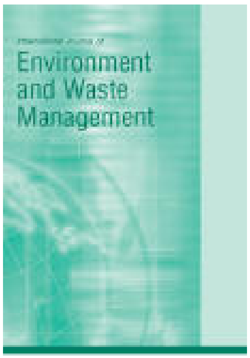

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Influence of fine waste from dimension stone processing on vermicomposting

Mirna A. Neves, Rodrigo S. de Faria, Eduardo de Sá Mendonça

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Influence of fine waste from dimension stone processing on vermicomposting

Mirna A. Neves*

Department of Geology,
Centre for Exact, Natural and Health Sciences,
Federal University of Espírito Santo, Brazil
Email: mirnaan@gmail.com
*Corresponding author

Rodrigo S. de Faria

Ache Laboratory,
Serra, Espírito Santo, Brazil
Email: rodrigosouzadefaria@yahoo.com.br

Eduardo de Sá Mendonça

Plant Production Department,
Centre for Agricultural Sciences and Engineering,
Federal University of Espírito Santo, Brazil
Email: eduardo.mendonca@ufes.br

Abstract: The fine wastes from dimension stone processing, generated when blocks of rock are cut into wall tiles, contain chemical elements essential for mineral enrichment of soil. However, these wastes have macro and micronutrients stocked in the crystalline structure of silicate minerals. The aim of this work was to use the vermicomposting process for increasing the release of these nutrients from dimension stone residues. In laboratory, different percentages of rock waste were mixed with an organic substrate, where worms (*Eisenia foetida*) were inoculated and maintained for 180 days. Vermicomposting occurred in all the treatments but was more efficient in the treatment with 25% of rock waste mixed into the organic matter. During the vermicomposting process, the rock powder added elements to the substrate, raising the concentration of Ca, Fe, Mn, Cu, Na and B. The pH-values increased, but remained at safe levels, even in the treatment with 50% of rock waste.

Keywords: stone meal; recycling; humus; earthworm; *Eisenia foetida*.

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Biographical notes: Mirna A. Neves is a Professor and researcher at the Department of Geology, Federal University of Espírito Santo, Brazil. Her areas of interest are environmental geology, water resources, and waste management. In the last decade she has south to understand the interactions between

industrial effluents and the environment, mainly involving the water and soil matrices. In response to a request of the state environment agency, she conducts research about the environmental behavior of the wastes from the dimension stone industry, which are discarded after sawing blocks and polishing plates of rocks. The use of wastes for diverse proposes also has been the focus of her research, such as applying rock waste as an amendment for soil mineral enrichment or as an aggregate for building material.

Rodrigo S. de Faria is a Zootechnician who graduated from the Federal University of Espírito Santo, Brazil. During his academic years, he studied the behaviour of earthworms and the production of organic compounds aggregated with inorganic residues. His academic job was funded by the Research Foundation of Espírito Santo State - FAPES, Brazil, in form of a fellowship and material for the research involving earthworms and production of vermicomposting aggregated with rock wastes. He also worked with teaching on agrarian and environmental fields, mainly on topics of interest to family farming and sustainable development. He has a specialisation degree in environmental technology and his current job is in the pharmaceutical industry.

Eduardo de Sá Mendonça is a Professor and Researcher at the Department of Agronomy, Federal University of Espírito Santo, Brazil. His research areas are on soil organic matter dynamic in tropical ecosystems; use of organic residues in agriculture; methods of organic matter studies in tropical ecosystems; dynamic and modelling of nutrients in organic agriculture and agroecological ecosystems.

1 Introduction

Brazil ranks among the world's leading producers of dimension stones and the state of Espírito Santo, in Southeastern Brazil, produces most of the country's marbles and granites, which are destined mainly for export markets (Brasil, 2019). These products are commercialised in the form of natural stone wall tiles and numerous other products used in the construction industry.

Cutting rocks into natural stone tiles generates a fine waste, also called abrasive slurry, which is composed by rock powder, lime, steel particles and water. These materials have properties that allow them to be used in various productive sectors, but they are frequently stored or disposed improperly, posing an environmental risk.

Given the paucity of research on the subject, there is no consensus about the real risk of environmental impacts caused by these wastes. Following the Brazilian technical standard NBR 10004 (ABNT, 2004), some authors (e.g., Braga et al., 2010; Manhães and Holanda, 2008) classify these wastes as non-inert, which means that they can release chemical substances into the environment. The fact that they release mineral nutrients into the environment indicates that these materials can be used as stone meal in agriculture. However, it is necessary to ensure that the elements released into the environment are suitable and that they will not surpass the thresholds defined by environmental laws.

