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ORIGINAL RESEARCH

Evaluation of microbial activity, N-NH_3 and CO_2 losses in poultry litter treated with basalt rock powder

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Abstract

Purpose Poultry litter (PL) and basalt rock powder (BRP) are raw materials highly produced in some Brazilian regions. The association of these products can generate greater added value for the agribusiness chain and be a sustainable source of fertilizer.

Method The experiment consisted of an incubation trial over time for chemical characterization of the materials. The treatments used were the mixtures 10, 20, 30, 40, and 50 g of BRP per 100 g of PL, as well as the pure PL and BRP controls. During the incubation period, the atmospheric releases of CO_2 (40 days) and N-NH_3 (43 days) were determined. At the end of the process, the chemical quantification of the essential elements in all treatments was performed.

Results In our study, we observed that adding 30% of BRP to the PL promoted less volatilization and a faster stabilization of the N-NH_3 release, associated with a greater release of CO_2 into the atmosphere. The extractable P and K contents decreased starting with treatment T30. The T10 treatment showed the highest total nutrient contents, although it showed no statistical difference for some nutrients when compared with PL.

Conclusion The use of up to 30% of BRP in PL can be an economic and advantageous alternative for sustainable agricultural fertilization.

Keywords Ammonium, Organic fertilizer, Sustainability, BRP, Composting

Introduction

The worldwide demand for fertilizers is a reality due to the increase in agricultural production. Natural inputs, both organic and mineral, can meet this demand as long as the available nutrient contents are compatible with the ones in products found on the market (Reetz 2017). For this, it is necessary to know their chemical compositions and allocate their uses according to agricultural aptitude (Silva 2017).

Silva et al. (2011) reported that the rising cost of commercial fertilizers and the increase in environmental pollution made the use of organic waste in agriculture an attractive option from an economic point of view due to the cycling of nutrients. These facts generate an increased demand for information in order to evaluate the technical and economic feasibility of using some of

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these residues in agricultural soils (Santos et al. 2011). This scenario highlights the waste generated in the livestock chains: poultry, pigs, and cattle, where these will return to nature properly, that is, without impacting the environment (Correa and Miele 2011; Kyakuwaire et al. 2019).

Brazilian poultry farming represents 2% of the country's gross domestic product (GDP) (Avicultura Industrial 2020). Poultry farming releases considerable waste into the soil and the environment, and poultry litter is the one that stands out the most. Poultry litter is a material composed mainly of sawdust or rice straw together with feces, urine, feed scraps, and feathers, thus being considered an animal product (Dutra et al. 2005; Kyakuwaire et al. 2019). Its main nutrients are N, P, and K, components that are also the basis of the main mineral fertilizers, of which 60% are imported, with high cost for acquisition (Brasil 2019).

Fávero (2012) analyzed various poultry litters to observe the potential increase in the amount of nutrients in the soil. It was reported that the most significant soil contents were P, K, and S. This release was linked to two biochemical processes in poultry litter: the volatilization of ammonia (NH_3) and the loss of carbon dioxide (CO_2) to the environment. Medeiros (2007) and Dunlop et al. (2016) explained that ammonia gas emissions can negatively influence both the poultry house and the rural and urban communities near them. These N losses involved in NH_3 volatilization can vary widely, ranging from 3 to 60% of the total N applied (Sharpe et al. 2004). N losses are highly dependent on environmental conditions and the management employed during the application of nitrogen fertilizers, influencing the availability of N and other nutrients in the raw material (Meisinger and Jokela 2000). Carbon (C) content is useful to evaluate the degree of residue humification since, with an increased composting time, there is a decrease in the organic matter (OM) content of the compost (Dias et al. 2010). The quantification of organic carbon content allows one to determine the C/N ratio, which is one of the regulating factors of the composting process (Jiménez and García 1989).

The industry has several processes to modify the chemical structure of their residues so that they can be applied to the soil and, consequently, an increase in productivity. Many products are applied to the soil to increase productivity, but some stand out for improving the performance of other products. Basalt rock powder (BRP) is a material of mineral origin that, by weathering processes suffers a reduction in its volume, altering its structure and mineral constituents. This means BRP promotes changes in the fertility index through the addition of released macronutrients and micronutrients and improves the physical and biological properties of the soil (Lobato 2020). In its mineralogical composition, BRP has the predominance of Silicon Oxide (SiO_2), as well as CaO, MgO, and K_2O. In addition, a significant part of these minerals occurs as small or amorphous crystals, which accelerates the solubilization of the elements contained in their structure (Brasil 2016).

