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Physical, chemical, and microbiological evaluation of a compost conditioned with zeolites

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Zeolites are minerals characterized by high cation exchange capacity (CEC). This study evaluated possible effects of zeolites on improving the composting process in terms of the physical, chemical, and microbiological quality of compost and the productivity of the test plant, *Raphanus sativus* L. Compost enriched with 1.5% ground zeolites exhibited 62% greater degradation of organic particles sized less than 0.125 mm and 26% higher CEC than compost prepared without zeolites, while total coliform and *Escherichia coli* content were 96 and 36% lower, respectively. Moreover, the dried root mass of *R. sativus* was 21% higher with zeolite-enriched compost, subject to complementary mineral fertilization with macronutrients. The addition of zeolites to the composting process improved the quality of obtained organic compost as well as the productivity of plants grown using this compost. Given that zeolites are used mainly in the treatment of effluents in Brazil, and considering their mineralogical properties, more study is necessary to explore the effects of zeolite-enriched composts on crops with longer phenological cycles and grown in low-fertility soils.

Key words: Composting, clinoptilolite, rock dust, radish, *Raphanus sativus* L., cation exchange capacity.

INTRODUCTION

Zeolites are a group of hydrated crystalline aluminosilicate minerals of alkaline or earth alkaline metals, structured in tridimensional, rigid crystalline nets, formed by tetrahedrons of AlO_4 and SiO_4 and variations of TO_4 (T = Si, Al, B, Ge, Fe, P, Co, etc.), bonded by oxygen atoms (Arimi, 2017). Annual production of natural zeolites in 2016 was estimated to be 2.5 - 3 million tons, with cost varying from USD 50 to 800 per ton, in the USA, depending on granulometry and rock purity (US

Geological Survey, 2016). However, exploitation in Brazil is still incipient and more research in terms of geological prospection is necessary (Luz, 1995; Resende and Mello Monte, 2008).

The main characteristic of zeolites is their high cation exchange capacity (Luz, 1995). Consequently, they have great potential as physical and chemical soil conditioners, and research investigating the effects of these minerals on soil and in crop productivity is urgently needed

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(Sangeetha and Baskar, 2016; Eroglu et al., 2017). To the best of our knowledge, few studies have thus far evaluated the effect of these minerals in soils. As reported in the limited literature available, zeolites have been found to increase the efficiency of nitrogen fertilization, reducing losses of NH_3 by volatilization from 76 to 24% (Giacomini et al., 2014; Villarreal-Núñez et al., 2015). An increase of up to 67% in available water capacity of an Entisol was also observed (Bernardi et al., 2009), and the addition of 2.5% zeolites was reported to increase water retention in Latosols (Barbosa et al., 2014). Furthermore, as zeolites can retain heavy metals in the treatment of effluents, when applied to cultivated soils, these could function as “filters” in the migration of cations and anions down the soil profile (Eroglu et al., 2017; Taamneh and Sharadqah, 2017). Further research regarding the agricultural value of these minerals could therefore stimulate large-scale exploitation and commercialization of zeolites in Brazil.

In view of the abovementioned qualities of zeolites in soil, the hypothesis of the present study was that incorporating these minerals during a composting process would improve the physical, chemical, and microbiological qualities of organic compost, consequently improving the productivity of plants cultivated using such compost. In this context, this study aimed at the following:

- i) Evaluating the effects of the addition of zeolites on the physical, chemical, and microbiological qualities of organic compost.
- ii) Evaluating the response to the addition of different dosages of organic compost produced with and without zeolites and with and without complementary fertilization on the productivity of radish (*Raphanus sativus* L.), using sandy soil as substrate.

MATERIALS AND METHODS

Study area

The experiment was carried out in the Faculty of Agronomy and Zootechnics of the Federal University of Mato Grosso (UFMT), Campus of Cuiabá, Mato Grosso State, Brazil (15.61156°S, 56.06484°W; altitude: 170 m). The climate in the region is Aw (tropical wet and dry or savanna), based on the Köppen–Geiger climatic classification (Alvares et al., 2014). The mean annual precipitation in Cuiabá is 1342.3 mm, and the annual average temperature is 25.8°C, with a mean relative humidity of 73.1%.

Collection of organic residue

Organic residue was collected from a horse stable at the Veterinary Hospital of UFMT. The residue was composed of feces and alfalfa remains (*Medicago sativa* L.), a leguminous plant, and tifton-85, a gramineous sterile hybrid resulting from the crossing of tifton-68 (*Cynodon nlemfuensis*) with *C. dactylon* from South Africa. These residues were kept in a stationary Brooks-type damp-cart with a volume of 7 m³. The estimated density of the material on the day of collection was 270 kg/m³ humid base and 188 kg/m³ dry base

(Kiehl, 2002).

Physical and chemical characterization of zeolites

Mineral zeolite material was acquired commercially from Brazil and presented predominantly coarse granulometry, i.e., ≥ 1.0 mm. The material was ground to increase the surface area until its texture was similar to that of rock dust, before the following tests were conducted: granulometry and routine chemical characterization (Silva, 2009), electrical conductivity at a 1:2 soil : water ratio (Gartley, 2011), and mineralogical analysis by X-ray diffraction (Moore and Reynolds, 1997). A D8 Advance instrument (Bruker, Billerica, MA, USA) was used, having a range of 5 - 90° at increments of 0.02° and an incidence time of 0.4 s per step. The instrument had a Cu2Ka goniometer with wavelength of 1.5406 Å and a dispersive slit width of 1.00 mm. Interpretation of the diffractograms was conducted using DIFFRAC.EVA version 3.1 software, with the database “Powder Diffraction File” produced by the International Center for Diffraction Data (ICDD, 2018). All analyses were carried out at the Laboratory of New Materials Characterization at UFMT.