Investigating alternative ways to treat and/or use disposable materials is considered essential to ensure the sustainability of industrial processes. In this context, efforts should focus on minimising environmental impacts while simultaneously generating profits from the use of wastes.

As for organic wastes, several studies have demonstrated the effectiveness of composting and vermicomposting to transform useless materials into reusable ones or to ensure their safe disposal. The treatment of organic wastes can prevent contamination with pathogenic organisms, help immobilise nitrogen because of the high C:N ratio, and prevent changes in soil pH levels resulting from the acidity or alkalinity of these wastes (Castilhos et al., 2008).

Composting accelerates the decomposition of organic matter and gives rise to a more stable product, while minimising odors and eliminating pathogenic organisms during the thermophilic phase (Ndegwa and Thompson, 2001). In the vermicomposting process, earthworms digest organic matter, causing its degradation (Kiehl, 1985). These worms are nourished by microorganisms that live in organic wastes, and the resulting fecal matter is more microbiologically active, finer, and more homogeneous than the original material (Ndegwa and Thompson, 2001). Vermicompost plays an important role in the formation of soil aggregates, the control of acidity, nutrient cycling, and waste decontamination (Landgraf et al., 2005).

Composting followed by vermicomposting represents a highly efficient treatment system that produces a substrate richer in nutrients than the original materials, since elements such as N, K, P, and Ca are transformed into soluble forms and become available for plants (Ndegwa and Thompson, 2001; Singh and Sharma, 2002). The weathering of K-feldspar is accelerated by earthworms on soil, promoting the nutrient cycling of the ecosystem (Liu et al., 2020). Moreover, while organic wastes are processed, earthworms can be raised for profit, since they reproduce quickly while the problematic substrate is processed (Costa et al., 2005).

Composting and vermicomposting are used for stabilisation and sanitation of biosolids from urban areas (Correa et al., 2007; Li et al., 2020). These materials can be mixed with other types of wastes, such as sugarcane bagasse (Silva et al., 2010) and wastes from paper and pulp mills (Mohapatra et al., 2019; Elvira et al., 1997). Agricultural wastes can be treated similarly (Amorim et al., 2005; Karmegam et al., 2021), as well as cotton carding waste (Costa et al., 2005; Tejada et al., 2001; Madejón et al, 2001), household solid waste (Loureiro et al., 2007) and even brewers' spent grains (Budroni et al., 2020). All the aforementioned researchers found that earthworms survived and reproduced during vermicomposting of various types of waste and processed the material efficiently.

Fine wastes from dimension stone processing are rich in elements that are important for soil enrichment with minerals, but most of these substances are insoluble. According to Lapido-Loureiro et al. (2009), the contact between rock and microorganisms or substances derived from microbial metabolism can biosolubilise chemical elements. From this premise, we aimed, in this work, to examine the effect of the addition of fine wastes generated in dimension stone processing on the vermicomposting process for the mineral enrichment of earthworm castings.

2 Material and method

The mixtures used here, as substrate for vermicomposting, were organic compost and fine wastes generated by dimension stone processing.

Table 1 Chemical characteristics and size particle of the rock waste used in the experiment

pH	*Ca*	*Mg*	*Na*	*K*	*Fe*	*Mn*	*Cu*	*Zn*	*coarse sand*	*fine sand*	*silt*	*clay*
	--- cmol.dm-3---		------------------- mg.dm-3 -------------------						----------------- g.kg-1 -----------------------			
9.0	2.8	0.4	439.0	449.0	3,172.0	83.0	3.3	4.8	147.0	175.0	578.0	100.0

Note: Grain size - coarse sand: 2.0 to 0.2 mm, fine sand: 0.2 to 0.05 mm, silt: 0.05 to 0.002 mm, clay: minor then 0.002 mm.

Table 2 Characteristics of the organic compost used in the experiment

pH	*MR-sol*	*OM-com*	*Ca*	*Mg*	*N*	*P*	*K*	*Fe*	*Mn*	*Cu*	*Zn*	*Na*	*B*
	---------- $g.kg^{-1}$ ----------							---------- $g.cm^{-3}$ ----------					
6.7	350.80	188.70	6.50	3.40	9.50	5.70	3.50	8876.0	281.0	24.0	96.0	874.0	3.0

Note: MR-sol = soluble mineral residue, OM-com = compostable organic material.