In view of the chemical, physical, and biological improvements promoted by BRP application in soil, its use in agriculture is gaining acceptance in the scientific community, mainly as a nutrient source (Zhang and He 2006). Although there are studies to quantify the benefits of the use of BRPs on chemical, physical, and biological properties of the soil (Melo et al. 2012; Mancuso et al. 2014; Martins et al. 2015; Luchese et al. 2021), the possibilities of associating this material with other agricultural residues to create a synergy of both are yet insufficiently studied. Thus, the objective of this work was to evaluate CO_2 release and NH_3 volatilization over incubation time and chemically analyze mixtures with different proportions of BRP and poultry litter for use in agriculture.

Materials and methods

The experiments were conducted at the Federal University of Paraná, Palotina and consisted of an incubation trial for chemical characterization of the materials. The poultry litter was obtained from poultry farms in the Western Region of Paraná and collected at the end of 12 lots.

The basalt powder used as a soil BRP was the RENUTRI® and belonged to MINERPAL Company (Mineradora Palotina Ltda, Palotina, Paraná, Brazil). This agricultural material is provisionally registered in the Brazilian Ministério da Agricultura, Pecuária e Abastecimento (MAPA). The characterization of the BRP was performed by X-ray fluorescence spectrometry, with a lithium tetraborate molten pellet (Table 1) and particle size analysis by sieving (Table 2).

Table 1 Chemical composition of the BRP used in the experiment by X-ray fluorescence spectrometry (XRF)

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	LOI	Sum
50.22	12.67	13.92	8.92	5.36	1.32	2.87	2.06	0.20	0.20	1.75	99.59

SiO_2: silicon dioxide; Al_2O_3: aluminum oxide; Fe_2O_3: iron oxide; CaO: calcium oxide; MgO: magnesium oxide; K_2O: potassium oxide; Na_2O: sodium oxide; TiO_2: titanium dioxide; MnO: manganese oxide; P_2O_5: phosphorus pentoxide; LOI: loss on ignition.

Table 2 Particle size analysis of BRP by sieving

Opening (mm)	4	2	1	0.5	0.25	0.125	0.063	0.044	<0.044
Retained mass (g)	0	0.04	0.83	36.51	18.32	35.42	53.29	60.29	66.85
% Sieved	100	99.98	99.56	97.28	88.12	70.41	43.77	33.42	0

Incubation test

For the incubation trial, an experiment was conducted containing 6 treatments and 5 replicates. The treatments were performed by adding an amount of BRP to 100 g of poultry litter. Thus, for treatment T10, 10 g of BRP was applied to 100 g of poultry litter; for T20, 20 g of BRP to 100 g of poultry litter, and so on (Table 3). The determination of microbial respiration was performed by capturing CO_2, following the methodology proposed by Silva et al. (2007) with 'minor adaptations'. Data collection started on the day of trial implementation and were performed daily for the first 14 days. After day 15, data collection was performed every 2 days until day 40.

To determine the volatilized ammonia, the gas trapping methodology proposed by Sampaio et al. (1999) was used.

NH_3 volatilization was evaluated daily until the third day and with a 2-day interval for the fourth evaluation. From days 5 to 11, the evaluations were performed every 3 days. After day 11, evaluations were performed at 4-day intervals until day 47.

Nutrient analyses were performed. N was analyzed using the Kjedahl method. P and K were extracted using the Mehlich 1 method, after which P was determined using spectrophotometry and K using flame photometry (Silva 2009).

Table 3 Description of the treatments used in the experiment

Nomenclature	Poultry litter (g)	BRP (g)
PL	100	0
T10	100	10
T20	100	20
T30	100	30
T40	100	40
T50	100	50

Statistical analysis

For the chemical quantification of CO_2 and NH_3, the experimental design used was a factorial arrangement with 5 replicates using the percentages of the BRP added to the poultry litter (0, 10, 20, 30, 40, and 50%) and the time in days. The results were subjected to normality, homogeneity, and analysis of variance tests. The means of the treatments were compared using the Tukey's test at 5% probability. The logarithmic regression model was applied for the CO_2 and NH_3 responses as a function of time, as recommended by Ferreira (2018).

