon, the methodology used by Chan *et al.* (2001) was then applied along with the following equation:

$$C.O._{fo} = \frac{V_{DIC} - V_{SFA}\, x\, 0,003\, x\, f_c\, x\, N\, x\, 100}{m} \qquad (4)$$

Where

$C.O._{fo}$ easily oxidizable organic carbon (dag kg^{-1})
V_{DIC} volume of dichromate consumed (mL)
V_{SFA} volume of ammonium ferrous sulfate consumed (mL)
N normality of the solution (mol$_c$ L^{-1})
f_c correction factor

The method used to determine the total nitrogen (N_{total}) and ammonia nitrogen (N_{ammon}) of the samples was the salicylic acid method, also referred to as the official method or Kjeldhal method (AOAC, 1970)

Statistical analyses. This experiment was conducted using two bedding-litter types (wood shavings and coffee husks) as well as four reutilization cycles in a completely randomized design with four replications. The data were analyzed for ANOVA with the "f" test. Correlations between the variables C, N, C:N ratio, pH and moisture content as a function of the number of cycles were there performed.

RESULTS AND DISCUSSION

According to the data obtained in the analysis of variance, there was no significant breakdown between the type of bedding, and the pH and ammonia nitrogen, or between the number of utilization cycles of the bedding, the moisture and total organic carbon. The results on the interaction of the bedding type with the number of utilization cycles, moisture, pH, total nitrogen, total organic carbon, C/N ratio and ammonia nitrogen did not present any significant differences (Table 1).

Table 1. Analysis of variance of the evaluated parameters in the wood-shaving and coffee-husk bedding.

	D.F	Mean Square					
		Moisture ($U_{d.b}$)	**pH**	**Total Nitrogen (N_{total})**	**Total Organic Carbon (CO_{fo})**	**C/N Ratio**	**Ammonia nitrogen (N_{ammon})**
Bedding (Be)	1	1301.35 **	0.00065 NS	1.43 *	898.91**	418.44 *	0.000005 NS
Cycle (Cy)	3	197.90NS	0.69060 *	0.77*	93.50 NS	187.67 *	0.002371 *
(BexCy)	3	257.04 NS	0.05459 NS	0.17 NS	82.70 NS	48.22 NS	0.001391 NS
Error	24	131.59	0.18792	0.23	52.06	24.67	0.002725
C.V (%)		25.56	5.23	26.67	27.73	29.37	30.23

**F significant at 1%
*F significant at 5%
NS not significant at 5%

Figure 2 shows the behavior of the litter moisture content as a function of the number of cycles. The moisture content of both of the litters did present a tendency to decrease with the number of use cycles, with values between 48% - 22% in the wood-shaving litter and 80% - 37% in the coffee-husk litter. Oliveira *et al.* (2003) found a similar behavior to the results obtained in this experiment between the relationship existing for the moisture content (%) and the number of reutilization cycles for litter composed of wood shavings and coffee husks.

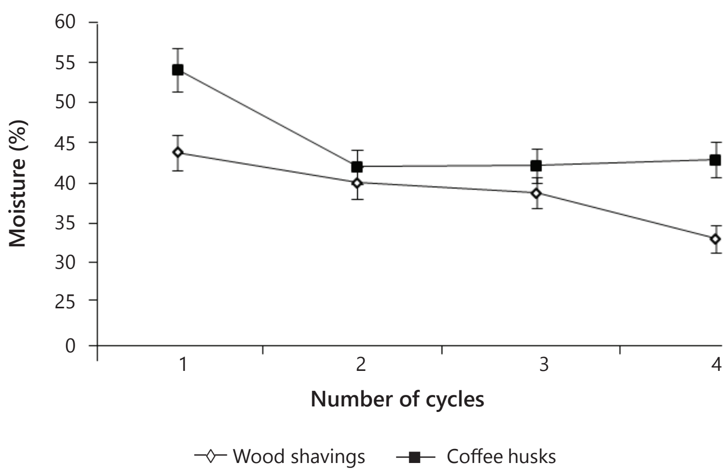

Figure 2. Relationship between the moisture content in dry basis and the number of reutilization cycles for litter composed of wood shavings and coffee husks.

