Revista Brasileira de Ciência do Solo

Division - Soil Use and Management | Commission - Soil fertility and plant nutrition

Cattle Manure Bioconversion Effect on the Availability of Nitrogen, Phosphorus, and Potassium in Soil

Daniel Pazzini Eckhardt[(1)*], Marciel Redin[(2)], Natielo Almeida Santana[(3)], Lessandro De Conti[(3)], Jorge Dominguez[(4)], Rodrigo Josemar Seminoti Jacques[(3)] and Zaida Inês Antoniolli[(3)]

[(1)] Universidade Federal do Pampa, *Campus* Dom Pedrito, Rio Grande do Sul, Brasil.
[(2)] Universidade Estadual do Rio Grande do Sul, Unidade Três Passos, Rio Grande do Sul, Brasil.
[(3)] Universidade Federal de Santa Maria, Departamento de Solos, Santa Maria, Rio Grande do Sul, Brasil.
[(4)] Universidade de Vigo, Departamento de Ecologia e Biologia Animal, Vigo, Galícia, Espanha.

ABSTRACT: The efficiency index (EI) refers to the ratio of nutrients mineralized/made available in the soil to the total amount of nutrients added by organic fertilizer. Therefore, understanding the EI is essential for recommendation of organic fertilization. The aim of this study was to evaluate the availability through mineralization and the efficiency index of nitrogen (N), phosphorus (P), and potassium (K) in organic fertilizers produced from cattle manure. The following treatments were evaluated in an incubation experiment under controlled conditions: soil without fertilizer (control); soil + beef cattle manure vermicompost; soil + beef cattle manure/straw compost; soil + beef cattle manure; soil + dairy cattle manure; and soil + vermicompost produced under conditions of high moisture and forced air. Nitrogen and P mineralization and K availability in the soil were evaluated at 0, 7, 14, 28, 56, 112, 224, and 365 days. Nitrogen availability in the soil increased after the bioconversion of cattle manure by composting, whereas phosphorus availability increased by vermicomposting. The average efficiency indices of N, P, and K of the fertilizers produced from cattle manure were 16, 57, and 82 %, respectively. These efficiency indices are lower than the values presented by the Liming and Fertilization Manual for the states of Rio Grande do Sul (RS) and Santa Catarina (SC), Brazil.

Keywords: organic fertilizers, vermicompost, efficiency index.

*** Corresponding author:**
E-mail: daniel.pazzini@hotmail.com

Received: September 27, 2017
Approved: April 3, 2018

How to cite: Eckhardt DP, Redin M, Santana NA, Conti L, Dominguez J, Jacques RJS, Antoniolli ZI. Cattle manure bioconversion effect on the availability of nitrogen, phosphorus, and potassium in soil. Rev Bras Cienc Solo. 2018;42:e0170327.
https://doi.org/10.1590/18069657rbcs20170327

INTRODUCTION

Brazil has the largest commercial cattle herd in the world, estimated at 240 million head. Of this total, approximately four million are raised in confinement (IBGE, 2010). The concentration of large amounts of organic waste is a problem resulting from the confinement system. In Brazil, the daily production of cattle manure can reach 40 thousand tons (Santos and Nogueira, 2012). Manure is typically applied to soil as a source of nutrients to crops, but it may result in soil and water contamination (Ciancio et al., 2014; Ciapparelli et al., 2016).

Cattle manure contains N and P in inorganic and organic forms. The content of these elements is dependent on the source material, degree of maturation, and storage time of the organic fertilizer. The organic forms need to be mineralized to be available to plants (Pitta et al., 2012; Masunga et al., 2016), while K is mostly readily available (Gonçalves, 2005). Lack of knowledge of nutrient availability leads to misuse of fertilizer, which may result in nutritional imbalance and impair crop development (Durigon et al., 2014). Furthermore, overapplication may result in environmental contamination by runoff and leaching of nutrients (Sharifi et al., 2014). Thus, it is essential to understand the rates of mineralization and nutrient availability to measure application rates and intervals of fertilizer aiming to synchronize nutrient availability and crop demand, promote maximum use by plants, and avoid losses and environmental contamination.

Environmental contamination is subject to legal penalties under the Brazilian Solid Waste Policy (Law 12305/2010). According to this law, residues generated in agricultural activities, including cattle manure, must be recycled or disposed of in an environmentally correct manner (Brasil, 2010). Thus, the fertilization of agricultural soils is an alternative for correct disposal of manure (Komiyama et al., 2013) and promotes the reuse of nutrients (Silva et al., 2014). However, the recycling of cattle manure should be preceded by bioconversion processes such as composting and vermicomposting (Domínguez and Edwards, 2011) that favor mineralization of nutrients and stabilization of organic material (Maňáková et al., 2014). Although, it is a fairly new technique in Brazil, vermicomposting in environments with high moisture is also an alternative for nutrient recycling through bioconversion (Nath and Singh, 2012).

