Journal of Agricultural Science; Vol. 12, No. 3; 2020
ISSN 1916-9752 E-ISSN 1916-9760
Published by Canadian Center of Science and Education

Poultry Farming Practices Affect the Chemical Composition of Poultry Manure and Its C and N Mineralization in a Ferric Acrisol

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Received: December 7, 2019 Accepted: January 9, 2020 Online Published: February 15, 2020

doi:10.5539/jas.v12n3p95 URL: https://doi.org/10.5539/jas.v12n3p95

Abstract

Industrial poultry farming is a booming sector in Africa. This activity generates a significant amount of manure that could be used to improve crop yields on low-productivity soils. We wanted to characterize the variability in the chemical composition of poultry manure and its ability to release mineral nitrogen when applied to soils compared to other organic sources of nutrients such as cattle manure and human feces. We conducted a survey in 79 poultry farms to characterize their practices such as the type of poultry raised, the type of feed and the bedding litter. Poultry manure, cattle manure and human feces samples were collected and analyzed to determine their chemical composition. An incubation study was conducted with all three types of organic resources for 91 days to measure mineral nitrogen release. We found that agricultural practices explain more than 60% of the chemical composition of poultry manure. Wood chips were the most common bedding litter (77% of cases) and about 70% of farms use industrial poultry feed. Broiler manure contains more C and N than laying hens that contain more Ca. Poultry manure releases nitrogen faster than cattle manure when applied to the soil. A combination of broiler chicken manure and laying hen manure could be more beneficial to the crops.

Keywords: poultry manure, Ferric Acrisol, incubation, mineral nitrogen release

1. Introduction

In addition to poor weather conditions and low fertility soils, agriculture in sub-Saharan Africa suffers from low mineral fertilizer inputs (Yasuhiro et al., 2019) resulting in low yields. Indeed, the quantities of mineral fertilizers applied are well below the quantities declared for other regions of the world. For example, the amount of nitrogen per hectare of cultivated land is less than 15 kg ha^{-1} in Africa compared to more than 100 kg per hectare in Asia (Ciceri et al., 2019). Several reasons are often cited to explain this low level of mineral fertilizer use, including low farmer income, lack of subsidies, inappropriate agricultural policies, and poor market access (Mugwe et al., 2019).

In such a context of farmers' inability to purchase mineral fertilizers, local organic resources remain the main source of nutrients for soil fertility management and agricultural production. The use of organic resources in agriculture is particularly relevant for the majority of soils in sub-Saharan Africa such as Ferric Acrisol, given their low aggregate stability, low organic matter content and low cation exchange capacity (Traoré et al., 2016). Therefore, the functioning of these soils and their ability to produce a good yield rely strongly on the quantity and quality of the organic resources applied.

While organic resources are important to improve the productivity of Ferric Acrisol, their availability and quality according to their origin remains a major challenge. Crop residues, due to the high demand for animal fodder, energy and other domestic uses, are exported from the fields, leading to nutrient mining when there is no return to the soil. The use of manure from small and large ruminants is limited by their low availability, especially when the animals are not in housing, which is the most common case in small farms. Composting has long been promoted as an option to produce good quality organic matter and also to solve the problem of lack of organic resources by combining different sources of animal and plant origin. For example, in Burkina Faso, the government launched the operation of compost pits in 2001 to promote the use of organic resources on farms (Lompo et al., 2009). However, the lack of water, labour for the transport of organic resources and regular turning of the compost limit the adoption of this technology by farmers.