The reduced moisture content as a function of the number of cycles may be due to the fact that, although there was constant depositing of feces and urine by the birds as well as a constant microbial processing of the organic matter, upon completing a poultry production cycle, fresh material was always added, which caused a collapse in the bedding moisture content. The decrease in moisture content in the two litters may also have been due to the fact that the experiment was performed during the summer; therefore, the temperatures both outside and inside the installation, as well as the heat generated during decomposition of the organic material, resulted in a loss of moisture from the residues through evaporation.

In Figure 3, it is observed that the pH values increased with reutilization of the litter, with values between 7 and 9. The pH results indicated that the different litter use cycles differed statistically, but there was not a significant difference between the litter types.

The results obtained for the relationship between the pH and number of cycles were likely due to the fact that, in each use of the litter, a large quantity of excretions (nitrogen) from the birds was added, but the coffee husk litter was only supplemented in very large amounts in the first cycle of use and in small quantities during the start of new cycles in which the litter was reused. Another explanation is seen in the microbial action, given that, during the process, as a function of the exiting reactions (organic acids reacting with bases released by organic matter), the pH of the mass increased, reaching values greater than eight (alkaline), as reported by Pereira and Mesquita (1992).

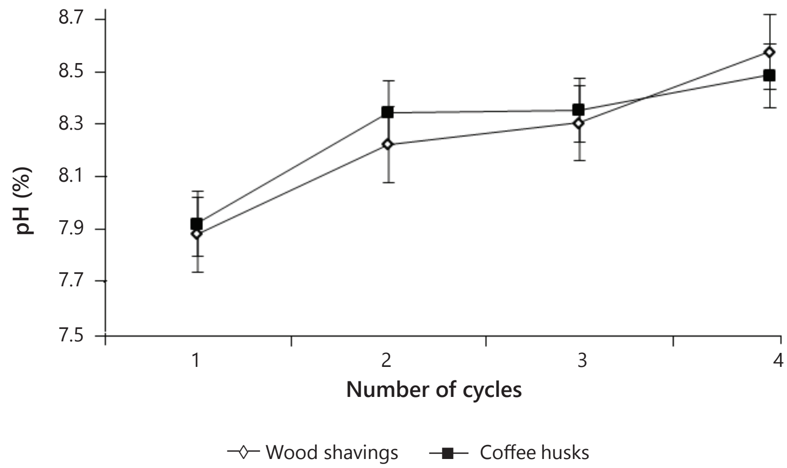

Figure 3. pH values in relation to the number of cycles for litter composed of wood shavings and coffee husks.

Figure 4 indicates that the value of the total organic carbon ($O.C._{eo}$) in the two evaluated beddings reflects a tendency to decrease with each reutilization, with values of the two litters in the first and fourth cycle varying between 32 and 18 dag kg^{-1}. Concentrations of N_{total} encountered in the two evaluated beddings in the experiment presented a maximum level of 1.63 dag kg^{-1} of N in the wood-

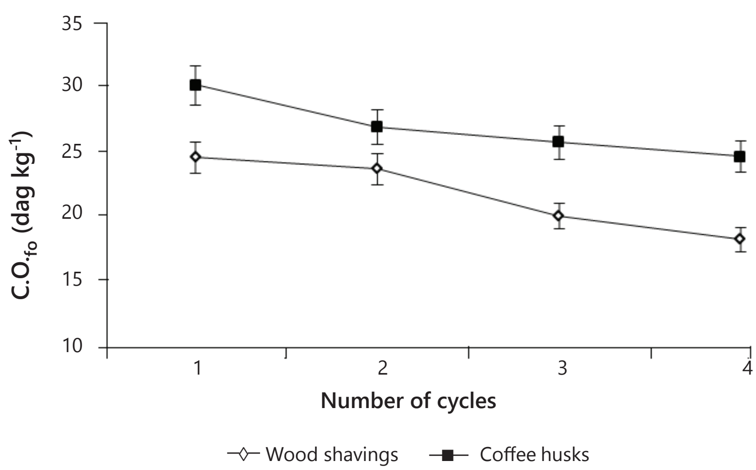

Figure 4. Values of total organic carbon ($C.O._{fo}$) in relation to the number of cycles of wood shavings and coffee husks.

shaving litter and 1.93 dag kg^{-1} of N in the coffee-husk litter (Figure 5).