The efficiency index (EI) refers to the ratio of nutrients mineralized/made available in the soil to the total amount added through fertilizers (CQFS-RS/SC, 2016). The recommendation for organic fertilizers such as cattle manure and derivatives considers an EI with fixed values. However, the EI may vary depending on the waste treatment processes and the period in which the mineralization and availability of the nutrients are evaluated. In general, short-term studies are done to evaluate the mineralization of organic fertilizers.

The hypothesis of this study was that the bioconversion of cattle manure increases nutrient availability. This study aimed to evaluate the mineralization/availability and the efficiency index of N, P, and K in five organic fertilizers from cattle manure.

MATERIALS AND METHODS

Samples of cattle manure and cattle manure-based fertilizers were incubated with soil for 365 days under controlled moisture and light conditions. The soil was collected at the 0.00-0.10 m soil layer in an area of native grassland (29° 45’ S, 53° 42’ W). The soil is classified as an *Argissolo Vermelho Distrófico arênico* (Santos et al., 2013), which corresponds to a Rhodic Paleudult (Soil Survey Staff, 2014), this soil is most used for dry cropping in the southern half of the state of Rio Grande do Sul. The soil was passed through a 4 mm mesh sieve, dried at 65 °C, and then analyzed according to Tedesco et al. (1995). It had the following properties: 5.6 pH(H_2O) at a ratio of 1:1; 6.5 SMP index; 80.6 % base saturation; 12 g kg^{-1} organic matter (Walkley-Black method); 1.3 g kg^{-1} total N (Kjeldahl);

1.95 mg kg^{-1} N-NH_4^+ (Kjeldahl); 5.83 mg kg^{-1} N-NO_2^- + N-NO_3 (Kjeldahl); 180 g dm^{-3} clay (Hydrometer); 18.0 mg dm^{-3} P (Mehlich-1); 0.19 cmol$_c$ dm^{-3} K (Mehlich-1); 2.5 cmol$_c$ dm^{-3} H+Al; 6.9 cmol$_c$ dm^{-3} Ca (KCl 1 mol L^{-1}), and 3.3 cmol$_c$ dm^{-3} Mg (KCl 1 mol L^{-1}).

The organic fertilizers used in the incubation experiment were produced from beef cattle manure (BCM). Part of the manure was mixed with native grass straw (*Axonopus affinis*, *Paspalum notatum*, *Andropogon lateralis*, and *Aristida laevis*) in a ratio of 1:1, and subjected to composting with forced air in the lower part of the pile whenever the temperature reached 65 °C (for 75 days), resulting in the beef cattle manure/straw compost (BCMSC). Another part of the manure was subjected to vermicomposting (40 days with *Eisenia andrei*) and resulted in the beef cattle manure vermicompost (BCMV). For the preparation of the high moisture vermicompost (HMV), the beef cattle manure was kept saturated with water, and vermicomposting (40 days with *E. andrei*) was carried out with forced air. Lastly, dairy cattle manure (DCM) without bioconversion was also evaluated. Fertilizer samples were dried at 65 °C and ground for analysis. Carbon and N contents were determined on a CHNS elemental autoanalyzer (Flash model EA 1112, Thermo Finnigan, Milan, Italy) (Table 1). The pH and the contents of mineral P, K, and N (N-NH_4^+ and N-NO_2^- + N-NO_3^-) were determined according to Tedesco et al. (1995).

The experiment was set up in incubators in a completely randomized design with four replicates. The following treatments were evaluated: T1) soil without fertilizer (control); T2) soil + BCMV; T3) soil + BCMSC; T4) soil + BCM; T5) soil + DCM; and T6) soil + HMV. The experimental units were set up in 120 mL cylindrical containers (5 cm in diameter and 6 cm in height).

The amount of organic fertilizer added to each acrylic container was 1.87, 1.97, 1.25, 1.16, and 1.52 g for BCMV, BCMSC, BCM, HMV, and DCM, respectively, equivalent to the addition of 100 kg ha^{-1} N. Each fertilizer was placed in a separate container with 134 g of soil (14.5 % gravimetric moisture). This was carried out in two steps to avoid differences in density between the top and bottom of the mixture, according to the methodology described by Redin et al. (2014). First, 67 g of soil and ½ the amount of fertilizer were added, homogenized, and compacted to a height of 2.5 cm. Then, the rest of the soil and the fertilizer were added, homogenized, and compacted to a height of 5 cm to reach a density of 1.2 Mg m^{-3}. Four of the containers were placed in 2 L glass pots (hermetically sealed) and then placed in the incubator at 25 ± 1 °C (in the absence of light). The pots were opened weekly for 10 min to avoid O_2 deficiency, at which point the soil moisture was monitored by weighing the experimental units. When weight loss exceeded 0.5 %, distilled water was added to the soil.

Nitrogen and P mineralization and K availability of the fertilizers were evaluated at 0, 7, 14, 28, 56, 112, 224, and 365 days after the start of incubation. At each evaluation date, the soil was removed from the containers and homogenized for chemical evaluations.