Among the organic resources, poultry manure from industrial farms is a potential available source. Indeed, on the outskirts of African cities, the poultry industry has grown so rapidly over the past decade due to the high food demand associated with rapid population growth. The development of this sector has created an important source of organic resources that can be used to improve soil productivity, particularly in peri-urban and semi-rural areas close to these organic resources. In Burkina Faso, the number of poultry heads is estimated at about 36.5 million (MRA, 2009). Coulibaly et al. (2018) showed in the Bobo-Dioulasso region, the second largest city in Burkina Faso, that extensive poultry farming, estimated at about 70% of farms, produces about 5 kg of manure per head of poultry per year, whereas for intensive livestock production this production can reach 19 kg. Considering the poultry population estimate by MRA (2009) and by Coulibaly et al. (2018), we can expect about 300,000 tons of poultry fertilizer per year. According to Coulibaly et al. (2018), the amount of poultry manure is estimated at about 35% of the total organic resources produced on farms.

Various materials are used as bedding in poultry farming. The quality of these materials such as their absorption capacity have an impact on poultry productivity (Garcia et al., 2012; Munir et al., 2019). Differences in poultry moisture have been observed with different bedding materials (Shepherd et al., 2017). Miles et al. (2011) have shown that the higher the humidity in the litter, the greater the loss of nitrogen by volatilization.

While much work has been done specifically on the impact of bedding materials on poultry productivity and nitrogen losses, little has been done on the overall practices of poultry farmers and their impact on the agronomic value of poultry manure (Dexter et al., 2019). In this study, we hypothesized that: i) the diversity of farming practices explains a large part of the variability of the chemical composition of the poultry manure, ii) among the farming practices, the type of bedding material is an important factor determining the chemical composition of the poultry manure and iii) the type of bedding determine the C:N ratio of the poultry manure leading to differences in nitrogen mineralization.

2. Material and Methods

2.1 Survey and Sampling

The study was conducted at the poultry farms located at the vicinity of the city of Ouagadougou in Burkina Faso (12°30′ and 12°25′ North latitude and 1°27′ and 1°35′ West longitude) at the communes of Komsilga, Pabré, Loumbila, Saaba, Koubri, Tanghin Dassouri, Sourgoubila, and Komki-Ipala. A survey was conducted in 79 poultry farms with an average of about 8 farm per commune. For a given commune a first farm was identified as a starting point of the survey and then the next farm was identified with the help of the previous farmer. Each farmer was questioned about the livestock practices namely the size of the farm, the type of poultry raised, the type of feed, the type of bedding litter used, the frequency of bedding litter change, the use of vaccine, the management strategies of the manures.

At each poultry farm, the manures were sampled at three points in the barns along the diagonal and mixed to yield one composite sample. For manures outside the barns and stored in pits or piles, samples were taken at different depth and points and a composite sample was also made for each type.

2.2 Incubation Study

The incubation study was conducted in laboratory at the research station of INERA Kamboinsé. A Ferric Acrisol from the long term field trial of Saria receiving 5 t ha^{-1} of manure every second year was used. This soil according to Kiba (2012) has a pH of about 5.8 and contains 3.73 g kg^{-1} of total C and 320, 149 and 32 mg kg^{-1} of total N, P and available Bray I P, respectively. The following treatments were considered: Control: non amended soil; LCNrD: soil + manures with low C:N ratio (17 to 21); HCNrD: soil + manures with high C:N ratio (41 to 82); CAM: soil+ cattle manure; HMF: soil+ human feces. The cattle manure was collected from a farm located at the vicinity of Ouagadougou and the human feces collected from popularized latrines within the ecological sanitation project (ECOSAN). For each sample, a carbon content of 2 g C from the substrate/kg dry soil was targeted when applying the organic substrates (AFNOR, 2009). According to this method, 35 mg N per kg of dry soil in the form of KNO_3 was also applied at the beginning of the incubation to ensure that the decomposition of the organic substrates will not be nitrogen limited.

After the application of the organic substrates and the KNO_3 the samples were moistened at 45% water holding capacity. For each sample of organic substrate 3 replicates were considered. An amount of 25 g of each treated soil was then placed in hermetically sealed jars. Two beakers, one containing 20 ml of NAOH 0.1 N to trap the

CO_2 released and another one containing 20 ml of water to maintain the moisture were also placed in each jar. The jars were then placed in an incubator at 25 °C. The CO_2 emission was measured at 1, 3, 7, 14 and 21 days after incubation. For each sample the mineral nitrogen (NO_3^- and NH_4^+) was also extracted at 0, 7, 14, 28, 49, 70 and 91 days of incubation and measured.