The difference in the Ntotal encountered for the two beddings as a function of the number of cycles may have been due to the fact that coffee husks have a greater nitrogen content, which, when combined with excretions from the birds, significantly increases its concentrations, as compared to wood shavings. The particle size of wood shavings also stimulates a more rapid degradation of organic material, resulting in nitrogen losses in the form of ammonia gas. Santos (1997) evaluated litter composed of wood shavings with two cycles of bird production and encountered total nitrogen levels (N_{total}) of 2.08 dag kg^{-1} and 2.54 dag kg^{-1} in litter from the first and second cycles, respectively; results that differ from those obtained in this experiment.

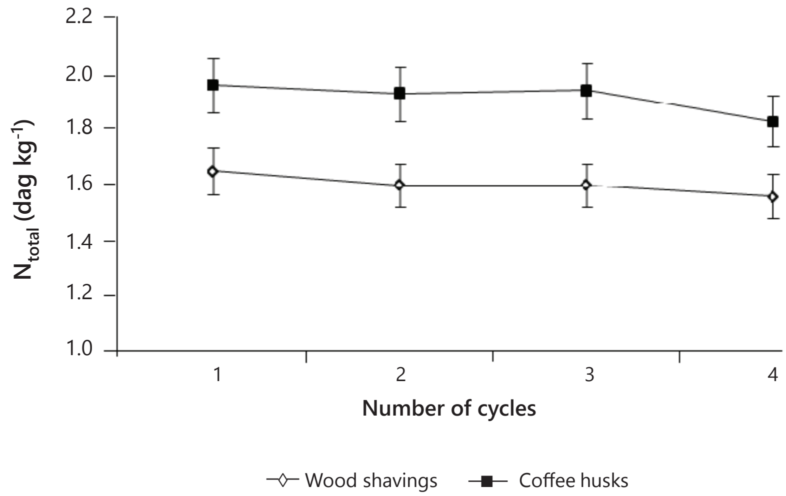

Figure 5. Total nitrogen values in relation to the number of cycles of the wood-shaving and coffee-husk litters.

Figure 6 presents the results obtained in relation to the concentration of the ammonia nitrogen (N_{ammon}) as a function of the number of litter reutilization cycles. It was found that, for both litter types, there was a tendency for an increase in the quantity of N_{ammon} as a function of the number of cycles, with an absence of significant differences between the litter types.

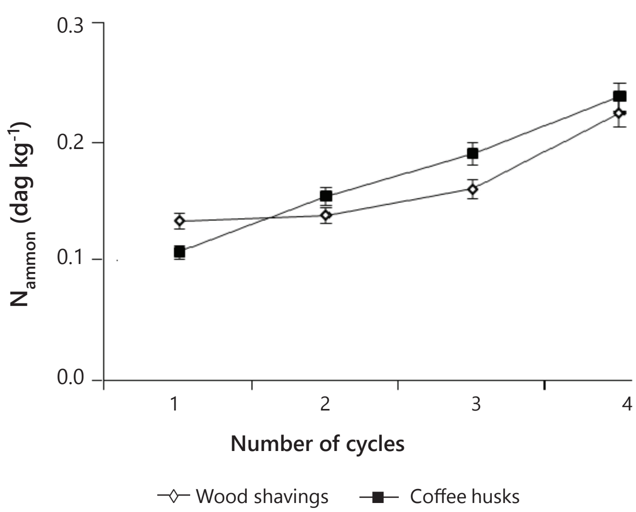

Figure 6. Concentrations of N_{ammon} as a function of the number of cycles of wood shavings and coffee husks.