Table 1. Chemical characterization of the organic fertilizers used in the incubation experiment

Fertilizers[1]	Total N	P	K	Total C	C/N	pH
	%					
BCMSC	1.99	2.01	1.97	23.2	11.6	7.0
BCMV	1.97	1.45	1.65	22.8	11.5	8.3
HMV	2.45	2.07	0.97	33.1	13.5	8.2
BCM	2.22	2.49	1.08	30.5	13.7	8.4
DCM	2.25	0.72	0.92	35.1	15.6	7.7

[1] Beef cattle manure/straw compost (BCMSC); beef cattle manure vermicompost (BCMV); high moisture vermicompost (HMV); beef cattle manure (BCM); and dairy cattle manure (DCM). Carbon and N contents were determined on a CHNS elemental autoanalyzer (Flash model EA 1112, Thermo Finnigan). Phosphorus and K: digestion with H_2O_2 and H_2SO_4; pH in water at a ratio of 1:5.

Samples were discarded after evaluation. The contents of ammonium ($N\text{-}NH_4^+$), nitrite ($N\text{-}NO_2^-$) + nitrate ($N\text{-}NO_3^-$), and available P and K (Mehlich-1) were determined as described by Tedesco et al. (1995). Soil mineral N (N_{min}) was obtained from the values of $N\text{-}NH_4^+$ and $N\text{-}NO_2^-$ + $N\text{-}NO_3^-$, according to equation 1:

$$N_{min} = N\text{-}NH_4^+ + N\text{-}NO_2^- + N\text{-}NO_3^- \quad \text{Eq. 1}$$

The mineralization or immobilization processes of the fertilizer N in the soil during the incubation period were evaluated through net N mineralization (N_{net}) (Equation 2):

$$N_{net} = N_{min\ of\ the\ soil\ with\ fertilizer} - N_{min\ of\ the\ control\ soil} \quad \text{Eq. 2}$$

The mineralization of P and the availability of K or the immobilization of fertilizer P and K in the soil were evaluated through net P mineralization (P_{net}) and net K availability (K_{net}), equations 3 and 4, respectively:

$$P_{net} = P_{min\ of\ the\ soil\ with\ fertilizer} - P_{min\ of\ the\ control\ soil} \quad \text{Eq. 3}$$

$$K_{net} = K_{av\ of\ the\ soil\ with\ fertilizer} - K_{av\ of\ the\ control\ soil} \quad \text{Eq. 4}$$

The EI of the fertilizers were calculated based on values of total N, P, and K (N_{tot}, P_{tot}, and K_{tot}) added via fertilizers, the mineralization of N (N_{min}) and P (P_{min}), and the availability of K (K_{av}) (Equations 5, 6, and 7):

$$EI = (N_{min}/N_{tot}) \quad \text{Eq. 5}$$

$$EI = (P_{min}/P_{tot}) \quad \text{Eq. 6}$$

$$EI = (K_{av}/K_{tot}) \quad \text{Eq. 7}$$

The data were tested for normality (Shapiro-Wilk with $p<0.05$). The values of mineralized N and P, available K, and the efficiency indices determined at each evaluation date were subjected to analysis of variance. When significant, the means were compared by the Tukey test at 5 % ($p<0.05$) using the Sisvar software (Ferreira, 2011).

RESULTS AND DISCUSSION

The pH of the fertilizers was close to neutral or slightly alkaline (Table 1), which is favorable in crop production. The addition of fertilizers with pH close to or above 7.0, depending on the amount, can correct soil acidity (Soares et al., 2004). This improves conditions for plant development, especially in acidic soils predominant in Brazil (Nicolodi et al., 2008).

The total mineralization of soil N (control) increased over the incubation period and ranged from 29.70 (day 0) to 70.60 mg kg^{-1} N (day 365). The BCMSC showed the highest net nitrogen mineralization throughout the evaluation period (average of 51 mg kg^{-1}) (Figure 1a). The BCMV and BCM showed intermediate values and similar N mineralization dynamics at all evaluation dates (average of 32 mg kg^{-1}). Mineralization is related to the low initial C/N ratio of these fertilizers (Table 1). However, even with a low C/N ratio, HMV showed reduced N mineralization (average of 10 mg kg^{-1}).

Biodegradation of organic matter occurs in the bioconversion of manure, resulting in reduction in the C/N ratio (Aquino et al., 2005). This behavior can be observed for BCMV and BCMSC. The C/N ratio is one of the parameters most used to indicate the stabilization of organic fertilizers, and a ratio between 15 and 20 is considered ideal (Dores-Silva et al., 2013). However, the results show N mineralization is benefited when the C/N ratio is close to 11.5.

The DCM showed strong N immobilization at 14 days, and especially at 56 days (-29.0 mg kg^{-1}) (Figure 1a). This result is associated with the initial composition of the fertilizer, evidenced by the lower N content, higher C_{total} content, and, consequently, higher C/N ratio (Table 1). The addition of a fertilizer with these characteristics tends to immobilize soil N (Balota et al., 2012), which is used by microorganisms involved in the decomposition of organic material (Moreira and Siqueira, 2006), and it may limit crop development, especially for non-nitrogen-fixing species.