Mounting and monitoring the composting process

Equine organic residues were placed in two compost bins, 5 m long and 1.20 m wide, with a lateral barrier 0.40 m high. To mount the layers, organic residue was homogenized manually with a rake and hayfork. A layer of leaves, about 0.10 m, obtained from the sweeping of the university gardens was deposited at the bottom of the compost bins to allow drainage of the liquid produced at the beginning of the composting process, thereby ensuring adequate gas exchange (Kiehl, 2002). Equine residue was then added until a 1 m high layer was reached. The initial volume of each pile of compost was approximately 5.25 m³ and the estimated dry base mass was 987 kg (Kiehl, 2002).

Fifteen kilograms of dust powder rich in zeolites was pulverized, intercalating with the organic residue in one of the compost bins in a proportion of 0.015 kg of zeolites per kilogram of dry base compost. This proportion was defined on the basis of the high cost (about USD 2.50 per kg) of commercial product in 2016, without considering grinding cost for increasing surface area. The material in the compost bins was homogenized, that is, turned out, weekly. The composting process was initiated on July 26, 2016 and finalized on November 28, 2016, with the process thus totaling 126 days.

The temperature of the residue under decomposition was measured daily at 7:30 and 14:00 with a calibrated digital thermometer inserted in the material after removal of about 0.10 m of the superficial layer; a mean value was subsequently calculated. If the surface layer of the compost was dry, 10 L of water was applied to both compost bins using a garden watering can.

Physical analysis of the compost

At the end of the composting process, 10 simple samples of approximately 4 L were drawn from the surface and base of the compost and were mixed to produce one sample. Part of this sample was used for chemical and microbiological analysis, while the remainder was used for granulometry determination using sieves with mesh sizes of 8, 4, 2, 1, 0.5, 0.25, and 0.125 mm and a base to collect particles of < 0.125 mm. For each compost, an aliquot of approximately 1 L was placed on the upper sieve and submitted to water jets until the eluate reached the last sieve. The material retained in each sieve was dried at 60°C for 72 h. This

Table 1. Physical and chemical characterization of the 0 - 0.20-m soil layer.

Sand ⁽¹⁾	Silt	Clay	Ca	Mg	Al	H	CEC	OM	pH	P	K	BS
(%)			(cmol _c dm ⁻³)					(g kg ⁻¹)	(CaCl ₂)	(mg kg ⁻¹)		(%)
81	8.4	10.6	3.55	1.25	0.0	1.6	6.53	27.1	6.6	18.1	50.6	75.5

⁽¹⁾Sand, silt and clay content was determined using the pipette method (Donagema et al., 2011); exchangeable Ca, Mg, and Al were extracted with KCl 1 mol L⁻¹; H and Al were extracted with a solution of calcium acetate at pH = 7; CEC is cation exchange capacity; OM (soil organic matter content) was determined by burning in a muffle furnace at 600°C for 6 h; pH in CaCl₂ 0.01 mol L⁻¹ was determined at a proportion of 1:2.5 (soil:CaCl₂); exchangeable P and K were extracted with a 0.05 mol L⁻¹ HCl solution and a 0.025 mol L⁻¹ H₂SO₄ solution (Mehlich I); BS is percent base saturation (Silva, 2009).

determination was done in eight replicates.

The dry and humid color of each sample of compost was determined on with the basis help of the "Munsell Soil Color Book" as well as and the wet consistency of the material in terms of plasticity and stickiness (Santos et al., 2013ab).

Chemical analysis of the compost

1 L aliquot of each compost was dried in an oven at 60°C for 72 h and then passed in a Willey-type knife mill coupled to a 0.30 mm sieve. Two sub-samples were dried at 105°C for 12 h to reduce water content. To determine the amounts of inorganic residue (ash) and incinerated organic material, 0.5 g of each ground material, in triplicate, were submitted to calcination at 600°C for 6 h in a muffle furnace (Silva, 2009).

To determine the nutrient content (P, K, Ca, Mg, S, Zn, Cu, Fe, Mn, and B), another subsample of 0.5 g was oxidized with hot acid solution (HNO₃:HClO₄ ratio of 3:1) to eliminate organic carbon and then passed through filter paper, retaining the insoluble residue. The filtered solution, referred to as mineral soluble material, was used to determine nutrient content using inductively coupled plasma optical emission spectrometry, previously calibrated with ISO 9001 certified standard solutions (Silva, 2009).

Determination of N-NH₄⁺ was done using the Kjeldahl method, consisting of acid digestion with H₂SO₄ followed by distillation in NaOH, with collection of NH₄⁺ in H₃BO₃ solution, which was titrated with HCl with an indicator (Silva, 2009).

Microbiological analysis of compost

We quantified coliform bacteria in 10 replicates for each compost. This bacterial group was selected because of the origin of the organic material, comprised primarily of equine feces, among other materials, that naturally contain high concentrations of these organisms. In the laboratory, 10 g of each compost was added to 90 mL of sterile extracting solution (0.1% sodium pyrophosphate and 0.1% Tween 80), with one vigorous agitation to obtain a 10⁻¹ dilution. From this solution, new dilutions were prepared. Determination of coliform bacteria (total coliforms and *Escherichia coli*) was done using the chromogenic-fluorogenic substrate method (system Colilert[®]/Quanti-Tray – INDEXX[®] Inc., Westbrook, ME, USA), with results expressed in most probable number (MPN) per 100 g.

Plant experiment

The plant experiment was carried out in vases in a vegetation house with a plastic roof and lateral net for protection against insects. We adopted the complete randomized design with four replicates in a triple factorial arrangement (5 × 2 × 2): (i) compost dosage; (ii) with and without zeolites; and (iii) with and without

complementary mineral fertilization, with 80 vases in total. The vases had a diameter of 10 cm and were 35 cm high. The response variable evaluated was the dry mass of the tuberous radish root (*R. sativus*, Hibrido Genius F1 100 GR – Tecnoseeds, Uberlândia, Brazil).