For the nutrient quantification analysis, the Scott-Knott test was applied at 5% probability comparing means with the help of the Sisvar Software (Ferreira 2008). Principal component analysis (PCA) was also performed using the Past software (Hammer et al. 2001). All data were obtained on Pearson correlation matrix with broken-stick principal component (PC) retention criteria.

Results and discussion

CO_2 emissions

There was a significant interaction between treatments and incubation time, demonstrating that the time factor was an important parameter for CO_2 release (Table 4).

Table 4 Summary of the analysis of variance for CO_2 emission and NH_3 volatilization as a function of treatments and incubation time

Source of variation	Df*		Mean Square (*p-value*)	
	CO_2	NH_3	CO_2	NH_3
Treatments (T)	5	5	0.279 (*P< 0.001*)	11.51 (*P< 0.001*)
Time (D)	26	14	32.162 (*P< 0.001*)	508.04 (*P< 0.001*)
TxD	130	70	0.0346 (*P< 0.001*)	1.61 (*P< 0.001*)
Error	648	355	0.0235	0.3086
CV (%)	9.31	29.32	-	-

*Df: degrees of freedom

Fig. 1 shows that the treatments expressed in logarithmic models presented similar behavior concerning their curvatures. The evaluation of CO_2 release as a function of time showed that, on average, in the first 5 days of incubation there was a greater release of CO_2 into the environment: 41% of all CO_2 released during the 40 days evaluated occurred during this period. From days 6 to

14, an additional 30.6% of the period's CO_2 was released and, on the remaining days (26 days), 28.4% of the assessed CO_2 was released (Fig. 1). This CO_2 emission to the environment occured as a result of the decomposition of organic matter caused by microbial respiration. Consequently, the greater the release, the greater the microbial activity (Anderson and Domsch 1978; Moreira and Siqueira 2006; Six et al. 2006; Cotta et al. 2015). Said-Pullicino et al. (2007) argued that the decrease in CO_2 release was directly related to the stability of the decomposition process of organic matter by microorganisms. This fact was proven by the studies of poultry litter composting, which verified the reduction of CO_2 emission according to carbon reduction during composting (Maragno et al. 2007; Lima et al. 2009). In our work, we observed that there was a decrease in CO_2 emission with an increase in the percentage of BRP in the poultry litter (Fig. 1), demonstrating that the application of BRT reduced the activity of microorganisms. The reduced activity of microorganisms can decrease the decomposition of organic matter and the loss of nutrients. However, the lower decomposition of organic matter reduced the release of organic acids, which, in turn, reduced the release of nutrients from the BRT. The solubilization of nutrients was also reduced by the direct action of microorganisms that usually assist in the solubilization process in mineral fertilizers (Basak and Biswas 2009). Treatments with up to 30% of BRT in the poultry litter, on average, showed higher CO_2 release as time went by (Fig. 1). On the other hand, the T40 and T50 treatments were the ones that statistically (Tukey, P<0.05) presented the lowest CO_2 concentration (Fig. 1). This shows that the excess of BRT can decrease microbial activity in a composting process.

Treatment	Equation	R^2	1st day*	40th day*
PL	$y = 12.056\ln(x) - 0.8489$	0.9870	3.89a	45.52a
10%	$y = 11.309\ln(x) + 0.0886$	0.9898	3.79a	45.58a
20%	$y = 11.887\ln(x) - 0.2201$	0.9888	4.03a	45.40a
40%	$y = 11.21\ln(x) - 0.0944$	0.9890	3.85a	42.93b
30%	$y = 12.18\ln(x) - 0.5939$	0.9880	3.98a	45.91a
50%	$y = 11.524\ln(x) - 0.575$	0.9877	3.80a	43.88b

*averages followed by the same letter in the column, do not differ statistically by the Tukey test (P>0.05)