2.3 Chemical Analyses

The pH in water of the different substrates was measured with a glass electrode pH meter and direct reading in a substrate/solution ratio of 1/2.5. The total C of the organic substrates was determined by weight loss after a calcination at 550 °C during 2 hours using an electrical furnace CARBOLITE. The total elements N and P contents of the composts were determined by an automatic colorimeter SKALAR (Skalar SANplus Segmented flow analyzer, Model 4000-02, Breda, Holland) after a wet digestion using the Kjedhal method adapted by Novozansky et al. (1983). The total potassium was determined in the digested samples by a JENCONS flame emission spectrophotometer using the method proposed by Walinga et al. (1989) while the total Ca, Fe, Mg, Zn, Mn were measured by atomic absorption spectrometry using the method proposed by Pinta (1973). The mineral nitrogen of the incubated samples was extracted using a potassium chloride solution at a ratio of 10g treated soil in 100 ml of KCl and measured in colorimetry with the SKALAR as described above.

2.4 Statistical Analyses

A non-parametric Kruskall-Wallis test was performed to compare the chemical composition of the poultry manure according to the poultry farming practices using GenStat 9.2. In the incubation study, one way analyze of variance was performed to compare the mean chemical composition of the two types of poultry manures, the cattle manure and the human feces using also GenStat 9.2. Principal Component Analysis was performed to study the variability of chemical composition of the poultry manures across the farms using CANOCO 5.1. A redundancy analysis using CANOCO 5.1 was performed to summarize the variability of the chemical composition and moisture of the poultry manures explained by poultry farming practices. The qualitative information was encoded as dummy variables using 1 for the presence and 0 for the absence.

3. Results

3.1 Poultry Farming Practices

The Table 1 shows that two types of poultry manures were encountered. These were manures not mixed with litter accounting for about 6% and manures mixed with various types of litter accounting for about 94%. The types of litter used for bedding were wood chips, rice bran, rice husk and peanut shells encountered in 77.5%, 4.5% 16.9% and 1.1% of cases, respectively. The raising of laying hen was the most important practice (55.7%) followed by broiler chicken (27.8%). The majority of the farms feed the animals with industrial food (70.9%) while about 20.3% of them produce the food locally.

Table 1. Poultry farming practices in percentage of cases in the peri urban areas of Ouagadougou, Burkina Faso

Manures purity		**Type of litter**		**Type of poultry**		**Type of feeding**	
Mixed with litter	93.7%	Wood chips	77.5%	Laying hen	55.7%	Local food	20.3%
		Rice bran	4.5%	Broiler chicken	27.8%	Industrial food	70.9%
Not mixed	6.3%	Rice husk	16.9%				
		Groundnut shell	1.1%	Other	16.5%	Both	8.9%

3.2 Variability of Farms According to the Chemical Composition of the Poultry Manures

The diversity of the farms is explained by about 50% of the chemical composition of their poultry manures (Figure 1). The horizontal axis explaining about 26% of the variability was correlated with the major nutrients N, P and K while the vertical axis explaining about 22% of the variability was correlated by the total carbon, pH, secondary and micro-nutrients.