The doses of each compost were 0, 15, 30, 45, and 60%, with vase height of 35 cm considered to be 100%. Structurally loose (sandy) soil was added to each vase, and the height was filled with compost. The content of the vase was withdrawn and placed on a tray, carefully mixed, and returned to the vase. This procedure aimed at simulating compost spreading applications on soil, allowing further incorporation of the compost into the soil. The soil used in this experiment was collected from the 0 - 0.20 m layer of Cambisol Haplic Eutrophic Tb, corresponding to Cambisols based on the Food and Agriculture Organization's World Reference Base for Soil Resources and to Inceptisols based on the US Department of Agriculture's Soil Taxonomy system (Santos et al., 2013a). Soil physical and chemical characteristics are given in Table 1.

Mineral fertilization of the soil followed technical recommendations for *R. sativus*, that is, doses of 10, 100, 40 kg ha⁻¹ of (NH₄)₂SO₄, MAP, and KCl, respectively. Vases were then irrigated until the water started to drain. One hour after the draining stopped, one extra vase for each treatment was used to determine water content at field capacity (kg kg⁻¹) (Pereira, 2011). In sequence, five radish seeds were placed in each vase at a standard depth of 1 cm, and five days after germination, the plants were thinned out, keeping only the most vigorous plants.

The vases were watered every day at 8:30, with the amount of water administered based on the difference between water content at field capacity and the daily weight of one replicate of each treatment, thus replacing water lost by evapotranspiration. Weekly, extra vases were weighed (in each treatment) to calculate losses and to minimize irrigation errors due to the growth of aerial parts and roots. After the radish harvest on the 32nd day after seeding, plant productivity was calculated as the dry mass of the *R. sativus* tubercle (dried at 60°C for 72 h) (g plant⁻¹).

Statistical analysis

The normality of data distribution was tested using the Shapiro-Wilk test ($p > 0.05$) (Hair et al., 2009). Once this was confirmed, compost granulometry, total coliform concentration, and the dry mass of the *R. sativus* tubercles were submitted to variance analysis at error probability of 5%. If a significant F-test result was obtained, the Tukey test was applied to compare mean values ($p < 0.05$) (Hair et al., 2009).

RESULTS AND DISCUSSION

Zeolite characteristics

There was a reduction in zeolite particle size after

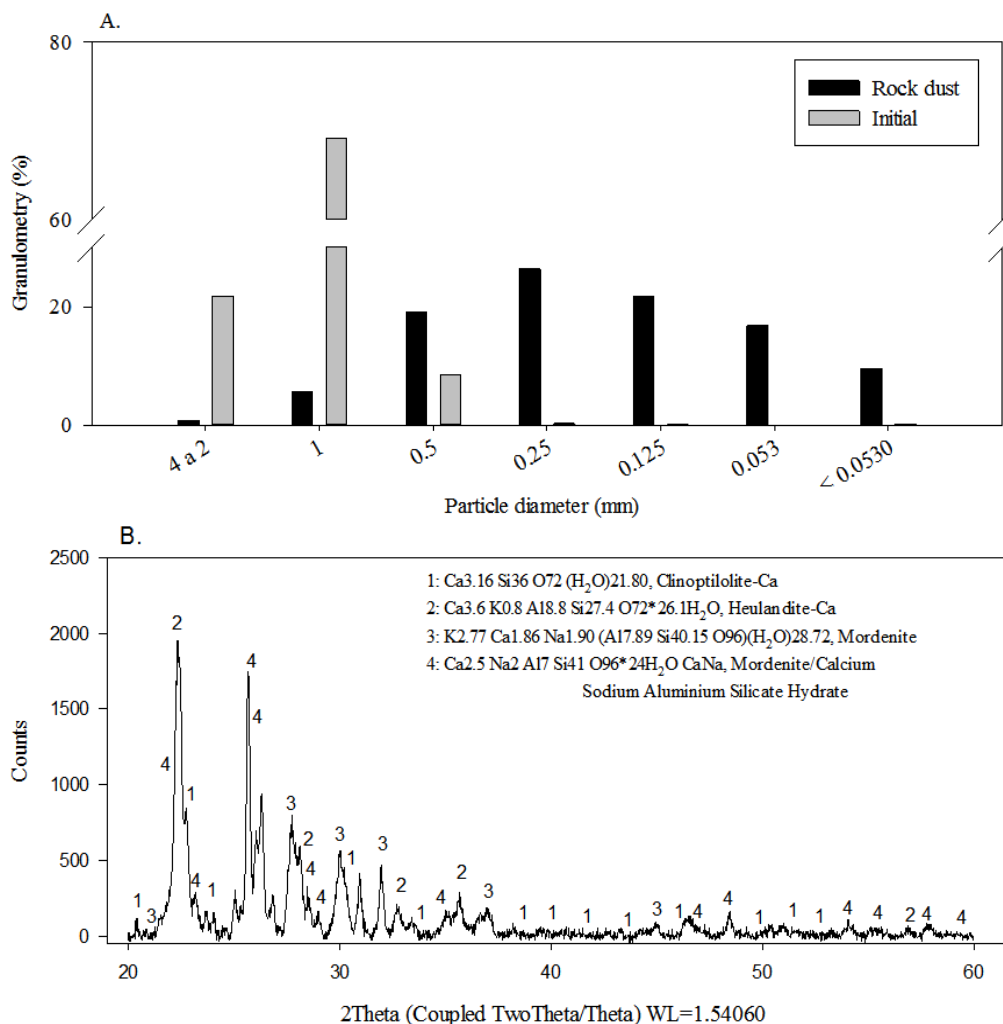


Figure 1. (A) Granulometry of zeolites before and after grinding, and (B) X-ray diffractometry of ground zeolites.