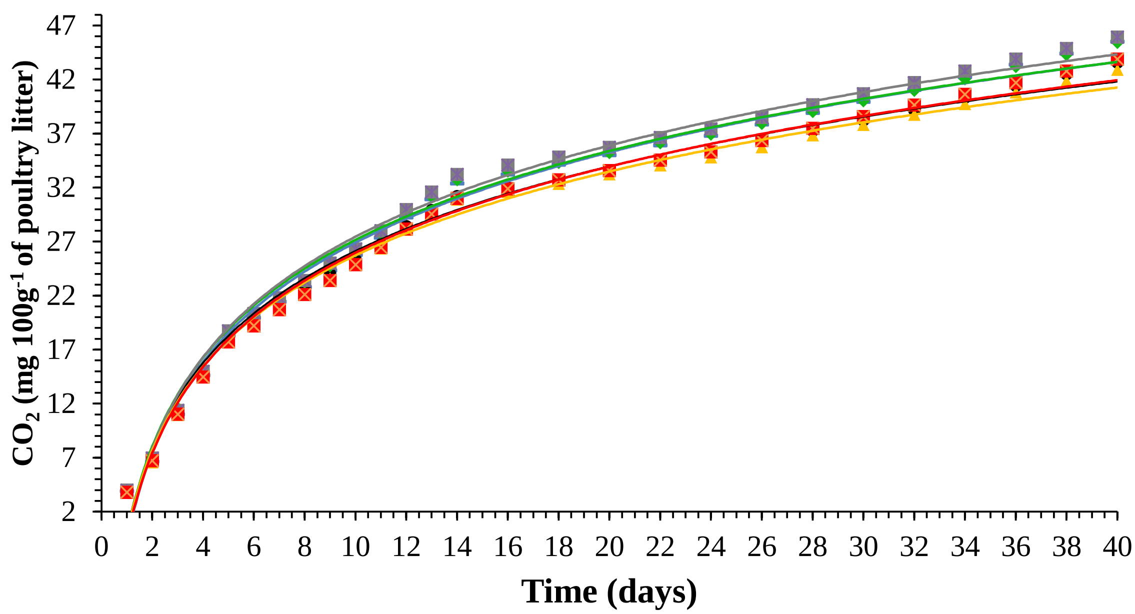

Fig. 1 Total CO_2 release in different treatments of poultry litter and BRP mixtures as a function of incubation time

Ammonia (NH_3) volatilization

There was a significant interaction between treatments and incubation time for NH_3 volatilization (Table 4). As with CO_2 release, the treatments expressed in logarithmic models showed the highest NH_3 losses to the atmosphere until the fifth day of evaluation. The accumulated NH_3 volatilization as a function of time showed that, on average, 74.5% of the total NH_3 lost to the atmosphere during the experimental period occurred in the first 5 days of incubation and the rest (25.5%) was slowly released by the end of the experiment (Fig. 2). The most significant loss of NH_3 at the beginning of the experiment (74.5%), compared to C losses in the form of CO_2 (41%), demonstrates that a significant amount of N was already in the poultry litter in some mineral form (presumably NH_4 and NO_3) and was readily volatilized with the initial wetting of the trial. We can verify that NH_3 losses in the first 24 hours of this study, whose values ranged from 11.86 to 15.81 mg 100 g^{-1} of poultry litter (T30 and T10 respectively, Fig. 1), were also reported by Medeiros et al. (2008), who found volatilized ammonia values of 28.6 mg 100 g^{-1} of poultry litter. In 42-day incubation trials, Choi and Moore (2008) found an average cumulative NH_3 volatilization of 30.7 g of N kg^{-1} of poultry litter. The T30 treatment had lower ammonia release on the first day (significantly lower than the others) and, at the end of the process, presented similar values to the PL treatment, being statistically different from the other treatments that received the addition of BRT. We can see that the NH_3 volatilization for T30 was lower throughout the evaluated period; this should promote a mixture with better characteristics for agricultural use (Fig. 2). The higher NH_3 losses by volatilization in the first days after poultry litter application is commonly described in the literature (Port et al. 2003; Turan 2009; Ashworth et al. 2017; Ashworth et al. 2018). After the initial heavy losses, there are continuous and less significant losses linked to the mineralization of organic matter from the poultry litter that begins to occur more slowly with the stabilization of the microbial activity of the system. In a greenhouse study, Stafanato et al. (2013) observed the highest ammonia losses by volatilization occurred in the first 3 days of analysis, with changes only on the eighteenth day. The volatility stabilized when they acted with fertilizers.