The use of a fertilizer stabilized by bioconversion (vermicomposting and composting) provides greater amounts of nutrients readily available to plants. This is because part of the nutrients (organic forms) is mineralized during bioconversion. For instance, according to Domínguez and Gómez-Brandón (2013) and Yadav and Garg (2016), bioconversion through vermicomposting promotes an increase in N, P, and K contents of organic fertilizers.

The total mineralization of soil P (control) fluctuated throughout the incubation period. The minimum value was observed at 28 days (8.10 mg kg^{-1} P), while the maximum value (9.62 mg kg^{-1} P) was observed at 112 days. The highest P mineralization rates were found in BCMV and BCMSC (Figure 1b). At all the evaluation dates, BCMV showed the highest availability of P (average value of 149 mg kg^{-1}), although it did not have the highest total P content among the fertilizers (Table 1). In the vermicomposting process, there is intense degradation of the organic compounds due to the synergistic action of earthworms and microorganisms, which can result in greater mineralization of the organic P when the fertilizer is added to the soil (Srivastava et al., 2012). The organic material will be decomposed more slowly by soil organisms without bioconversion, and temporary immobilization of nutrients such as P may occur.

The BCM was not subjected to bioconversion by composting or vermicomposting and had lower P availability. Similar results were found by Dores-Silva et al. (2013) in comparing the efficiency of these processes in the stabilization of organic fertilizers. They noted that both processes concentrate the P content of the fertilizer, especially vermicomposting. This is due to decomposition of the organic material and reduction in the volume of waste. The low P mineralization of DCM, in turn, is associated with its source material. Dairy cattle manure has lower levels of P, since considerable amounts are used in lactation (0.95 g of P per liter of milk produced). The maintenance feed of a 450 kg animal contains approximately 7 g of P per day (NRC, 2000). These results support the idea that the nutrient content of organic fertilizers is dependent on the source material (Gómez-Brandón et al., 2015).

The highest P mineralization occurred at the beginning of the incubation period up to 14 days (Figure 1b), except for BCMV, which occurred at 224 days. This was due to microbial action. For BCMSC, HMV, and DCM, the highest mineralization occurred soon after its addition to the soil (day 0), while the highest mineralization was at 28 days for BCM. The lower availability of P after the initial period may be a result of the association of P with mineral soil particles, decreasing its availability over time. After the addition of P, its transfer from the soil solution to the solid phase occurs, where it is specifically adsorbed to Fe and Al oxides, and becomes unavailable to crops (Ranno et al., 2007).

The total availability of soil K (control) fluctuated over the incubation period, ranging from 40.62 (365 days) to 53.06 mg kg^{-1} (28 days). Potassium availability among the fertilizers created two distinct groups (Figure 1c). The first group consisted of BCM, HMV, and BCMV and showed high K availability (values higher than 137 mg kg^{-1}). The K availability by vermicompost (BCMV and HMV), although higher at the beginning of the evaluation period, remained stable through the last evaluation. In contrast, BCMSC and DCM showed lower K availability. For DCM, this result is associated with lower initial K content (Table 1).

The highest K availability (Figure 1c) in all fertilizers occurred at the beginning of the incubation period (up to 14 days). This dynamic is related to the adsorption of cations (such as K) to soil colloids, reducing its availability over time (Pavinato and Rosolem, 2008). The K content in the soil solution is typically low and tends to deplete in a few