Table 2. Physical and chemical attributes of rock dust rich in zeolites.

pH ⁽¹⁾	P	K	Ca ²⁺	Mg ²⁺	Al ³⁺	H ⁺	CEC	OM
(CaCl ₂)	(mg dm ⁻³)		(cmol _c dm ⁻³)					(g dm ⁻³)
6.1	57.1	0.553	66.0	6.64	0.0	1.7	74.9	11.2

⁽¹⁾pH in CaCl₂ 0.01 mol L⁻¹ was at a proportion of 1:2.5 (rock dust:CaCl₂); exchangeable P and K were extracted with a 0.05 mol L⁻¹ HCl solution and a 0.025 mol L⁻¹ H₂SO₄ solution (Mehlich I); exchangeable Ca, Mg, and Al were extracted with 1 mol L⁻¹ KCl; H and Al were extracted with calcium acetate at pH = 7; CEC is cation exchange capacity; OM (soil organic matter content) was determined by the oxidation method with potassium dichromate and colorimetric determination (Silva, 2009).

commercial zeolites were ground, with a more homogeneous distribution in size classes (Figure 1A). The mineralogical characterization of particles showed that zeolites were rich in Ca (Figure 1B), considering that these zeolite minerals are classified as a function to the predominant alkaline or earth-alkaline metal ions (Arimi, 2017; Eroglu et al., 2017).

The predominance of exchangeable Ca was confirmed

by chemical analysis of the rock powder, which showed a high exchangeable amount of this metal, associated with a high cation exchange capacity (CEC) of 74.90 cmol_c dm⁻³ (Table 2). This zeolite mineral was classified as non-saline since the aqueous electrical conductivity of the ground zeolite sample was only 0.077 mmhos cm⁻¹ (< 0.40 mmhos cm⁻¹) (Gartley, 2011). High CEC was therefore caused mainly by adsorption and not by the

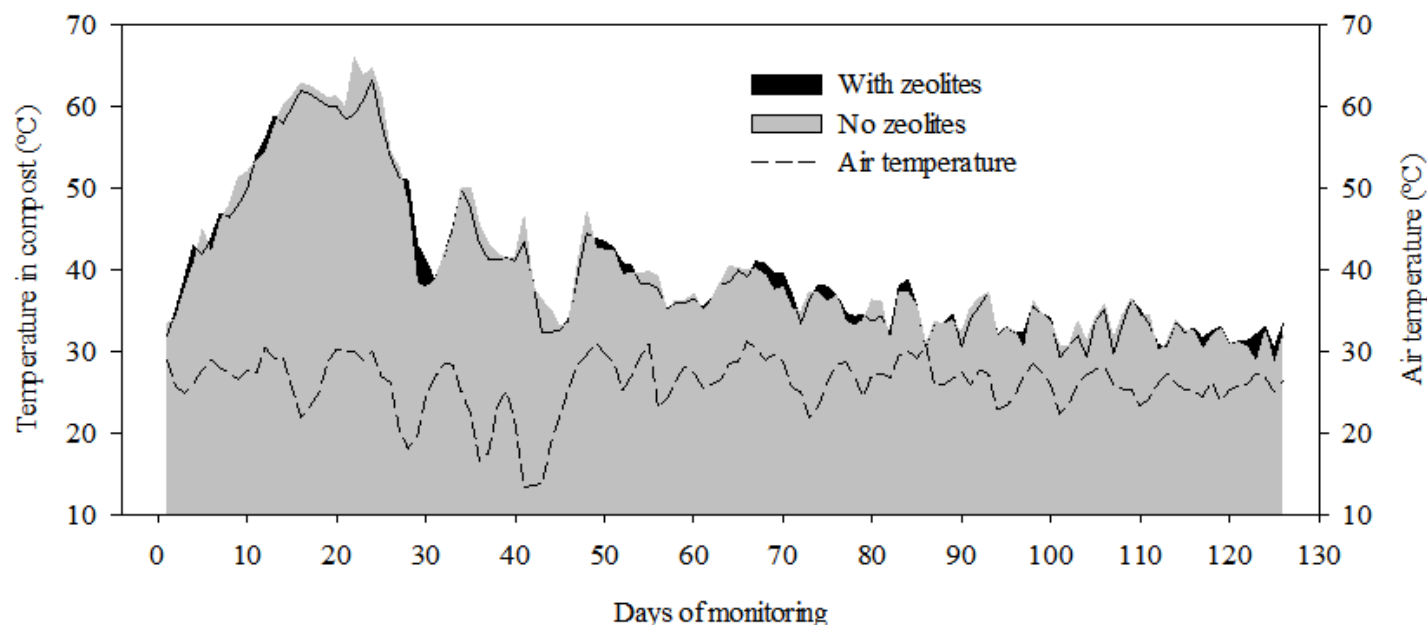


Figure 2. Temperature of air and of compost, with and without zeolites.

presence of soluble salts.

The CEC of zeolite powder was about four times that of tropical clayey soils with high CEC, that is, with CEC > 18 $\text{cmol}_c \text{ dm}^{-3}$ (Sousa and Lobato, 2004). Moreover, the soluble P content of the zeolite powder was high (> 25.0 mg dm^{-3}) and three times higher than the P content of soil used in this experiment (Table 1). Depending on the amount of zeolites mixed with the soil and whether the addition was made to a sandy soil with low CEC, a considerable increase in CEC was therefore to be expected, with benefits for development of plants cultivated in sandy soils (Bernardi et al., 2009; Barbosa et al., 2014) of natural low fertility, also contributing to reduced fertilizer losses by leaching (Taamneh and Sharadqah, 2017).

