Applied Soil Ecology 69 (2013) 56–60

Contents lists available at SciVerse ScienceDirect

Applied Soil Ecology

journal homepage: www.elsevier.com/locate/apsoil

Vermicomposting with rock powder increases plant growth

Maria Eunice Paula de Souza[a], André Mundstock Xavier de Carvalho[a], Daniely de Cássia Deliberali[a], Ivo Jucksch[a], George Gardner Brown[b], Eduardo Sá Mendonça[c], Irene Maria Cardoso[a,*]

[a] Soil Science Department, Federal University of Viçosa, Av. P.H. Rolfs s/n, Campus universitário Viçosa, MG, CEP 36570-000, Brazil
[b] Embrapa Forestry, Estrada da Ribeira Km. 111, C.P. 319, Colombo, PR, CEP 83411-000, Brazil
[c] Federal University of Espirito Santo, Agriculture Science Center, Plant Production Department, 29500-000 Alegre, ES, Brazil

ARTICLE INFO

Article history:
Received 19 December 2010
Received in revised form
28 December 2012
Accepted 21 January 2013

Keywords:
Earthworms
Rock powder
Eisenia andrei
Soil fertilisation
Maize

ABSTRACT

The growth of earthworms in substrates enriched with rock (gneiss and steatite) powder, and the potential of vermicomposting in increasing solubilisation of minerals present in rock powder and in promoting plant growth were evaluated. Cattle manure (400 g), was enriched with 0, 5 and 20% of gneiss or steatite powder. Each pot with this mixture received nine earthworms (*Eisenia andrei*), at a density of 1000 indiv. m^{-3}. After 60 d, earthworms were collected, counted and weighed (fresh and dry). Maize was cultivated in a greenhouse in pots with an Oxisol that was fertilised with the vermicompost obtained above. Treatments with Oxisol fertilised with gneiss or steatite only and unfertilised soil were used as controls. Shoot length was measured weekly from the soil surface to the tips of the leaves. After 73 d, the plants were harvested, the roots washed from the soil and shoots and roots dried and weighed. Plants fertilised with vermicompost enriched with rock powder were taller and heavier than plants fertilised with non-enriched vermicompost. Plants grown on soil fertilised with rock powder but not with vermicompost were larger than plants grown on unfertilised soil. Vermicompost enriched with steatite powder resulted in a larger effect on plant growth than the mere sum of applying vermicompost of non-enriched manure and steatite alone to the soil. A similar, but non-significant effect was also observed for gneiss. The different effects between gneiss and steatite may be associated with the lower resistance to chemical weathering of steatite minerals compared to gneiss minerals, as well as the former being softer than the latter. The effect of vermicompost on the optimisation of nutrient release from silicate rocks seems to depend on the rock type.

1. Introduction

The use of earthworms in vermicomposting is designed mainly to recycle organic residues and produce stabilized organic fertilizer (Aquino and Nogueira, 2001). Earthworms have the capacity to increase availability of nutrients present in the material they ingest (Bartz et al., 2010), which includes organic matter and the mineral components of soil. This occurs because these materials are crushed by the earthworms and subjected to digestive enzymes present in their intestines, including amylases, cellulases, proteases, lipases and chitinases (Michel and Devillez, 1978; Edwards and Fletcher, 1988). In addition, earthworms excrete excess mineralized calcium in the form of $CaCO_3$ through calciferous glands, thus increasing the pH of the gut contents (Barois and Lavelle, 1986) and of the vermicompost, making it more basic than organic compost (Longo, 1995) and contributing to changing the solubility of some nutrients.

In addition to increasing the availability of nutrients, vermicomposting allows for greater stabilization of organic residues, because these residues are converted to humic substances when subjected to enzymatic action (mainly microbial, but also-earthworm derived) in the earthworm gut and castings (Hartenstein and Hartenstein, 1981; Aira and Domínguez, 2010). Furthermore, vermicompost has a high microbial load many of them plant growth promoters that increase soil quality (Domínguez et al., 2010a). Therefore, earthworm castings not only provide nutrients and stabilize organic compounds but also favour soil microbes and their activity.