In Figure 7, N_{ammon} values as a function of the pH of the wood shavings and coffee husks can be observed. It was found in both cases that there was a direct relationship between the N_{ammon} and the pH, which predicted the trend according to the equations shown in Figure 7. The relationship between the N_{ammon} and pH presented a behavior similar to the one observed by Miles *et al*. (2011). According to Vale *et al*. (1997), when the concentration of N_{ammon} increases with an elevated pH, potentially due to the liberation of N_{ammon} through volatilization, it might return to the soil mass, a behavior which may have occurred in the results of this study.

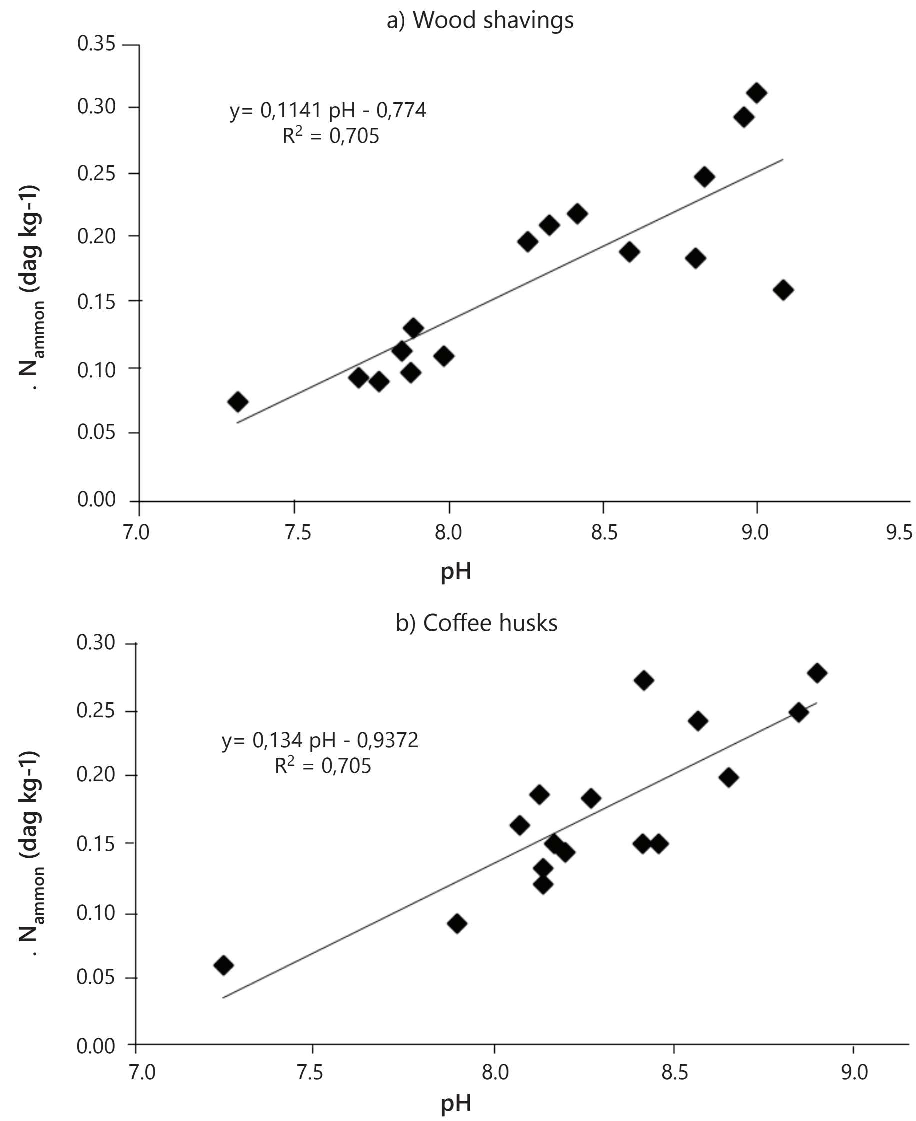

Figure 7. N_{ammon} values as a function of the pH: a) wood shavings; b) coffee husks.

Regarding the results of N_{ammon} shown in Figures 6 and 7, according to Blake (2001), N_{ammon} that is formed in the bed can be encountered in two forms: as ammonia (NH_3) (uncharged) or with an ammonia ion (NH_4^+). For litter with a greater pH, there is a lower conversion of NH_3, which is volatile. In this case, there were significant increases in the pH, which may have permitted volatilization of the ammonia for both bedding types.