Physical characteristics of composts

No significant difference was observed in the daily temperatures of compost with and without zeolites. In fact, readings were close and strongly correlated ($r = 0.9852$; $p < 0.0001$). However, no correlation was observed between the temperatures of air and compost when considering all sampled days ($r < 0.12$; $p > 0.9889$) (Figure 2). The mean temperature of zeolite-enriched compost was 39.89°C (standard deviation, $s = 8.86$), whereas that of compost without zeolites was 40.10°C ($s = 9.36$). Nevertheless, a moderate and significant correlation between compost and air temperatures was observed ($r = 0.4625$; $p < 0.0001$, with zeolites, and $r = 0.4318$; $p < 0.0001$, without zeolites) after the 60th day,

during the humification (final composting) stage, which experiences lower biological activity (Ozimek and Kopeć, 2012).

The humification stage is characterized by a reduction in heat production and release mainly of carbon dioxide and water vapor (Kučić et al., 2013). This is because the availability of easily degradable organic matter declines over time, with the accumulation of recalcitrant material diminishing biological activity and hydrolysis of organic compounds, thereby diminishing heat release (Kiehl, 2002). Conversely, at the beginning of the composting process, compost temperature increases. The thermophile phase (40 - 65°C), which in the present study occurred from the 4th to the 41st day, is followed by the mesophile phase (predominance of temperatures from 30 to 40°C), observed from the 41st day onwards (Figure 2). The most critical phase is the latter, since it is responsible for destroying most pathogenic microorganisms. The temperature observed in the present study was within established quality criteria for aerobic composting, that is, temperatures of > 40°C for at least 14 days (National Council for the Environment, 2006).

Despite the similarity between the temperatures of both composts (Figure 2), treatment with zeolites allowed accumulation of particles with smaller diameters (Figure 3). This indicates that decomposition was favored in this treatment probably because of more adequate equilibrium between water content in the compost and its oxygenation over time (Kiehl, 2002). Since the amount of water used for irrigation was the same in both composts, the probable reason for the presence of coarser particles in the compost without zeolites was poorer oxygenation,

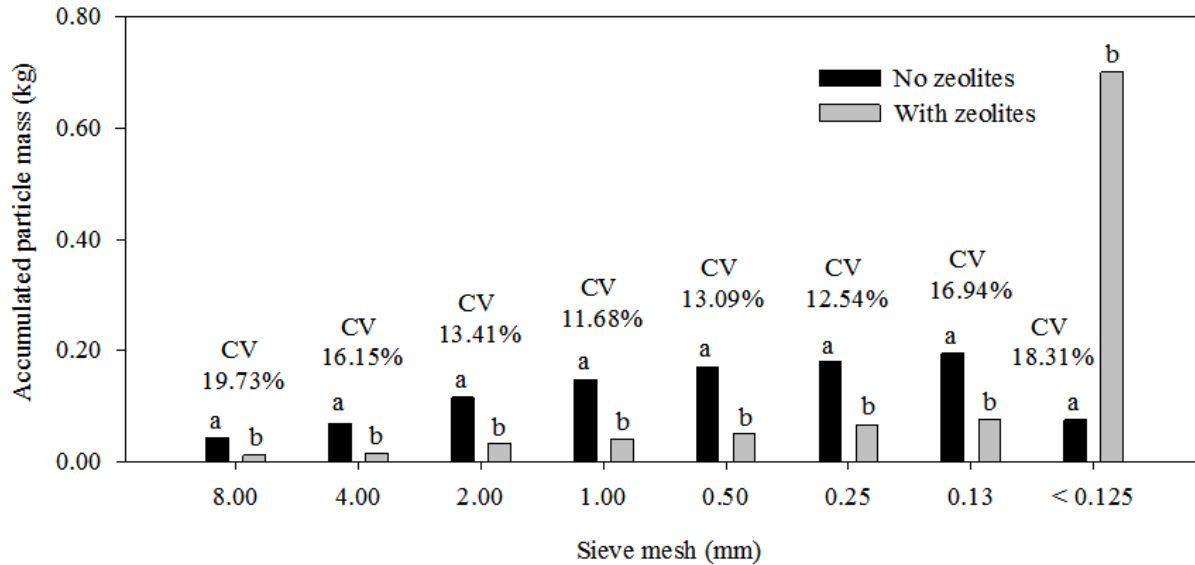


Figure 3. Granulometric curve of compost with and without zeolites, determined for a 1 kg sample. Mean values for the same sieve mesh with the same letter do not differ significantly, according to the Tukey test results ($p < 0.05$); CV: coefficient of variation.

given that the rate of anaerobic degradation of organic matter is slower than that of aerobic degradation (Erses et al., 2008). This hypothesis is justified by the higher concentration of total soluble Fe and Mn in the compost without zeolites, as discussed next.

Furthermore, whereas the humid color of zeolite-enriched compost was “dark brown” (7.5R 3/2), the color of that without zeolites was “black” (10YR 2/1), and whereas zeolite-enriched compost did not show any stickiness or capability to form a 4 cm diameter ball, the compost without zeolites showed both these characteristics. Mature organic material does not stick to the hands and does not flow through the fingers when compressed in the hand (Pons and Zonneveld, 1965), as observed with the zeolite-enriched compost. The opposite was observed for compost without zeolites, with this having low stickiness, behaving as a quasi-matured material. These observations therefore confirm reduced aerobic conditions in the compost without zeolites, that is, with slower decomposition.

Chemical compost characteristics

The greatest difference observed was a 26% increase in CEC and a reduction in soluble micronutrients (particularly Mn and Fe) in the zeolite-enriched compost, as compared to the compost without zeolites (Table 3).

It has been reported that natural zeolites promptly adsorb almost all exchangeable metals (Villaseñor et al., 2011), retaining metals by ion exchange and adsorption processes when these are released from the decomposition

of organic matter (Stylianou et al., 2008). It is therefore likely that the 81.53 and 43.64% reductions in Mn and Fe solubility, respectively, in the treatment with zeolites were related to both the adsorption capability of the zeolites and the effect of aeration caused by zeolite addition. The compost without zeolites was always more humid, favoring anaerobic chemical reactions and causing the occurrence of reduction reactions in the compost, leading to higher availability of Fe (Chérif et al., 2009) and Mn (Millaleo et al., 2010).