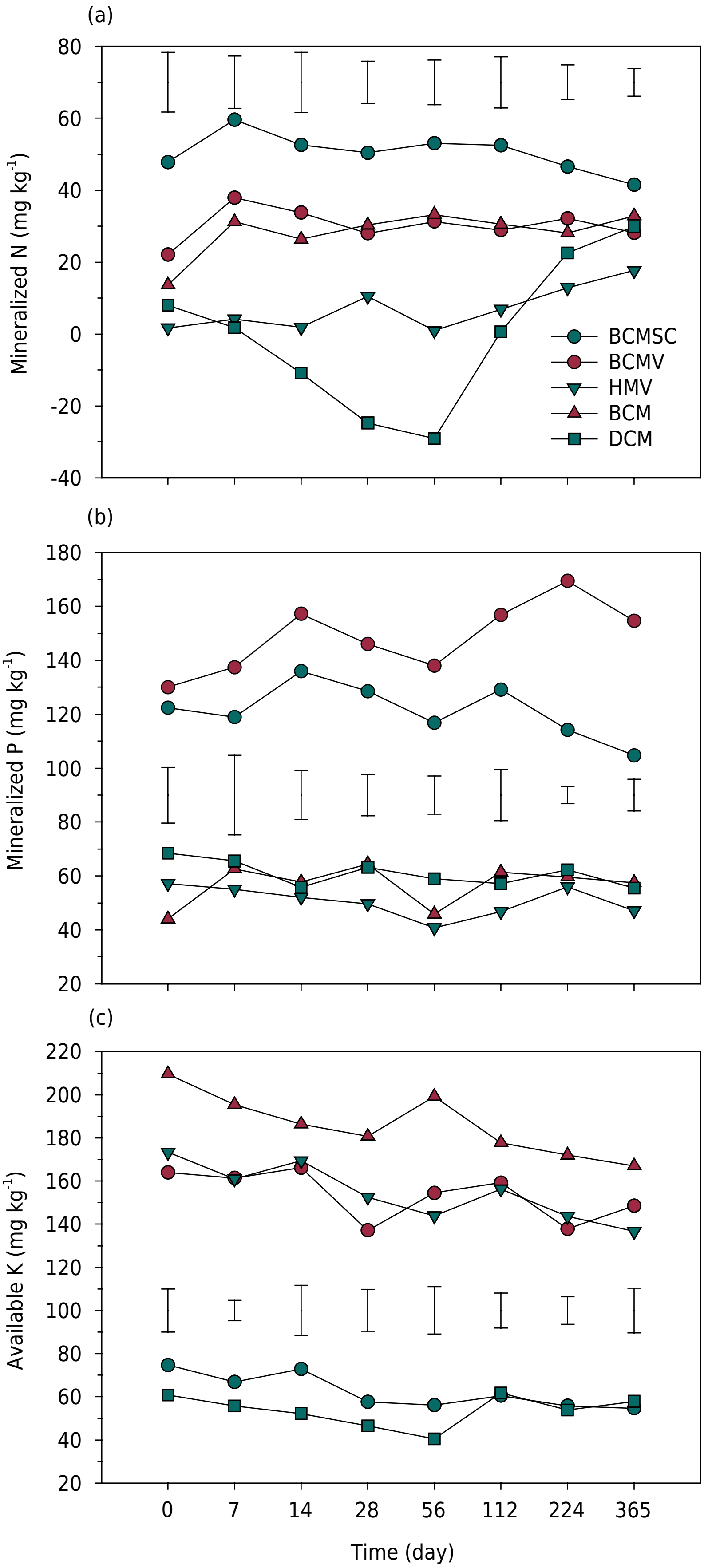

Figure 1. Nitrogen (a) and phosphorus (b) net mineralization, and available potassium (c) of the organic fertilizers in the soil. Beef cattle manure/straw compost (BCMSC); beef cattle manure vermicompost (BCMV); high moisture vermicompost (HMV); beef cattle manure (BCM); and dairy cattle manure (DCM). Values indicate the means of the four replicates. Vertical bars represent the least significant difference (Tukey test, p<0.05).

days (Ernani et al., 2007). Thus, to meet the requirement for K in crop production, these fertilizers should be added close to the growing season, and this should be done for inorganic fertilizers as well (Kaminski et al., 2007).

The BCMSC showed the highest N efficiency index, with an average value of 0.16 (16 %) during the experimental period (Table 2). These results are in agreement with Oliveira et al. (2012), who studied N mineralization of 15 organic compounds for 28 days. It should be noted that HMV showed an EI lower than 0.1 on all the evaluation dates, and DCM showed N immobilization (14 to 56 days). In a study on mineralization and the N efficiency index of cattle manure fertilizers, Eckhardt et al. (2016) found EI of 0.27, 0.23, and 0.22 for cattle manure compost, cattle manure vermicompost, and cattle manure, respectively.

The N mineralization rates found in all the fertilizers and on all the evaluation dates in this study are lower than the EI values indicated by the Liming and Fertilization Manual for the states of RS and SC (CQFS-RS/SC, 2016), which indicate an EI of 0.3 for cattle manure and derivatives. Similar results were found by Fioreze et al. (2012). The mineralization of N in an incubation study is evaluated under ideal conditions (temperature, moisture, and luminosity), that is, it tends to be higher than under field conditions. The extrapolation of the EI for fertilizers such as DCM results in fertilization that is lower than what is required. This results in lower yields and consequent lack of interest for organic fertilization and waste processing.

The BCMV showed the highest P efficiency index, with an average value of 0.57 (57 %) during the experimental period (Table 2). The BCMSC had the lowest EI values (0.29 to 0.39), although exhibiting a high amount of P available in the soil. The HMV, DCM, and BCM had average EIs of 0.52, 0.49, and 0.48, respectively. According to the Liming and Fertilization Manual for the states of RS and SC (CQFS-RS/SC, 2016), cattle manure should

Table 2. Organic fertilizer efficiency index of beef cattle manure/straw compost (BCMSC), beef cattle manure vermicompost (BCMV), high moisture vermicompost (HMV), beef cattle manure (BCM), and dairy cattle manure (DCM)