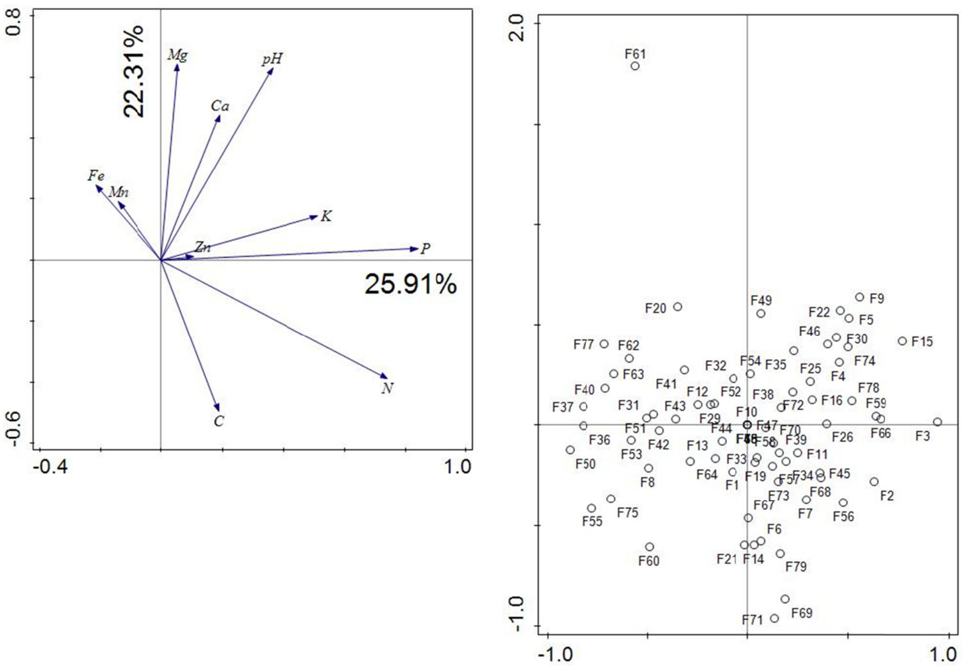

Figure 1. Principal component analysis showing the variability of chemical composition of the poultry manures across the farms at the periphery of Ouagadougou, Burkina Faso. The arrows indicate the chemical composition; the circles indicate the farms

3.3 Variability of the Poultry Manures as Affected by Livestock Practices

Livestock practices explained about 60% of the variability in moisture and chemical composition of poultry manures (Figure 2). The horizontal axis explaining about 34% of the variability was correlated with turkey, guinea fowl farming and the use of rice straw as litter. The vertical axis explaining about 26% of the variability was correlated with the rearing of laying hens and local chickens. The Zn content of poultry manures was positively correlated with the absence of litter and the rearing of quail. The C content was positively correlated with the use of rice husk and wood chips as bedding. Ca content and pH were positively correlated with the rearing of laying hens. The Fe content was positively correlated with guinea fowl rearing. The content of N, P, K, Mg in poultry manure were positively correlated with the use of the vaccine and negatively correlated with the rearing of local chickens and mixed breed chicken. The type of food, whether produced locally or by industry, had little influence on the variability of the chemical composition of the manures.

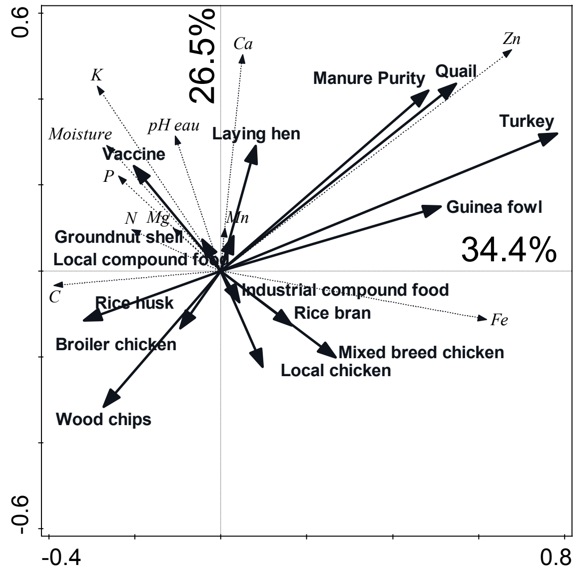

Figure 2. Redundancy analysis summarizing the variability of the chemical composition and moisture of the poultry manures explained by poultry farming practices at the periphery of Ouagadougou, Burkina Faso. The dotted arrows indicate the chemical composition; the bold arrows indicate the livestock practices

3.4 Chemical Composition of the Poultry Manures

The chemical composition of the poultry manures was not affected by most of the livestock practices (Table 2). Significant differences were only observed for the total C, N and Ca contents between the manures from laying hen and those from the broiler chickens. Indeed, the manures from broiler chickens showed the highest C and N contents while the manures from laying hen showed the highest Ca content.