The waste rock was collected from a rock processing company in Cachoeiro de Itapemirim, located in the southern part of the State of Espírito Santo, Brazil. The material was collected, using a hand-drilling machine, at a landfill containing stone cutting waste from various types of silicate rock. Samples of this waste were analysed by X-Ray fluorescence spectrometry, and the results are presented in Table 1. The high pH levels and the concentration of Fe and Mn, and part of Ca and Mg are due to the lime and steel particles contained in the slurry. The other parameters pertain to the processed rocks, that are mainly igneous rocks.

The organic matter used for composting consisted of a mixture of cow manure and Napier grass (*Pennisetum purpureum*) in a 3:1 ratio. The material was separated into piles and stored outdoors but protected from rain, irrigated, and mixed once a week for 90 days. During the first 20 days of composting, the temperature of the material varied from 30ºC to 50ºC, reaching 60ºC on day 10, thereafter stabilising at approximately 27ºC. After 90 days of composting, the organic compost was analysed (Table 2) according to the method described below.

The organic compost and the waste rock were air dried, disaggregated, and sifted through a 2 mm mesh sieve. The experiment was conducted in a completely randomised design, with five treatments and three replications. The treatments consist of mixtures of organic compost with the addition of 0, 12.5, 25.0, 37.5 and 50.0% of waste rock (Table 3), mixed for 30 minutes and then stored in 10 L polyethylene containers with drainage holes.

Table 3 Composition of the treatments that constituted the experimental units, where the worms were inoculated

Treatments (% in mixing)	
Organic compost	*Rock waste*
100.0	0.0*
87.5	12.5
75.0	25.0
63.0	37.0
50.0	50.0

Note: * blank sample or testimony.

40 adult earthworms (in reproductive phase) of the species *Eisenia foetida*, corresponding to about 13 grams of worms, were placed in each container. The containers were kept under a roof and were protected at the top and bottom by a screen to allow for water drainage and to prevent the entrance of predators. The contents of the containers were irrigated every two days, and moisture was checked daily to prevent dryness or saturation of the substrate. Natural ventilation was provided on hot days to keep the temperature at about 25ºC.

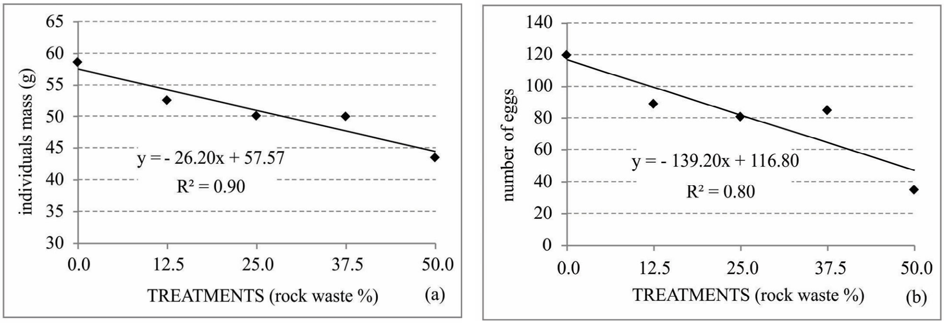
The experiment was finalised after 180 days. According to previous works (e.g., Benitez et al., 1999; Lowe and Butt, 2005), in this period the earthworms have already reached reproductive maturity. The earthworms and their eggs were removed from the containers; eggs were counted manually, and individuals weighed on a precision scale. The substrates were quartered five times to obtain 250 g of samples, which were stored in polyethylene jars, cooled and sent to the laboratory.

The samples were analysed according to the procedures described in Brasil (2014). Measurements were taken of the samples' pH levels, using CaCl2 0.01mol.L-1; the mineral residues were determined through the loss on ignition; the quantification of N levels used the sulfuric digestion (Kjeldahl method); organic Carbon (C-org) and compostable organic matter (OM-com) were quantified by titulometry using dichromate; P through the spectrophotometric method of molybdovanadophosphoric acid; Ca, Mg, Cu, Fe, Mn and Zn were extracted by HCl and measured through atomic absorption spectrometry; Na and K were determined by flame spectrometry; and B by colorimetry using azomethine H.