Chemical characterization

There were statistically significant reductions in the extractable K contents starting from the T20 treatment and in P contents starting from the T30 treatment, demonstrating that the application of high amounts of BRP in the compost proportion triggered a reduction of available P and K (Table 5). The low concentration of K and P contents presented in the BRP (Table 1), as well as its low solubility, widely described in the literature (Melo et al. 2012; Mancuso et al. 2014; Martins et al. 2015; Luchese et al. 2021) promotes these results.

Table 5 Extractable potassium (K) and phosphorus (P) contents in the different treatments

Treatments	**K (g kg^{-1})**	**P (g kg^{-1})**
PL-poultry litter	20.96 a	7.18 a
T10-10% BRP	21.63 a	7.47 a
T20-20% BRP	19.86 b	7.09 a
T30-30% BRP	17.63 b	6.19 b
T40-40% BRP	19.08 b	6.59 b
T50-50% BRP	18.09 b	6.36 b
Averages*	19.54 (±1.122)	6.18 (±0.430)

*Averages followed by the same letter in the column do not differ statistically by the Scott-Knott test ($P<0.05$). Mean ± standard deviation.

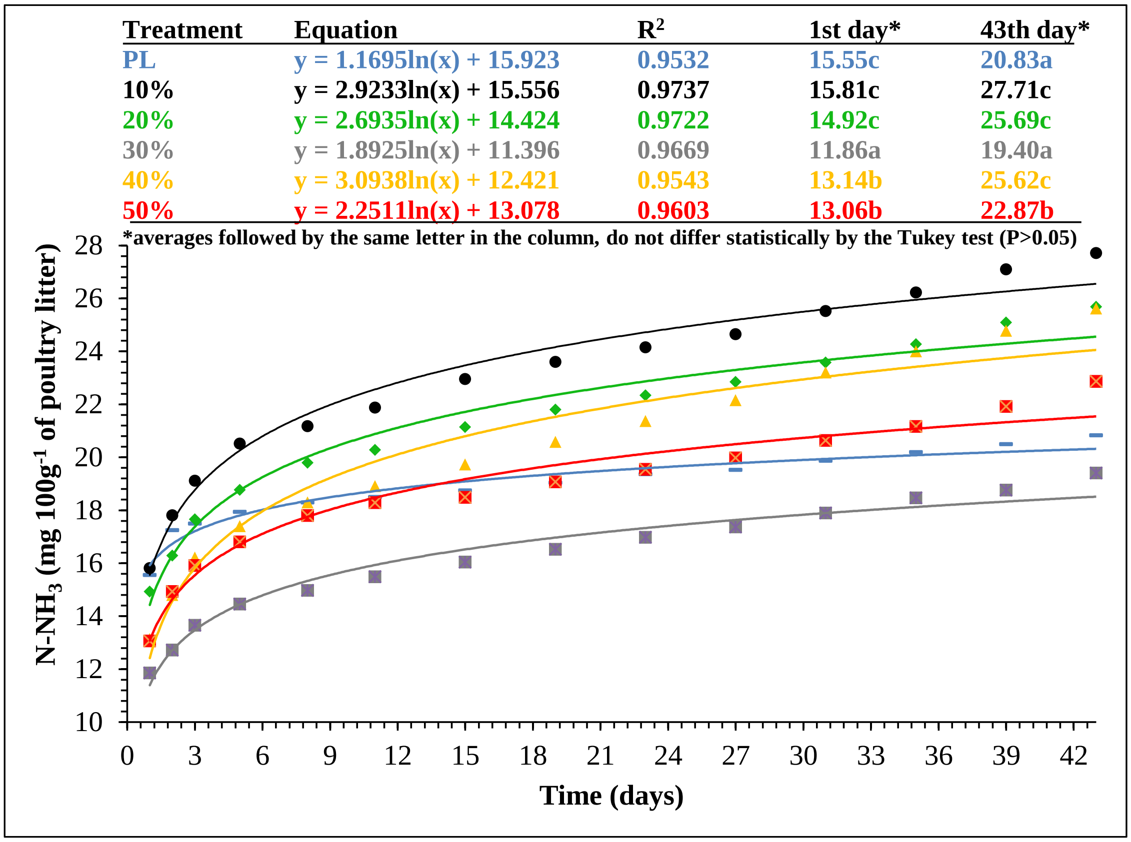

Fig. 2 Total N-NH_3 volatilization in different treatments of poultry litter and BRP mixtures as a function of incubation time

The results obtained differ in part from those found in the literature, which concluded that the addition of small amounts of materials derived from stones promotes an increase in available P and K contents (Biswas et al. 2009; Tavares et al. 2018).