In the results obtained in this experiment for both litter types, there was a lower concentration of ammonia nitrogen (N_{ammon}) when the pH was neutral and there was a greater concentration for the more alkaline pH levels, which may have been attributed to the fact that N_{ammon}, together with pH, tends to increase with each reuse of the litter, and the moisture content and temperature were not encountered at sufficiently high levels for N losses as ammonia gas; similar behavior was found by Oliveira *et al*. (2012) and Fioreze and Ceretta (2006). Due to this behavior, the contamination potential increased with the number of reutilizations of both materials, the wood-shaving and the coffee-husk litters, resulting in greater ammonia emissions; but significant differences were not detected between the bedding types.

It is observed from Figure 8 that, independent of the litter cycles, the C/N ratio was always greater when the coffee-husk litter was used, as compared to the wood-shaving litter. In both cases, the C/N ratio decreased with the number of reuses. In the first and second cycle of the litters, the C/N ratio for the litter of wood shavings and coffee husks, was 22:1 and 18:1, respectively. In cycles 3 and 4, this ratio decreased, reaching a proportion of 9:1. Although the litter from the third or fourth cycle can also be used to start a composting process, the addition of other residues with a higher C/N ratio would be required to reach the established ideal high range (25:1 – 35:1).

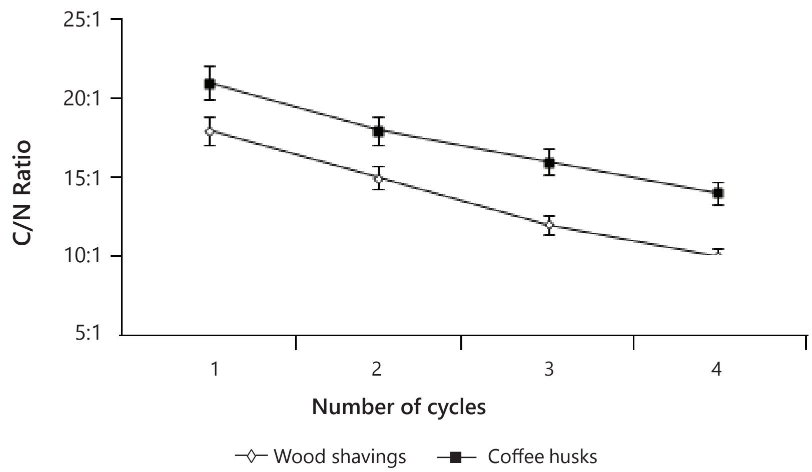

Figure 8. C/N ratio of the wood-shaving and coffee-husk litters as a function of the number of cycles.

The C/N ratio was analyzed as a function of the number of litter reutilization cycles to determine which cycle presented the best value for use as an organic fertilizer, and it was found that the carbon/nitrogen ratio tended to decrease as the number of times the litter was used increased. The explanation for this fact is that, in both beddings, there was a rapid decomposition of the organic matter, which led to a decrease in the carbon and a bigger release of total nitrogen per litter reutilization cycle, in agreement with the observations of Aquino *et al*. (2005).

According to the C/N ratio, in terms of the fertilizer potential, the wood-shaving litter from the first cycle and the coffee-husk litter from the first and second cycles presented the best behavior for use as a compost material. For both litter types, wood shavings and coffee husks, the higher the number of litter reutilization is, the lower the concentration of the total organic carbon is and the greater the concentration of the total nitrogen is, which influences the reduction in the C/N ratio. According to Kiehl (2002), this type of behavior may have been due to the mineralization process, which generates the decomposition of organic compounds.

CONCLUSIONS

The behavior of wood-shaving and coffee-husk as poultry bedding litters, as a function of the number of cycles, had not been reported before this study. Contrary to the common belief of poultry producers, the results showed that increasing the number of reutilizations of both materials resulted in a greater ammonia emission. However, there was not significant difference between the litter types; the N_{ammon} content of the coffee-husk litter was higher than expected.

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