Fertilizer[1]	Day							
	0	7	14	28	56	112	224	365
				Nitrogen Efficiency Index ($E.I_N$)[2][3]				
BCMSC	0.16 a[4]	0.19 a	0.17 a	0.16 a	0.17 a	0.17 a	0.15 a	0.13 a
BCMV	0.08 b	0.14 b	0.12 a	0.10 b	0.15 a	0.11 a	0.12 a	0.10 b
HMV	0.01 c	0.02 c	0.01 b	0.05 b	0.01 b	0.03 b	0.06 b	0.08 b
BCM	0.06 b	0.15 b	0.13 a	0.19 a	0.16 a	0.15 a	0.14 a	0.15 a
DCM	0.03 c	0.01 c	-0.04 b	-0.01 c	-0.11 c	0.00 b	0.15 a	0.12 a
				Phosphorus Efficiency Index ($E.I_P$)[5]				
BCMSC	0.39 c	0.33 b	0.38 d	0.35 c	0.34 c	0.36 c	0.32 c	0.29 b
BCMV	0.49 b	0.55 a	0.62 a	0.61 a	0.53 a	0.56 a	0.62 a	0.54 a
HMV	0.58 a	0.55 a	0.53 b	0.50 b	0.44 b	0.48 b	0.57 a	0.48 a
BCM	0.42 c	0.52 a	0.49 c	0.54 b	0.40 b	0.52 a	0.50 b	0.48 a
DCM	0.55 a	0.52 a	0.47 c	0.50 b	0.49 a	0.46 b	0.50 b	0.45 a
				Potassium Efficiency Index ($E.I_K$)[6]				
BCMSC	0.20 c	0.18 d	0.17 c	0.16 d	0.16 c	0.18 c	0.15 c	0.16 b
BCMV	0.68 b	0.68 b	0.70 b	0.63 b	0.69 a	0.67 b	0.58 b	0.64 a
HMV	0.82 a	0.82 a	0.81 a	0.72 a	0.73 a	0.79 a	0.68 a	0.65 a
BCM	0.78 a	0.70 b	0.72 b	0.65 b	0.76 a	0.65 b	0.62 a	0.64 a
DCM	0.62 b	0.57 c	0.50 d	0.47 c	0.45 b	0.64 b	0.55 b	0.60 a

[1] For N, the rate of 100 kg ha^{-1} N of each fertilizer was added; for P, the rates of 101.00 (BCMSC), 73.60 (BCMV), 84.40 (HMV), 112.20 (BCM), and 32.00 (DCM) kg ha^{-1} P were added; and for K, the rates of 98.90 (BCMSC), 83.70 (BCMV), 39.60 (HMV), 48.65 (BCM), and 40.90 (DCM) kg ha^{-1} K was added. [2] Negative values indicate N immobilization in the soil. [3] $E.I_N = (N_{min}/N_{tot})$. [4] Means followed by the same letter in the columns do not differ by the Tukey test ($p<0.05$). [5] $E.I_P = (P_{min}/P_{tot})$. [6] $E.I_K = (K_{av}/K_{tot})$.

have an EI of 0.8 (80 %). This was not found in any of the fertilizers evaluated in this study. These low efficiency indices may result in nutritional stress, especially in crops susceptible to P stress or which demand available P in the soil.

The HMV showed the highest K efficiency index, with percentages ranging from 0.65 (65 %) to 0.82 (82 %) (Table 2). In contrast, although BCMSC had higher initial K content (Table 1), it exhibited the lowest EI on all the evaluation dates, with values ranging from 0.15 (15 %) to 0.20 (20 %). The EI for K was expected to be close to 100 % for all the fertilizers (Gonçalves, 2005). This behavior may be the result of an increase in soil pH caused by the addition of the organic fertilizers, which generates negative charges and consequent adsorption of potassium in non-available fractions (Pavinato and Rosolem, 2008). The Liming and Fertilization Manual for the states of RS and SC (CQFS-RS/SC, 2016) indicates that cattle manure and derivatives should provide all K (1.0). The low efficiency indices (especially for BCMSC) may result in K deficiency, especially in demanding crops.

CONCLUSIONS

Nitrogen and phosphorus have increased availability after the bioconversion of cattle manure by composting and vermicomposting.

Potassium is more readily available without the bioconversion of cattle manure. However, vermicomposting produced with high moisture and forced air increases the potassium efficiency index.

The average efficiency indices of nitrogen, phosphorus, and potassium of the fertilizers produced from cattle manure were 16, 57, and 82 %, respectively. These values are lower than those indicated by the Liming and Fertilization Manual for the states of Rio Grande do Sul and Santa Catarina.

REFERENCES

Aquino AM, Almeida DL, Guerra JGM, De-Polli H. Biomassa microbiana, colóides orgânicos e nitrogênio inorgânico durante a vermicompostagem de diferentes substratos. Pesq Agropec Bras. 2005;40:1087-93. https://doi.org/10.1590/S0100-204X2005001100006

Balota EL, Machineski O, Matos MA. Soil microbial biomass under different tillage and levels of applied pig slurry. R Bras Eng Agric Ambiental. 2012;16:487-95. https://doi.org/10.1590/S1415-43662012000500004

Brasil. Lei n° 12.305, de 2 de agosto de 2010. Institui a Política Nacional de Resíduos Sólidos; altera a Lei n° 9.605, de 12 de fevereiro de 1998; e dá outras providências [acesso em 20 jul 2017]. Disponível em: http://www.mma.gov.br/port/conama/legiabre.cfm?codlegi=636.