Inorganic residues such as rock powders also have the potential to increase soil nutrient reserves, but for this to occur the solubility of their minerals must be increased, in order to release nutrients (Melamed et al., 2007). The addition of rock powder in agriculture also favours plant resistance to biotic and abiotic stresses by improving their nutritional status (Melamed et al., 2007).

* Corresponding author. Tel.: +55 3138991045; fax: +55 3138992646.
E-mail addresses: maria.paula@ufv.br (M.E.P. de Souza), andre.carvalho@ufv.br (A.M.X. de Carvalho), ddeliberali@yahoo.com.br (D.d.C. Deliberali), ivo@ufv.br (I. Jucksch), george.brown@embrapa.br (G.G. Brown), esmjplia@gmail.com (E.S. Mendonça), irene@ufv.br (I.M. Cardoso).

0929-1393/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.apsoil.2013.01.016

Nevertheless, the use of powdered rock residue should prioritise material that is found in the region and is easily accessible to farmers. These may be quarry wastes from gravel production and residues from local marble quarries. Rock powder may also be obtained from rocky material found on or near the farmer's property, though the rock must be ground. In addition to allowing residues to be put to use, another advantage of using rock powder is that nutrient release occurs gradually, reducing leaching losses and favouring long-term action of the added materials (Leonardos et al., 2000).

Vermicomposting may accelerate the solubilisation of the inorganic residues such as rock powder, added to organic residues because the minerals undergo chemical (Carpenter et al., 2007) and physical (Suzuki et al., 2003) weathering, due to enzymatic action and grinding of the materials as they pass through the earthworm's intestine.

The search for low-cost and easy-to-manage techniques that increase mineral solubilisation and improve the fertilisation of agroecosystems, such as vermicomposting, could transform the use of inorganic residues such as rock powder into environmentally and economically sound alternatives for farmers. Therefore, fertilisation with rock powder could become an environmentally and economically viable option to fertilise tropical soils that are generally highly leached and poor in plant-available nutrients (Leonardos et al., 2000).

Therefore, the objectives of this study were to evaluate the growth of earthworms in substrates enriched with gneiss and steatite powder, and the potential of vermicompost in increasing the solubilisation of minerals present in rock powder and in promoting plant growth.

2. Materials and methods

The work was done in the Zona da Mata of Minas Gerais (20°45′S and 42°52′W) in the Atlantic Rainforest Biome of Brazil. The region has a tropical highland climate with an average temperature of 18 °C, average annual precipitation of 1500 mm, and 2–4 dry months yr^{-1}. The area is hilly, with slopes ranging from 20 to 45% and altitudes from 200 to 1800 m (Golfari, 1975). Oxisols are the main soil type; they are deep and well-drained, but acidic and poor in available nutrients. The main type of rock is gneiss. However, the Zona da Mata borders the Iron Square region, where steatite is a common rock used for handcraft.

2.1. Rock powders

The gneiss and steatite powders used were obtained from quarries (gneiss from the Zona da Mata region) or from handcraft production (steatite from the Iron Square region). The materials were standardised as to particle size distribution in order to minimise possible effects of different surface areas. This standardisation consisted of only using the fractions that passed through a 0.150-mm mesh sieve and were retained on a 0.053-mm mesh sieve. The materials were oven-dried at 65 °C for 72 h. Bulk samples of each rock underwent qualitative mineralogical characterisation through X-ray diffraction (Whittig and Allardice, 1986). Macroelements present in the rock powders were analysed with X-ray fluorescence spectrometry. Micro-elements were quantified by inductively-coupled plasma atomic emission spectroscopy (ICP-AES) after multi-acid digestion (EPA 3052, 1996).

2.2. Growth of earthworms in substrates enriched with rock powder

The substrate for the preparation of the vermicompost was cattle manure. It was homogenised and moisture and granulometry were standardised after which it was used in the experimental units. These consisted of cylindrical plastic pots with a 2 dm^3 capacity. Each experimental unit received 400 g cattle manure either enriched with rock powder or not.

The experiment was performed in a completely randomised design with 5 treatments: two rock powders, gneiss (G) and steatite (S), two doses (5% and 20%), and a treatment with manure without rock powder, each with 5 replicates.