It is important to observe that at the lowest addition, up to 10% BRP, T10 showed slightly higher values than PL, possibly demonstrating that higher additions are not suitable for composting. This corroborates the results found in other studies that indicated responses with low additions. This partial divergence of results may mean that the formation of organic acids that would be responsible for solubilizing P and K, or even chelating P from the compost (Vassilev et al. 2006), did not occur satisfactorily with large increments of BRT.

It is important to point out that the loss of nitrogen in organic matter decomposition processes is inherent to the process itself. The fact that the addition of BRT to the process significantly reduced the N content compared to the control (pure poultry litter) may be due to a dilution of the organic fraction and the narrow C/N ratio range.

Corroborating the present study, Tavares et al. (2018), in their research with bokashi and phonolite type composts, also observed that with decreasing organic matter and increasing phonolite, there was a reduction of nitrogen.

With regard to total nutrient contents, only Mg did not differ statistically among the treatments (Table 6).

Table 6 Total levels of N, Mg, Ca, K and P in the different treatments

Treatments	N (g kg^{-1})	Mg (g kg^{-1})	Ca (g kg^{-1})	K (g kg^{-1})	P (g kg^{-1})
PL-poultry litter	34.35 a	11.08 a	44.55 b	37.84 a	27.27 a
T10-10% BRP	29.61 b	12.27 a	50.92 a	39.22 a	29.07 a
T20-20% BRP	26.40 c	9.69 a	47.81 a	35.04 b	22.84 b
T30-30% BRP	26.14 c	11.21 a	42.91 b	30.53 c	18.03 c
T40-40% BRP	21.15 d	11.93 a	42.45 b	29.96 c	14.10 d
T50-50% BRP	20.20 d	14.36 a	39.83 b	28.77 c	11.74 d
Averages*	26.30 ± 1.255	11.75 ± 2.292	44.74 ± 3.023	33.56 ±2.355	16.01 ± 2.264

*Averages followed by the same letter do not differ statistically by Scott Knott test (*P*<0.05). Mean ± standard deviation.

In our study, the highest total Ca contents were found for the T10 and T20 treatments. The other treatments remained statistically equal to pure poultry litter (Table 6). With the increase of BRT in the poultry litter, an increase in Ca and Mg BRP was expected due to the contents present in its chemical composition (Table 1). However, for Mg, there was no statistical difference among the treatments (Table 6). As for Ca, there was a significant difference among the treatments, and the contents found are considered adequate.

For both P and K, we expected the results to show low concentrations due to the rock's chemical composition (Table 1). Branco et al. (2001) pointed out that low pH and the presence of organic acids can reduce phosphorus fixation, thus increasing the availability of the element. They also agreed that organic acids tend to increase phosphorus availability. In the present study, the PL and T10 treatments had the highest concentrations of P and K (Table 6).

Meena and Biswas (2014) found improvements in phosphorus release when organic sources and phosphate stone meal were applied together. This may be evidenced that the incorporation of basalt stone meal can improve the concentrations of this nutrient. However, in our work, the best results were found for the PL and T10 treatments (Table 6).

The PCA analysis shows the relationship between T10 and the extractable K and P variables, total Ca and K, and high NH_3 volatilization (Fig. 3). On the other hand, T30 stands out for low NH_3 volatilization, since it negatively correlates with this variable. The PL and T20 treatments are highly correlated with total N and P, as well as with high CO_2 emission to the atmosphere. The two main components explain more than 84% of the variation in the variables as a function of the treatments evaluated.

A study by Orrico Júnior et al. (2010) evaluating the release of some nutrients for compost production with poultry litter reported lower results than ours. Their results indicated that the application of BRP can increase the release of the nutrient in this raw material.

According to the Brazilian organic fertilizer legislation, the minimum nitrogen content should be 1.00% (m/m). Thus, we verified that the addition of BRT, which did not present N in its composition, did not decrease the N content of any of the treatments to the point of preventing its commercialization, as the N contents remained within the levels required by law (Brasil 2009).