Microbiological compost characteristics

The addition of zeolites to the composting process reduced the concentration of total coliforms by 96% and the concentration of *E. coli* (Figure 4) by 36%. It is likely that this result was related to zeolite adsorption properties. When used as a filter in sewage treatment, a natural zeolite was found to remove approximately 70% of total coliforms present in residual water. However, this removal was not selective to a specific organism (Cifuentes et al., 2012), meaning that the high adsorption capacity of zeolites leads to retention of all types of coliforms, due to the honeycomb-like microporous structure of these minerals (Smit and Maesen, 2008; Corona et al., 2009).

E. coli does not reproduce outside the intestinal tract of warm-blooded animals (Gruber et al., 2014), that is, its presence is an indicator of recent fecal contamination. The limited reduction in *E. coli* of only 36% may be related to possible contamination of the water used for

Table 3. Chemical characterization of compost produced with and without zeolites.

Observed variables	Results in dry base		
	With zeolites (a)	Without zeolites (b)	Difference
 105°C		(a) - (b)
Total mineral residue (g kg ⁻¹)	447.8	474.6	-2.68
Insoluble mineral residue (g kg ⁻¹)	208.3	276.6	-6.83
Soluble mineral residue (g kg ⁻¹)	239.6	198.1	4.15
Total organic matter (combustion) (g kg ⁻¹)	552.2	525.4	2.68
Organic carbon (g kg ⁻¹)	172.9	143.5	2.94
pH CaCl ₂ 0.01 mol L ⁻¹ (1:5)	6.7	6.4	0.3
Total nitrogen (g kg ⁻¹)	19.5	18.9	0.06
C _{total} /N _{total} ratio	17/1	16/1	1
C _{org} /N _{total} ratio	9/1	7/1	2
Total P ₂ O ₅ (g kg ⁻¹)	13.2	12.90	-0.03
Total K ₂ O (g kg ⁻¹)	20.9	16.50	-0.44
Total Ca (g kg ⁻¹)	24.9	18.70	-0.62
Total Mg (g kg ⁻¹)	6.7	5.70	-0.1
Total S (g kg ⁻¹)	2.9	2.50	-0.04
Total Zn, mg kg ⁻¹	167.28	182.56	-15.28
Total Cu, mg kg ⁻¹	37.62	47.23	-9.61
Total Mn, mg kg ⁻¹	50.07	271.23	-221.16
Total B, mg kg ⁻¹	106.1	121.7	-15.6
Total Fe, mg kg ⁻¹	199.21	353.52	-154.31
CEC, mmolc kg ⁻¹ (1)	670	495	175

(1) CE: cation exchange capacity.

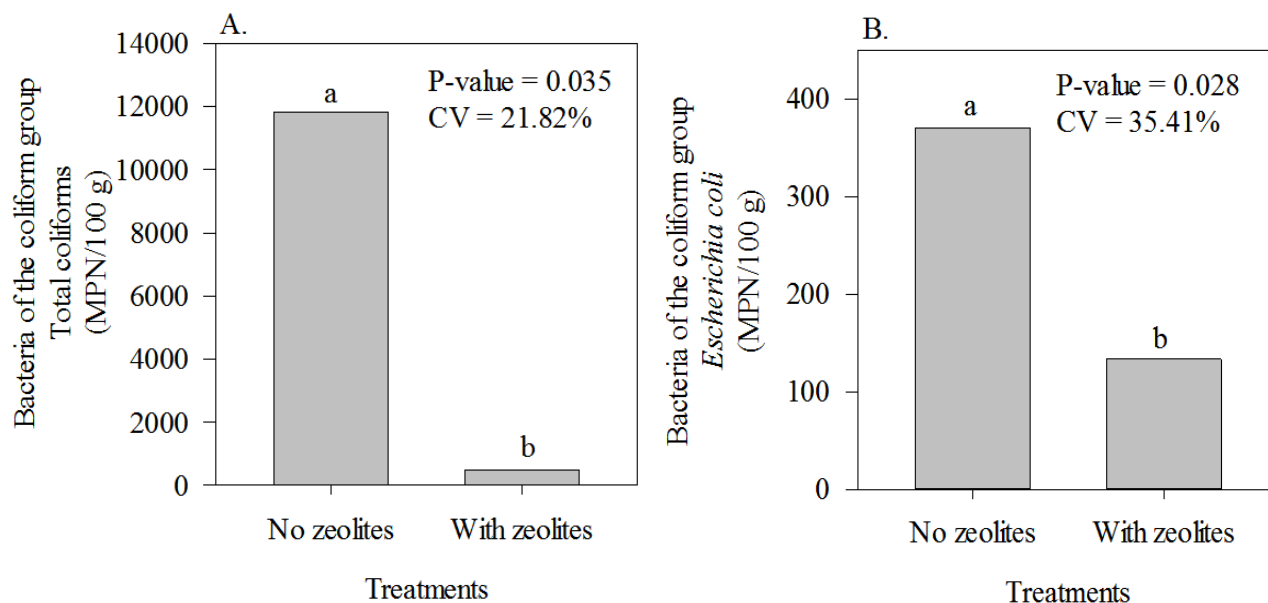


Figure 4. Mean coliform bacteria concentration in compost with and without zeolites: (A) total coliform (B) *Escherichia coli*. CV: coefficient of variation; MPN: most probable number of microorganisms.

irrigation, which was stored in water boxes placed on the soil and was used for garden watering by university

employees. Nevertheless, the use of zeolites for pathogen removal seems promising. The efficiency of

Table 4. Mean comparison test for dry mass (g) of radish roots (*Raphanus sativus*); factor 1: compost dosages; factor 3: complementary fertilization with NPK.