The earthworms (*Eisenia andrei* Bouché, 1972) used were incubated in a mixture of manure and rock powder for a week prior to the experiment so that the remaining substrate from their place of origin was flushed from their intestines. Each pot then received nine individuals (Aquino and Assis, 2005) of *E. andrei*, at a density of c. 1000 indiv. m^{-3} (600 g m^{-3}). The pots were kept at room temperature in the dark, under constant moisture (40%; controlled weekly by adding an amount of water similar to the weight loss of each pot), for a period of 60 d. At the end of this period, the earthworms were collected and counted, and fresh and dry weights determined. The vermicompost obtained in each treatment was homogenised and characterised in terms of organic C content (data not shown) to set up the agronomic trial.

2.3. Agronomic trial-plant growth

With the vermicompost obtained above, an agronomic trial was conducted to assess the abilities of these compounds to promote plant growth. The maize variety UFV M100 (non-transgenic) was cultivated for 73 d in a greenhouse in pots (5 dm^3) containing 3 kg of an Oxisol collected in Viçosa, MG, Brazil (Table 1) and fertilised with the products obtained in the pot trial. These consisted of non-enriched vermicompost (Vc), vermicompost processed either with 5 or 20% of gneiss (G_5 and G_{20}) or steatite (S_5 and S_{20}). We also included treatments with soil fertilized only with gneiss and steatite without vermicompost (G and S, respectively), and a control (C) consisting of manure without vermicompost and rock powder. Hence, there were eight treatments in total: VcG_5, VcG_{20}, VcS_5, VcS_{20}, Vc, G, S and C. The doses of vermicompost applied to the pots were set based on those recommended by Ribeiro et al. (1999), and corresponded to 12.6 t ha^{-1} of total organic carbon (TOC). For this, the average TOC of each treatment (ranging from 35.5 dag kg^{-1} to 28.4 dag kg^{-1}) was used to calculate the amount of vermicompost added to each pot.

To ensure that the rock powder for the gneiss (G) and steatite (S) treatments were exposed to moisture for the same amount of time as was the vermicompost, they were simultaneously incubated in the test vessels for 60 d under the same moisture, temperature and light conditions. In the treatments with only rock powder, the dose of gneiss was 13.4 g, equivalent to the treatment VcG_{20} and the dose of steatite was 14.74 g, equivalent to the treatment VcS_{20}.

The experimental units, each of which consisted of a pot with two plants in it, were placed in a greenhouse, under a completely randomised design with four replicates. Soil moisture was controlled and maintained at 70% of field capacity. The experiment was conducted at the Federal University of Viçosa from March to May 2010.

The sum of shoot sizes, consisting of the sum of the sizes of all leaves of the maize plant, was measured weekly during 73 days. The measurement was taken from the base (soil) to the apex of each leaf (Cardoso et al., 2004; Janssen, 1990). For each measurement, the average of the sum of shoot sizes of the two plants per pot was calculated. The sum of the shoot sizes was used as a growth parameter because this allows for the monitoring of plant growth in a non-destructive manner. For grasses, there is a linear correlation between the sum of the lengths of shoots and the production of dry matter (Janssen, 1990).

Table 1
Selected chemical characteristics of the Oxisol used to evaluate the effects of vermicomposting with gneiss and steatite rock powder on plant growth.

pH (H_2O)	P	K	Ca^{2+}	Mg^{2+}	Al^{3+}	SB[a]	CEC[b]	BS[c]	AS[d]	OM[e]
	mg dm^{-3}		cmolc dm^{-3}					%		dag kg^{-1}
5.0	1.4	4	0.1	0.0	0.4	0.11	3.58	3	78	1.4

[a] Sum of bases.
[b] Cation exchange capacity.
[c] Base saturation.
[d] Aluminium saturation.
[e] Organic matter.

Table 2
Bulk chemical characterisation of rock powders used in the experiment evaluating effects of vermicomposting with rock powder on plant growth.