3 Results

The earthworms survived in all the experimental units, although their growth and oviposition diminished in response to increasing amounts of waste rock added to the organic compost (Figure 1). The addition of 50% of waste rock reduced the mass of earthworms by 25.7%, while the number of eggs decreased to 70.8% of the number found in pure vermicompost.

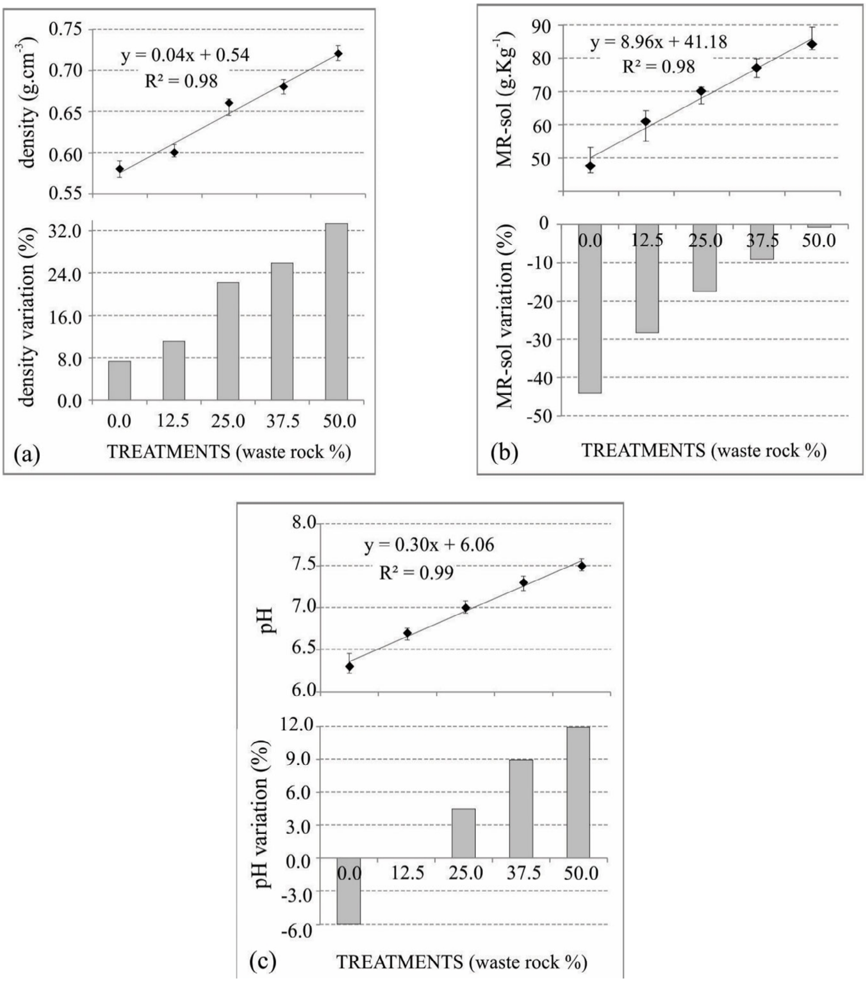
Figure 1 (a) Total mass of earthworms and (b) number of eggs in each experimental unit at the end of the experiment (after 180 days of vermicomposting)



The density of the mixtures increased gradually in response to increasing amounts of waste rock added to the organic compost [Figure 2(a)]. This was ascribed to the high Fe content in the steel particles used for sawing rocks. The density of the blank sample increased by 7.4% in comparison to that of the original compost, possibly as a result of water percolation. The addition of 50% of waste rock to the organic compost caused the density of the vermicompost to increase by 33%. Along with the increase in density, the permeability of the vermicompost may also have diminished with the addition of the waste rock. The soluble mineral residue (MR-sol) increased in response to increasing percentages of waste [Figure 2(b)]. The blank sample contained 40% of mineral residue, but this percentage dropped to only 1% in the sample containing the largest amount of waste rock. The addition of rock powder in the mixtures caused the increase of pH levels, which is explained by the high pH of the waste [Figure 2(c)]. The unprocessed compost showed a pH level of 6.7, while that of the blank sample (pure vermicompost, 0% of waste) decreased to 6.3. The pH of the vermicompost became neutral after the addition of

25% of waste rock to the organic compost and, at the highest dosage (treatment with 50% of waste rock), the pH was around 7.5.