Ciancio NR, Ceretta CA, Lourenzi CR, Ferreira PAA, Trentin G, Lorensini F, Tiecher TL, De Conti L, Girotto E, Brunetto G. Crop response to organic fertilization with supplementary mineral nitrogen. Rev Bras Cienc Solo. 2014;38:912-22. https://doi.org/10.1590/S0100-06832014000300023

Ciapparelli IC, Iorio AF, García AR. Phosphorus downward movement in soil highly charged with cattle manure. Environ Earth Sci. 2016;75:568. https://doi.org/10.1007/s12665-016-5284-3

Comissão de Química e Fertilidade do Solo - CQFS-RS/SC. Manual de calagem e adubação para os Estados do Rio Grande do Sul e de Santa Catarina. 11. ed. Porto Alegre: Sociedade Brasileira de Ciência do Solo - Núcleo Regional Sul; 2016.

Dominguez J, Edwards CA. Relationships between composting and vermicomposting. In: Edwards CA, Arancon NQ, Sherman RL, editors. Vermiculture technology: earthworms, organic waste and environmental management. Boca Raton: CRC Press; 2011. p. 11-25.

Domínguez J, Gómez-Brandón M. The influence of earthworms on nutrient dynamics during the process of vermicomposting. Waste Manage Res. 2013;31:859-68. https://doi.org/10.1177/0734242X13497079

Dores-Silva PR, Landgraf MD, Rezende MOO. Processo de estabilização de resíduos orgânicos: vermicompostagem versus compostagem. Quim Nova. 2013;36:640-5. https://doi.org/10.1590/S0100-40422013000500005

Durigon MR, Blume E, Muniz MFB, Milanesi PM, Santos RF, Heckler LI, Cerini JB. Adubações orgânicas e mineral e controle biológico sobre a incidência de podridões de colmo e produtividade de milho. Semin Cienc Agrar. 2014;35:1249-56. https://doi.org/10.5433/1679-0359.2014v35n3p1249

Eckhardt DP, Redin M, Jacques RJS, Lorensini F, Santos MLS, Weiler DA, Antoniolli ZI. Mineralization and efficiency index of nitrogen in cattle manure fertilizers on the soil. Cienc Rural. 2016;46:472-7. https://doi.org/10.1590/0103-8478cr20140958

Ernani PR, Almeida JA, Santos FC. Potássio. In: Novais RF, Alvarez V VH, Barros NF, Fontes RLF, Cantarutti RB, Neves JCL, editores. Fertilidade do solo. Viçosa, MG: Sociedade Brasileira de Ciência do Solo; 2007. p. 551-94.

Ferreira DF. Sisvar: a computer statistical analysis system. Cienc Agrotec. 2011;35:1039-42. https://doi.org/10.1590/S1413-70542011000600001

Fioreze C, Ceretta CA, Giacomini SJ, Trentin G, Lorensini F. Liberação do N em solos de diferentes texturas com ou sem adubos orgânicos. Cienc Rural. 2012;42:1187-92. https://doi.org/10.1590/S0103-84782012005000045

Gómez-Brandón M, Vela M, Martínez-Toledo MV, Insam H, Domínguez J. Effects of compost and vermicompost teas as organic fertilizers. In: Sinha S, Pant KK, Bajpai S, editors. Advances in fertilizer: technology synthesis. Houston: Studium Press; 2015. p. 300-18.

Gonçalves MS. Gestão de resíduos orgânicos. Porto: Editora Principia; 2005.

Instituto Brasileiro de Geografia e Estatística - IBGE. Pesquisa Nacional de Saneamento Básico 2008. Rio de Janeiro: IBGE; 2010 [acesso em 21 set 2017]. Disponível em: https://biblioteca.ibge.gov.br/visualizacao/livros/liv45351.pdf.

Kaminski J, Brunetto G, Moterle DF, Rheinheimer DS. Depleção de formas de potássio do solo afetada por cultivos sucessivos. Rev Bras Cienc Solo. 2007;31:1003-10. https://doi.org/10.1590/S0100-06832007000500017

Komiyama T, Kobayashi A, Yahag M. The chemical characteristics of ashes from cattle, swine and poultry manure. J Mater Cycles Waste Manag. 2013;15:106-10. https://doi.org/10.1007/S10163-012-0089-2

Maňáková B, Kuta J, Svobodová M, Hofman J. Effects of combined composting and vermicomposting of waste sludge on arsenic fate and bioavailability. J Hazard Mater. 2014;280:544-51. https://doi.org/10.1016/j.jhazmat.2014.08.024

Masunga RH, Uzokwe VN, Mlay PD, Odeh I, Singh A, Buchan D, De Neve S. Nitrogen mineralization dynamics of different valuable organic amendments commonly used in agriculture. Appl Soil Ecol. 2016;101:185-93. https://doi.org/10.1016/j.apsoil.2016.01.006

Moreira FMS, Siqueira JO. Microbiologia e bioquímica do solo. 2. ed. atual. rev. Lavras: Editora UFLA; 2006.