The comparison between selected high and low C:N ratios manures, cattle manure and human feces (Table 3) showed significant differences for the contents of C, N, P, Fe, Mg, Zn, pH, C:N ratio and no differences for K, Ca and Mn contents. Human feces had the highest pH, the highest Mg, Zn contents, the lowest C content and the lowest C:N ratio. The lowest N content was measured in the high C:N ratio poultry manures and the human feces while the lowest P content was measured in the high C:N ratio poultry manures and the cattle manure. Excluding Fe, all measured elements had low levels in poultry manure with a high C:N ratio compared to poultry manure with a low C:N ratio.

Table 2. Chemical composition of poultry manures as affected by the livestock practices. LHM: laying hen manures; BCM: Broiler chicken manures

Poultry farming practices	C	N	P	K	Ca	Fe	Mg	Zn	Mn	pH	C:N
	--------------------------- gkg^{-1} ---------------------------							----- $mgkg^{-1}$ -----			
Type of poultry											
LHM	385	14.6	7.2	19.5	14.2	7.6	5.1	214	298	7.7	30.3
BCM	452	18.2	8.6	21.0	9.0	6.9	6.1	145	193	7.6	30.0
p value[1]	**	*	*NS*	*NS*	***	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
Barn litter type											
Wood ships	405	15.7	7.5	19.3	11.6	8.7	5.4	144.2	262.7	7.6	30.2
Other litter	351	15.3	7.1	21.2	15.2	10.7	5.1	426.6	271.3	7.6	24.6
p value[1]	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
Type of feed											
Industrial	407	17.8	7.4	21.4	13.9	8.2	6.1	184.8	397.5	7.7	30.3
Local	394	15.0	7.4	*19.0*	11.6	9.2	5.2	183.0	225.7	7.6	26.3
p value[1]	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*

Note. [1]Kruskal-Wallis non parametric test Chi-square probability.

Table 3. Chemical composition of poultry manures, cattle manure and human feces used in soil incubation study. LCNrPM: Low C:N ratio poultry manures; HCNrPM: High C:N ratio poultry manures, CAM: Cattle manure; HMF: Human feces; Pro: Probability; LSD: Least significant difference

		LCNrPM	HCNrPM	CAM	HMF	*Pro*	*LSD*
C		420	386	446	75.1	<0.001	82
N		20.2	5.42	13.5	8.80	<0.001	5.21
P		13.1	2.76	1.75	8.61	<0.001	2.24
K	gkg^{-1}	22.8	19.8	19.5	25.9	0.402	9.31
Ca		14.8	8.62	5.22	10.7	0.220	9.65
Fe		7.30	14.1	4.36	4.27	0.003	4.52
Mg		5.81	3.99	3.28	15.0	<0.001	4.03
Zn	$mgkg^{-1}$	157	176	126	857	<0.001	139
Mn		405	255	224	378	0.450	294
pH		8.0	7.8	8.3	9.3	<0.001	0.5
C:N		21.2	75.4	34.3	8.7	0.002	25.4

3.5 Mineralization of Poultry Manures

The incubation study (Figure 3A) showed a decrease in CO_2 emission from day 1 to day 3 in the control treatment, cattle manure and human excreta, while an increase was observed with poultry manures with high and low C:N ratios. Cattle manure and control treatments reached the CO_2 emission peak at 7 days of incubation while for other treatments, the peak was reached later at 14 days of incubation. The treatments were distributed as follows with regard to the CO_2 emissions Human feces < cattle manure < Low C:N poultry manure < High C:N poultry manure ratio.