Figure 2 (a) Density, (b) soluble mineral residue (MR-sol), and (c) pH-values of the substratum after vermicomposting and variations relative to the pure unprocessed compost (0.0 = blank sample)



The analysis of the compostable organic matter (OM-com) [Figure 3(a)] showed that the addition of 12.5% of waste rock to organic compost favoured the vermicomposting process. In the samples treated with up to 25% of waste, the loss of OM-com was lower than in the organic compost, and in the treatment with 37.5% of waste, the result was the same as that obtained with the blank sample. The OM-com in the blank sample was about 60% lower than in the original compost. On the other hand, in the sample containing 50% of waste rock, the OM-com decreased to 68%, i.e., it was 8% lower than in the blank sample.

Figure 3 Concentrations of (a) compostable organic material (OM-com), (b) N, (c) P, (d) K, (e) Ca and (f) Mg in the treatments after vermicomposting and variations relative to the pure unprocessed compost (0.0 = blank sample)

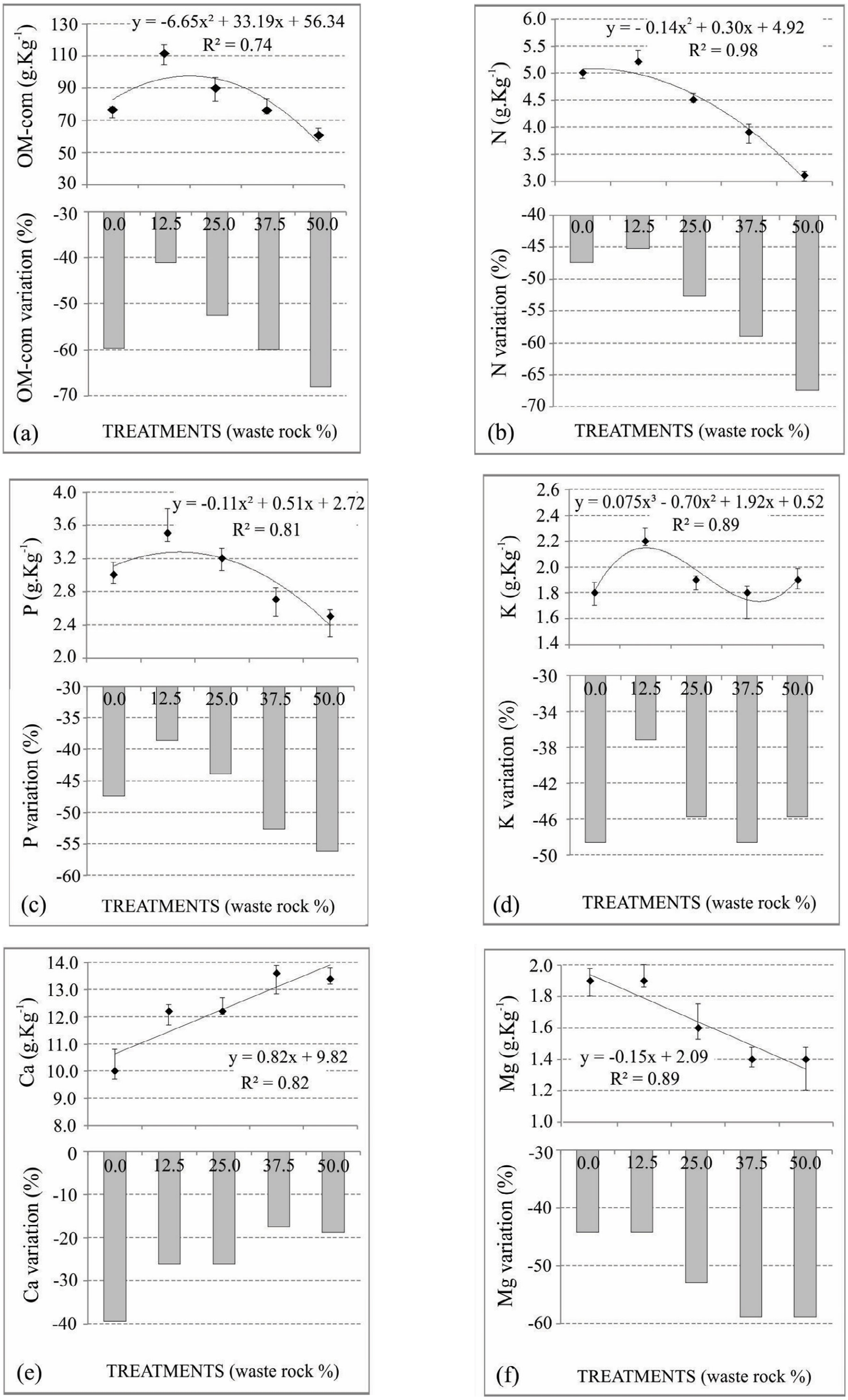
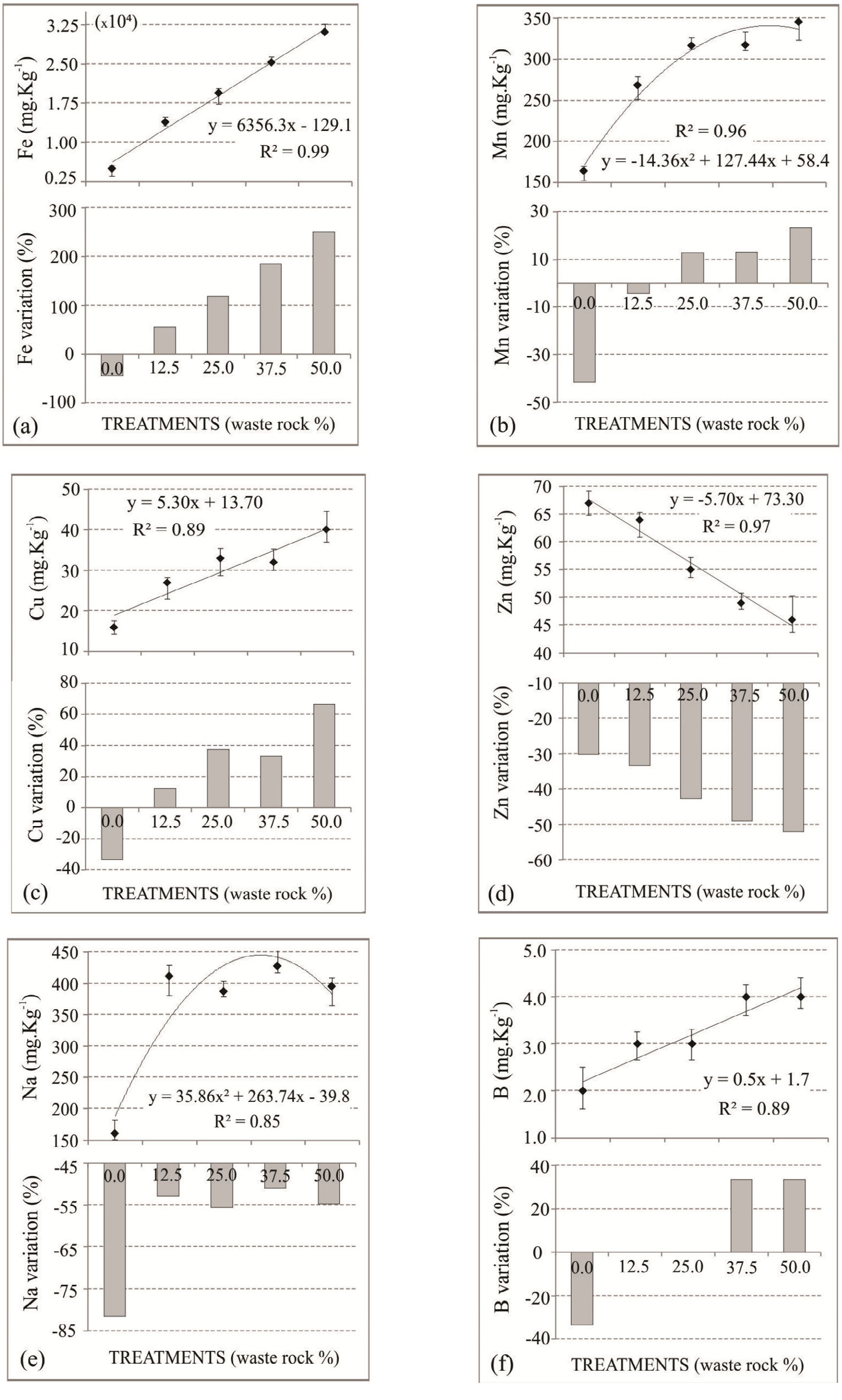