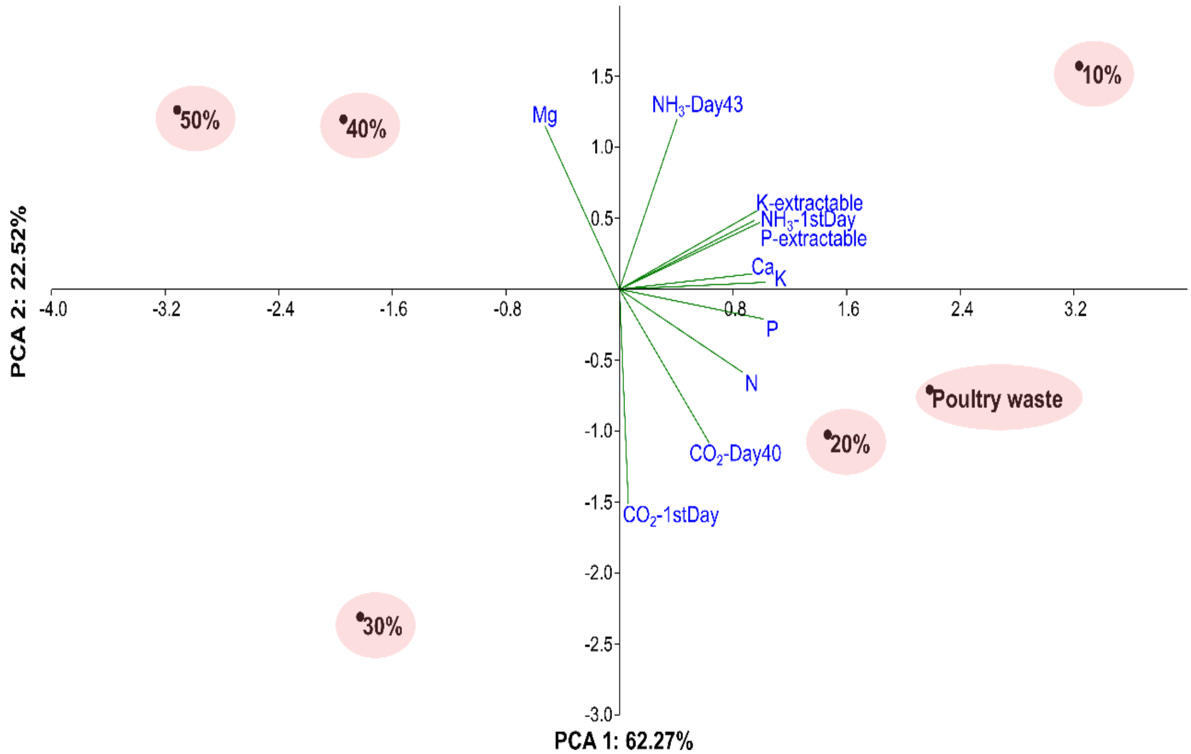

Fig. 3 Principal Component Analysis (PCA) for the variables related to extractable and total nutrients, CO_2, and NH_3. (PCA 1 and PCA 2 explained 62.27% and 22.52% of the variation, respectively)

Conclusion

This study showed some findings about the process of stabilization of poultry litter with the application of basalt rock powder seeking the higher solubilization of basalt rock powder nutrients, in order to develop a new fertilizer. The search for novel sources of nutrients is extremely important to tropical agriculture due to its current heavy dependence on soluble fertilizers. The highest CO_2 emissions to the atmosphere were found until the fifth day of incubation for the treatment with 30% of BRT. The ammonia volatilization occurred intensively until the fifth day after the application of the treatments. By presenting, at the end of the evaluation period, the lowest NH_3 volatilizations (lower loss of N to the atmosphere) and highest CO_2 emissions (indicative of higher microbial activity), the application of up to 30% of BRP to the poultry litter may be an excellent alternative as a source of sustainable agricultural fertilization.The extractable P and K contents reduced starting from the treatment with 30% of BRP due to its mineralogical composition and, possibly, the slow release of these nutrients as well. The treatment with the addition of 10% of BRT (T10) to the poultry litter registered a higher amount of nutrients. However, regarding most nutrients, it did not differ from the control (poultry litter).

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Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest associated with this study.

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