Doses (%)	Factor 1: General mean	Complementary fertilization with NPK	Factor 3: General mean
0	0.31063b ¹	With zeolites	0.73500a ¹
10	0.77250a	Without zeolites	0.58075b
20	0.82688a	Dms	0.07467
40	0.70500a	CV (%)	25.18
60	0.67438a	Probability F-test	< 0.0001
Dms ²	0.16603		
CV (%) ³	23.09		
Probability F-test	< 0.0001		

¹Mean values followed by the same letter do not differ statistically, according to the Tukey test ($p < 0.05$) results; ²Dms: minimum significant difference; ³CV(%): coefficient of variation. Data showed normal distribution according to the Shapiro–Wilk test ($p > 0.05$).

total coliform removal by coarse particle zeolites (> 2.36 mm) has already been demonstrated (Cifuentes et al., 2012), and an increase in the powder surface area may intensify this removal efficiency, as observed in our study, where the addition of only 0.015 kg of zeolites per kg of compost (dry base) caused a reduction of 96% in total coliforms.

Production of radish root

Statistically, no interaction between the studied factors was observed in the variance analysis. However, the general means of compost dosage and complementary fertilization with NPK differed significantly (Table 4).

In the Tukey test, factor 2, that is, treatment with and without zeolites without NPK, did not cause significant variations in radish root dry mass. However, the use of composts with zeolites, which were reinforced with base fertilization to correct soil NPK deficiencies, significantly increased root dry mass. Furthermore, the addition of only 10% compost, with or without zeolites, was important to increase radish root dry mass (Table 4). The addition of compost to soil is recommended for any greenery because of improvement in physical, chemical, and biological soil properties resulting from organic matter (Walsh and McDonnell, 2012). Similarly, an adequate amount of organic matter in soil is essential, since this enhances CEC, reducing nutrient leaching and ensuring a more constant supply of nutrients to plants (Maia et al., 2013).

Zeolites, particularly when rich in ground clinoptilolite, have been used for more than a century in Japan to improve the quality of agricultural soil because of their ability to enhance the adsorption of nutrients and water retention in soil (Luz, 1995). However, in Brazil, zeolites are mostly used in effluent treatments and, to the best of our knowledge, this is the first study evaluating the effects of zeolites on the composting process (Luz, 1995). More research is needed to evaluate the effect of

different dosages of zeolites on composting and in soil for crops with longer phenological cycles. Moreover, it is important to assess the possible role of zeolites as pesticide-retaining filters, possibly limiting contamination of groundwater. It is therefore likely that zeolites will play a more important role in agricultural practice and food safety in the near future (Eroglu et al., 2017).

Conclusions

The addition of zeolite minerals with clinoptilolite, heulandite, and mordenite to a composting process using equine organic residues improved the physical, chemical, and microbiological quality of the obtained organic compost. Regardless of the addition of zeolites to the compost, the dry mass of radish root depended upon the proportion of organic compost mixed into the soil. However, a dose of 10% gave a dry mass similar to the 60% dose. Considering the long timeframe for producing compost using traditional processes, the use of the lower dose is recommended for radish cultivation. The dry mass of the radish tuberous root was also dependent upon complementary base fertilization (NPK); when this was applied to the zeolite-enriched compost, there was an increase in root dry mass, regardless of compost dosage. Therefore, when zeolites are used in soil, it is necessary to correct its macronutrient content, including N, P, and K.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

- Alvares CA, Stape JL, Sentelhas PC, de Moraes Gonçalves JL, Sparovek G (2014). Köppen's climate classification map for Brazil. *Meteorol. Z.* 22(6):711-728.