The highest nitrogen release during the incubation period (Figure 3B) was observed with human feces up to 14 days, from which time the release increased with poultry manures with low and high C:N ratios. A decrease in nitrogen release was observed with cattle manure, which led to the lowest release, even below the control treatment, between 0 and 7 days of incubation before it started to increase.

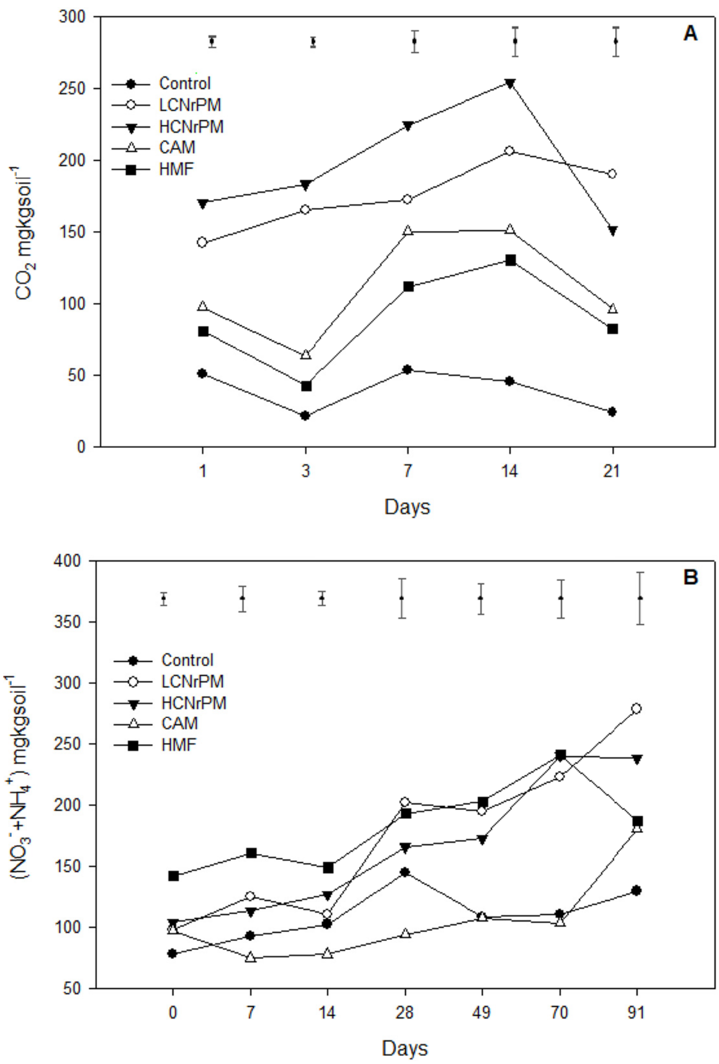

Figure 3. CO_2 (A) and mineral nitrogen (B) release in soil amended with poultry manures, cattle manure and human feces during a soil incubation. LCNrPM: Low C:N ratio manures; HCNrPM: High C:N ratio manures; CAM: cattle manure; HMF: human feces; Error bars are LSD:5

4. Discussion

4.1 Diversity of Poultry Farming Practices

The choice of litter type depends on many factors such as cost, availability, ease of handling, reusability, absorption capacity (Garcia et al., 2012). In our case, wood chips are an available material that can be collected from wood industries. Rice husks are available ressources at farm level probably because they are difficult to compost given their high C:N ratio and also because this biomass is not recommended to feed animals due to their low cellulose and sugar contents (Thiyageshwari et al., 2018). The study of Garcia et al. (2012) also showed that the use of wood chips and rice husk as bedding materials was the best option for Brazilian poultry farmers who base their judgment mainly on the possibility of reuse, followed by ease of handling and cost. It is interesting to notice that farmers' criteria for selecting litters are based on their ability to improve poultry productivity rather than obtaining good poultry manure. One of the main differences between laying hens (55.7% of cases) and broilers (27.8% of cases) is the length of time they are kept, which can influence the quality of manure. In most cases, broiler chicken rearing lasts about 45 days, whereas with laying hens, it can take up to 24 months.