Nath G, Singh K. Effect of vermiwash of different vermicomposts on the kharif crops. J Cent Eur Agric. 2012;13:379-402. https://doi.org/10.5513/JCEA01/13.2.1063

National Research Council - NRC. Nutrient requirements of beef cattle. 7th ed. Washington, DC: The National Academies Press; 2000.

Nicolodi M, Anghinoni I, Gianello C. Indicadores da acidez do solo para recomendação de calagem no sistema plantio direto. Rev Bras Cienc Solo. 2008;32:237-47. https://doi.org/10.1590/S0100-06832008000100023

Oliveira LB, Accioly AMA, Menezes RSC, Alves RN, Barbosa FS, Santos CLR. Parâmetros indicadores do potencial de mineralização do nitrogênio de compostos orgânicos. Idesia. 2012;30:65-73. https://doi.org/10.4067/S0718-34292012000100008

Pavinato PS, Rosolem CA. Disponibilidade de nutrientes no solo - decomposição e liberação de compostos orgânicos de resíduos vegetais. Rev Bras Cien Solo. 2008;32:911-20. https://doi.org/10.1590/S0100-06832008000300001

Pitta CSR, Adami PF, Pelissari A, Assamann TS, Franchin MF, Cassol LC, Sartor LR. Year-round poultry litter decomposition and N, P, K and Ca release. Rev Bras Cien Solo. 2012;36:1043-53. https://doi.org/10.1590/S0100-06832012000300034

Ranno SK, Silva LS, Gatiboni LC, Rhoden AC. Capacidade de adsorção de fósforo em solos de várzea do estado do Rio Grande do Sul. Rev Bras Cien Solo. 2007;31:21-8. https://doi.org/10.1590/S0100-06832007000100003

Redin M, Recous S, Aita C, Dietrich G, Skolaude AC, Ludke WH, Schmatz R, Giacomini SJ. How the chemical composition and heterogeneity of crop residue mixtures decomposing at the soil surface affects C and N mineralization. Soil Biol Biochem. 2014;78:65-75. https://doi.org/10.1016/j.soilbio.2014.07.014

Santos HG, Jacomine PKT, Anjos LHC, Oliveira VA, Oliveira JB, Coelho MR, Lumbreras JF, Cunha TJF. Sistema brasileiro de classificação de solos. 3. ed. rev. ampl. Rio de Janeiro: Embrapa Solos; 2013.

Santos IA, Nogueira LAH. Estudo energético do esterco bovino: seu valor de substituição e impacto da biodigestão anaeróbia. Revista Agrogeoambiental. 2012;4:41-9. https://doi.org/10.18406/2316-1817v4n12012373

Sharifi M, Zebarth BJ, Miller JJ, Burton DL, Grant CA. Soil nitrogen mineralization in a soil with long-term history of fresh and composted manure containing straw or wood-chip bedding. Nutr Cycl Agroecosyst. 2014;99:63-78. https://doi.org/10.1007/S10705-014-9618-9

Silva VB, Silva AP, Dias BO, Araujo JL, Santos D, Franco RP. Decomposição e liberação de N, P e K de esterco bovino e de cama de frango isolados ou misturados. Rev Bras Cien Solo. 2014;38:1537-46. https://doi.org/10.1590/S0100-06832014000500019

Soares JP, Souza JA, Cavalheiro ETG. Caracterização de amostras comerciais de vermicomposto de esterco bovino e avaliação da influência do pH e do tempo na adsorção de Co(II), Zn(II) and Cu(II). Quim Nova. 2004;27:5-9. https://doi.org/10.1590/S0100-40422004000100002

Soil Survey Staff. Keys to soil taxonomy. 12th ed. Washington, DC: United States Department of Agriculture, Natural Resources Conservation Service; 2014.

Srivastava PK, Gupta M, Upadhyay RK, Sharma S, Shikha, Singh N, Tewart SK, Singh B. Effects of combined application of vermicompost and mineral fertilizer on the growth of Allium cepa L. and soil fertility. J Plant Nutr Soil Sci. 2012;175:101-7. https://doi.org/10.1002/jpln.201000390

Tedesco MJ, Gianello C, Bissani CA, Bohnen H, Volkweiss SJ. Análise de solo, plantas e outros materiais. 2. ed. Porto Alegre: Universidade Federal do Rio Grande do Sul; 1995. (Boletim técnico, 5).

Yadav A, Garg VK. Influence of stocking density on the vermicomposting of an effluent treatment plant sludge amended with cow dung. Environ Sci Pollut Res. 2016;23:13317-26. https://doi.org/10.1007/s11356-016-6522-7