- Arimi MM (2017). Modified natural zeolite as heterogeneous Fenton catalyst in treatment of recalcitrants in industrial effluent. *Prog. Nat. Sci. Mater.* 27(2):275-282.
- Barbosa SM, De Oliveira GC, Carducci CE, Silva BM (2014). Potential use of zeolites in attenuation water deficit in cerrado Laotosol. *Semin: Cien. Agrar.* 35(4): 2357-2368.
- Bernardi ACC, Mendonça FC, Haim PG, Werneck CG, Monte MBM (2009). Water availability and rice yield due to levels of zeolitic concentrate. *Irriga.* 14(2):123-134.
- Chérif M, Audebert A, Fofana M, Zouzou M (2009). Evaluation of iron toxicity on lowland irrigated rice in West Africa. *Tropicultura.* 27(2):88-92.
- Cifuentes DRA, Felizzola SMB, Ante CAO, Sánchez IJL (2012). Removal of pathogenic microorganisms present in mixed liquor under laboratory conditions by using filters packed in natural zeolite. *Rev. Ing. Univ. Medellín.* 11(21):39-52.
- Corona OL, Hernández MA, Hernández F, Rojas F, Portillo R, Lara VH, Carlos FM (2009). Adsorption properties in zeolites containing 8-membered rings I. Microporosity and external surface area. *Rev. Matéria.* 14(3):918-931.
- Donagema GK, Campos DVB, Calderano SB, Teixeira WG, Viana JHM (2011). "Manual de Métodos de Análise de Solo." 2. ed. Rio de Janeiro, RJ: Embrapa Solos 230 p.
- Eroglu N, Emekci M, Athanassiou CG (2017). Applications of natural zeolites on agriculture and food production. *J. Sci. Food. Agric.* 97(11):3487-3499.
- Erses AS, Onay TT, Yenigun O (2008). Comparison of aerobic and anaerobic degradation of municipal solid waste in bioreactor landfills. *Bioresour. Technol.* 99(13):5418-5426.
- Gartley KL (2011). Recommended methods for measuring soluble salts in soils. In: Northeast Coordinating Committee for Soil Testing (Ed.). "Recommended Soil Testing Procedures for the Northeastern United States." 3rd ed. Newark, DE: University of Delaware, College of Agriculture and Natural Resources, pp. 87-94.
- Giacomini DA, Aita C, Pujol SB, Giacomini SJ, Doneda A, Cantú RR, Dessbesell A, Lüdtke RC, Silveira CAP (2014). Mitigation of ammonia emissions by natural zeolites during pig slurry composting. *Pesq. Agropec. Bras.* 49(7):521-530. (In Portuguese).
- Gruber JS, Ercumen A, Colford JM (2014). Coliform bacteria as indicators of diarrheal risk in household drinking water: Systematic review and meta-analysis. *PLoS One.* 9(9):1-14.
- Hair JF, Black WC, Babin BJ, Anderson RE, Tatham RL (2009). "Análise Multivariada de Dados." Passo Fundo: Bookman 688p.
- ICDD(2018). The International Centre for Diffraction Data. Available in: <http://www.icdd.com/> Access in: 02/22/2018.
- Kiehl EJ (Ed.) (2002). Manual de Compostagem: Maturação e Qualidade de Composto." 3rd ed. Piracicaba: Publisher, 171p.
- Kučić D, Kopčić N, Briški F (2013). Zeolite and potting soil sorption of CO₂ and NH₃ evolved during co-composting of grape and tobacco waste. *Chem. Pap.* 67(9):1172-1180.
- Luz AB (1995). "Zeólitas: Propriedades e Usos Industriais." Rio de Janeiro: CETEM/CNPq. 35 p.
- Maia CMBF, Novotny EH, Rittl TF, Hayes MHB (2013). Soil organic matter: Chemical and physical characteristics and analytical methods. A review. *Curr. Org. Chem.* 17(14):2985-2990.
- Millaleo R, Reyes-Díaz M, Ivanov AG, Mora ML, Alberdi M (2010). Manganese as essential and toxic element for plants: Transport, accumulation and resistance mechanisms. *J. Soil. Sci. Plant. Nutr.* 10(4):476-494.
- Moore DM, Reynolds RC (1997). "X-ray diffraction and the Identification and Analysis of Clay Minerals." 2. ed. New York: Oxford University Press, 400 p.
- National Council for the Environment (Conselho Nacional Do Meio Ambiente) (2006). Resolução Conama No. 380, de 31 de Outubro de 2006." Available from: <http://www.mma.gov.br/port/conama/legiabre.cfm?codlegi=514>. Accessed: Nov. 2017.
- Ozimek A, Kopeć M (2012). Assessment of biological activity of biomass at different stages of composting process with use of the OxiTop control measurement system. *Acta Agrophys.* 19(2):379-390.
- Pereira AR (2011). Balanço Hídrico Para Irrigação de Precisão Aplicada em Pomares. Campinas: Fundag 90 p.
- Pons LJ, Zonneveld IS (1965). Soil Ripening and Soil Classification: Initial Soil Formation of Alluvial Deposits with a Classification of the Resulting Soils. Wageningen: International Institute of Land Reclamation and Improvement, 128 p. <http://edepot.wur.nl/60013>
- Resende NGAM, Mello Monte, MB (2008). Zeólitas Naturais. In: Luz AB, Lins FAF (Ed). Rochas and minerais Industriais: usos e especificações. 2.Ed. Rio de Janeiro: CETEM/MCT pp. 669-720.
- Sangeetha C, Baskar P (2016). Zeolite and its potential uses in agriculture: A critical review. *Agric. Rev.* 37(2):101-108.
- Santos HG, Jacomine PKT, Anjos LHC, Oliveira VA, Lumbrellas JF, Coelho MR, Almeida JA, Cunha TJF, Oliveira JB (2013a). "Sistema Brasileiro de Classificação de Solo." 3rd ed. Rio de Janeiro, RJ: Embrapa Solos. <http://vendasliv.sct.embrapa.br/liv4/efetuaPedido.do?metodo=adicionar&codigoProduto=00084450>
- Santos RD, Lemos RC, Santos HG, Ker JC, Anjos LHC, Shimizu SH (2013b). "Manual de Descrição e Coleta de Solo no Campo." 6th ed. Viçosa: Sociedade Brasileira de Ciência do Solo 102 p.
- Silva FC (2009). "Manual de Análises Químicas de Solos, Plantas e Fertilizantes." 2nd. ed. Brasília: Embrapa Informação Tecnológica. 627 p.
- Smit B, Maesen TLM (2008). Molecular simulations of zeolites: Adsorption, diffusion, and shape selectivity. *Chem. Rev.* 108(10):4125-4184.
- Sousa DMG, Lobato E (2004). "Cerrado: Correção do Solo e Adubação." 2. ed. Brasília: Embrapa Informação Tecnológica. 416p.
- Stylianou MA, Inglezakis VJ, Moustakas KG, Loizidou MD (2008). Improvement of the quality of sewage sludge compost by adding natural clinoptilolite. *Desalination* 224(1):240-249.
- Taamneh Y, Sharadqah S (2017). The removal of heavy metals from aqueous solution using natural Jordanian zeolite. *Appl. Water. Sci.* 7(4):2021-2028.
- US Geological Survey (2016). Mineral Commodity Summaries 2016. Available from: <http://dx.doi.org/10.3133/70140094>. Accessed: Nov. 2017.
- Villarreal-Núñez JE, Barahona-Amores LA, Castillo-Ortiz AO (2015). Effect of zeolite on the nitrogen fertilizer efficiency in rice crop. *Agron. Mesoam.* 26(2):315-321.
- Villaseñor J, Rodríguez L, Fernández FJ (2011). Composting domestic sewage sludge with natural zeolites in a rotary drum reactor. *Bioresour. Technol.* 102(2):1447-1454.
- Walsh E, McDonnell KP (2012). The influence of added organic matter on soil physical, chemical, and biological properties: A small-scale and short-time experiment using straw. *Arch. Agron. Soil Sci.* 58(1):201-205.