4.2 Effects of Poultry Farming Practices on Poultry Manure Chemical Composition

The highest level of micronutrients such as Zn in pure manure, mainly quail manure, is due to the fact that the contents are not diluted by the addition of bedding materials. With the poultry farming practices studied, we were able to explain about 60% of the variability in the chemical composition and moisture content of poultry manure with the two canonical axes suggesting that the production of good poultry manure for agronomic purposes should be achieved through better chickens breeding practice. Rice husks and wood chips as bedding, due to their high carbon content, have increased the C content in poultry manure. The fact that litter influences the chemical composition of poultry manure is known (Bolan et al., 2010). Poultry farmers to obtain solid eggs enrich chicken feed with certain products such as bone meal and egg shells. Waheed et al. (2019) have shown that egg shell waste is an important source of Ca that can be used for food fortification and the production of calcium-rich food sources. This explains the high Ca content of laying hen manure compared to broiler chicken. Our results show that, whether it is the use of industrial or local food, the chemical composition of poultry manure does not change significantly. This suggests that farmers have a certain level of knowledge to produce good quality food locally assuming that industrial and homemade feed have the same quality. It is logical to believe that healthy poultry release the best excreta and therefore to understand the positive relationship between vaccine use and manure N, P, K and Mg content. Clearly, these vaccines have been used more for purebred chicken than for mixed and local chicken. The high C and N content of broiler manure compared to laying hen manure is due to the short breeding time of broiler chicken, which does not allow a long period of manure mineralization. Poultry manure with a high C:N ratio probably received more litter than that with a low C:N ratio, which explains the low nutrient levels due to a dilution effect. High nutrient levels in poultry manure with a low C:N ratio compared to cattle manure support the conclusions of Saha et al. (2007). The higher P content in poultry manure compared to cattle manure is due to the fact that cereals known to have a high P (phytate) reserve are an important part of poultry feed.

4.4 Nitrogen Mineralization of Poultry Manure

Poultry manure with a low C:N (21) or high C:N (75) ratio is better mineralized than cattle manure, as evidenced by the higher release of CO_2 and mineral nitrogen. Previous studies have also shown the high mineralization potential of poultry manure applied to the soil (Shah et al., 2013; Abbasi & Khaliq, 2016). In addition to the C:N ratio, the C form is also an important factor determining the mineralization potential of the organic amendment. Cattle manure is a combination of cattle excrement and the rest of cereal straw, which can contain a large amount of lignin known to contain component difficult to mineralize and is therefore an important factor in the decomposition of litter (Yue et al., 2016). Abbasi and Khaliq (2016) reported lignin levels 2 times higher in wheat straw than in poultry manure, respectively. These recalcitrant components may have created mineral nitrogen immobilization from day 7 to day 50, as our results show. Such immobilization induced by the application of C from dairy cow manure has also been demonstrated by Griffin et al. (2005). Human feces due to their low C:N ratio and probably the absence of recalcitrant components are easily mineralized as evidenced by the high release of mineral nitrogen during the incubation period. Our results suggest that poultry manure and human feces are potential and better sources of nitrogen for plants than cattle manure.

5. Conclusion

Poultry manure is an important source of nutrients that can be used to improve the productivity of Ferric Acrisol. These sources release mineral nitrogen faster than cattle manure when applied to the soil. The quality of poultry manure is influenced by the farming practices, which account for more than 60% of the variability in their chemical composition. It was found that the manure of broiler chicken contained more C and N than that of laying hens, which contained more Ca. These results suggest that a combination of these two types of poultry manure could be more beneficial to crops.

Acknowledgements

The study was financed by the “Fonds National de la Recherche et de l’Innovation pour le Développement (FONRID)”. The authors are gratefull to Moyenga Momini and Ramdé Martin for their technical support to the laboratory.

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