Figure 4 Concentrations of (a) Fe, (b) Mn, (c) cu, (d) Zn, (e) Na and (f) B in the treatments after the vermicomposting and their variations relative to the pure unprocessed compost (0.0 = blank sample)



In the blank sample loss of 47% in N and P, and of 49% in K occurred, in comparison to the original compost [Figures 3(b), 3(c) and 3(d)]. The contents of K did not show a clear tendency, but the variation in comparison to K content in the original compost indicates loss through leaching. By the other hand, the levels of Ca raised with increasing dosage of waste [Figure 3(e)]. The Mg concentrations decreased after the experiment [Figure 3(f)] and the rock waste was not able to supply this element due to the low Mg levels in the silicate rocks.

In this experiment, the ratio of organic C to total N (C:N-org) varied from 9:1, in the pure vermicompost, to 12:1 in the treatment with 12.5% of waste, and remained in 11:1 in the other treatments (Table 4).

Table 4 Relations between C and N in the treatments after vermicomposting

Relation	*TREATMENTS (percentage of waste rock)*				
	0.0%	*12.5%*	*25.0%*	*37.5%*	*50.0%*
C-org:N	9:1	12:1	11:1	11:1	11:1

Note: (C-org:N = relation between organic carbon and total nitrogen content).

The unprocessed compost was rich in Fe, Mn, Cu, and Zn (Table 2), but all these elements underwent leaching during the experiment. However, the Fe, Mn, and Cu concentrations increased through the addition of waste rock to the mixtures [Figures 4(a), 4(b) and 4(c)]. Zn was the only micronutrient that decreased with the addition of wastes [Figure 4(d)]. Considering that Zn was present in the tested waste, it is possible that the earthworms consumed this element during vermicomposting or that it was complexed with the mineral fraction. The Na underwent strong leaching in the blank sample, but in the other treatments, its loss was minimal because this element was supplied by the waste rock [Figure 4(e)]. The same applies to B, whose concentration diminished in the pure vermicompost but increased in the other treatments [Figure 4(f)].

4 Discussion

During the vermicomposting process, the growth rate of adult earthworm populations tends to decline due to the increase in population density (Ndegwa et al., 2000) or to the decrease in available food, depending on the stabilisation of the organic matter (Aquino et al., 2005). In our work, the quantification of individuals took into account the total mass of worms (not just the adult individuals), which was reduced due to the decline in available food as a result of the introduction of waste rock. Besides that, the fine texture of these wastes reduced the permeability of the substrate and increase its density. Bertossi et al. (2012) conducted experiments to test the effects of fine rock wastes on soil permeability and found that the addition of 40% of wastes to soil reduced its hydraulic conductivity but did not render the material impermeable. In fact, large amounts of fine wastes can potentially seal the substrate, which should make it difficult for earthworms to grow and reproduce, although it did not prevent them from surviving.

Regarding to chemical characteristics of the vermicompost, the pH levels provide reliable information about the decomposition of organic matter subjected to fermentation (Kiehl, 1985). The pH of stabilised composts made from different types of organic wastes is usually alkaline (Bernal et al., 1998; Tejada et al., 2001; Veras and Povinelli, 2004;

Costa et al., 2005). While the pH of bio-stabilised composts is expected to be close to neutral, that of humified compost is expected to be higher. In the experiment presented here, the pH of the vermicompost became neutral only after the addition of 25% of waste rock to the organic compost, in response to the alkalinity of the waste. This indicates that the material became bio-stabilised but not necessarily humified.

The ideal soil pH level for agriculture ranges from 5.5 to 6.5, and the availability of micronutrients may decrease at higher levels (Malavolta, 2006). In the case of acidic soil, some researchers have discussed the possibility of using waste rock for correcting the pH (e.g., Raymundo et al., 2013; Tozsin et al., 2015) and for mineral enrichment of soil (Fyfe et al., 2006; Theodoro and Leonardos, 2006; Silva et al., 2008). In such cases, the addition of organic matter with alkaline pH could be an ecologically safe alternative. A relevant data showed here is that the maximum pH-value reached with adding 50% of rock waste in the organic compost was near 7.5, which is an environmentally safe level.

Reduction in the N levels occurred due to volatilisation during the vermicomposting process. This loss was probably caused by the earthworms mixing the material, which accelerated the process of compost mineralisation. According to Da Silva et al. (2002), through the intake of organic matter, earthworms break the structures of organic compounds and provide P. However, the vermicompost produced in our experiment was not enriched in this element when compared to the unprocessed compost. The levels of P also decreased, probably because of the retention in the earthworm's digestive tracts (Rodriguez et al., 2000), reducing the amount of P available in the vermicompost. P can also be retained in the organic matter through chemical bonds with the O of reactive groups (Stevenson, 1994), reducing the levels of available P.

The access of earthworms to the OM was hindered by the decrease in permeability, and possibly by the complexation of OM with the mineral compounds. Therefore, a significant portion of the organic matter was not processed during the vermicomposting. Nevertheless, the C:N ratio is the parameter traditionally used for determining the maturity of an organic compost (Loureiro et al., 2007) and, in stabilised organic matter, this ratio is about 10:1 (Kiehl, 1985). The values measured in the ratio of organic C to total N (C:N-org) were even better than those found by Ramnarain et al. (2019) in vermicompost obtained from pure organic material (grass, rice straw and cow manure).

The pure organic compost underwent strong leaching of mineral nutrients, and the waste rock supplied minerals to the vermicompost. Therefore, it is relevant to highlight the potential of using the mixing of rock waste with organic compost for soil liming. Soil liming (adding basic compounds containing Ca and Mg to soil for neutralising acidity) is an important practice in tropical regions where the soil is acidic. Among other advantages, this procedure increases soil pH, immobilises toxic metals such as Al, Fe and Mn, supplies Ca and Mg, and increases the effective cation exchange capacity (Prezotti et al., 2007). According to Mupambwa and MnKeni (2018), vermicomposting process can improve nutrient mineralisation in organic wastes amended with inorganic materials as rock powder.

Special attention is required to the levels of Fe, Mn, and Cu, which, in high levels, can be toxic for plants and, in excessive amounts, could impair soil permeability by forming lateritic crusts and undergo leaching to the groundwater. However, these elements tend to immobilise when the pH is close to neutral. Some researchers used marble wastes to immobilise toxic metals in mining areas, which was achieved by correcting pH levels (Pérez-Sirvent et al., 2007). Important to report that the presence of these elements in the studied waste is probably due to the cut in conventional looms, that use steel particles for sawing rocks. By using diamond wire looms, these elements will probably be absent or occur in safe concentrations.

The high Na content in the waste had to be evaluated carefully because of the possibility of soil salinisation. In addition to salinity, an excess of Na can cause toxicity, wilting and death of plants (Prezotti et al., 2007), particularly in arid and semi-arid regions where poor drainage favours the accumulation of salts. In regions of humid climate, the high mobility of Na promotes its rapid lixiviation, which can become a problem in the percolation water (Ayers and Westcot, 1994). Relating to the element B, its concentration in soil is not prefixed, and the composts produced in this study can meet the needs of some cultivations (Correa et al., 1985).

Although the heavy metals were not focused here, it is relevant to point out some constraints in this line. Souza et al. (2019) relate that gneiss powder can improve the chemical quality of the vermicompost, without causing the rising of heavy metals in plants and soil, while another rock type (steatite) should be treated with caution as a fertiliser because of the high amount of Ni and Cr. Also studying rock dust waste in Brazil, Vitó et al. (2020) found Cd concentrations in residual rock dust waste above the maximum permitted limit for remineralisers and substrates for plants.

5 Conclusions

The addition of fine wastes from dimension stone processing to the organic compost did not hinder the vermicomposting process. Even at high doses, i.e., 50% of waste rock added to the organic compost, the earthworms survived and reproduced. However, a reduction in the permeability of the vermicompost was observed, impairing the growth of earthworms.

Although the vermicomposting process was successfully achieved in all treatments, its effectiveness diminished with increasing percentages of waste rock mixed into the organic matter. The best vermicomposting performance was attained in the treatment with 25% of waste mixed into the organic compost.

The waste rock supplied Ca, Fe, Mn, Cu, Na and B to the organic substrate and raised the pH-value of the vermicompost up to 7.5, at the highest dosage applied (treatment with 50% of waste rock). The contents of Fe and Mn detach the advantage of using diamond rock saws to prevent the release of heavy metals into the waste.

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