Rock powder	Macro-elements (%)							
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	P_2O_5	MnO
Gneiss	54.67	14.78	12.28	6.14	2.38	2.54	1.12	0.16
Steatite	47.16	4.24	9.44	2.19	27.61	0.01	0.01	0.12

	Micro-elements (mg kg^{-1})					
	Ba	Co	Cr	Cu	Ni	Zn
Gneiss	1532	16	13	11	<3	148
Steatite	6	87	869	39	1513	84

At the end of the experiment, the two plants of each pot were collected, the roots isolated from the soil (with water) and the whole plant (shoots and roots) dried in an oven (60 °C) and weighed. For each pot, the average dry weight of the two plants was assessed.

3. Statistical analyses

Statistical analyses were carried out using SAEG program, version 9.1 (FUNARBE, 2006). Analyses of variance (ANOVA), followed by Tukey test ($p < 0.05$) were used to test differences between treatments. To assess effects of the vermicomposting process on nutrient release from rock powders, contrasts were established. To assess if the effect of the combined $VcRock_{20}$ treatment was greater than the sum of the effects of the Vc and Rock treatments, the following contrasts were used:

$$C_1 = (\text{average } VcG_{20} - \text{average C}) - ((\text{average Vc} - \text{average C}) + (\text{average G} - \text{average C}))$$

and

$$C_1 = (\text{average } VcS_{20} - \text{average C}) - ((\text{average Vc} - \text{average C}) + (\text{average S} - \text{average C}))$$

In the comparisons, VcG_{20} and VcS_{20} were used because the doses of rocks used in these treatments corresponded to those used in the treatments with only rock powders (G or S). The contrast estimates were tested by the Scheffé test ($p < 0.05$).

4. Results

The gneiss used consisted primarily of quartz, orthoclase, andesine, rutile, and apatite, whereas the steatite was composed mainly of talc and dolomite. Macro and micro-elements present in the rocks are shown in Table 2. Gneiss had higher contents of Si, Al, Fe, Ca, K, P, Mn, Ba and Zn than steatite. Steatite had higher contents of Mg, Co, Cr, Cu and Ni.

The numbers of earthworms recovered at the end of the vermicomposting process did not differ among treatments ($p < 0.05$),

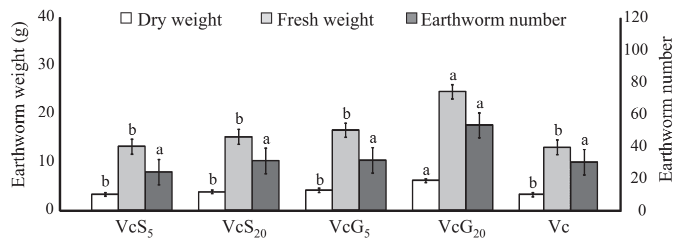

Fig. 1. Mean and s.e. ($n = 5$) fresh and dry weights (g) and numbers of earthworms at the end of the vermicomposting process. Manure was either enriched with 5 or 20% steatite (VcS_5, VcS_{20}) or gneiss (VcG_5, VcG_{20}) powder or not enriched (Vc). Means with the same letters within the same treatment are not significantly different at the 0.05 level.

but fresh and dry biomass in the treatment with 20% gneiss were higher than in the other treatments ($p < 0.05$) (Fig. 1).

Differences in maize growth among the treatments were evident starting at Day 20 (Fig. 2). At the end of the experiment (73 d), plants fertilised with vermicompost enriched with rock powder (VcS_5, VcS_{20}, VcG_5, VcG_{20}) were taller ($p < 0.05$) than plants in all other treatments, including those fertilised with non-enriched vermicompost (Vc). Plants grown on soil fertilised with rock powder without vermicompost (S or G) were smaller than those in Vc, but taller ($p < 0.05$) than plants grown in unfertilised soil (C). Therefore, maize cultivated in vermicompost with rock powder grew on average 53% more than the control plants, 39% more than the plants fertilised only with steatite, 35% more than those fertilised only with gneiss and 21.5% more than those fertilised with non-enriched vermicompost.

Dry matter production was larger ($p < 0.05$) for treatments fertilised with vermicomposts enriched with rock powders (VcS_5,

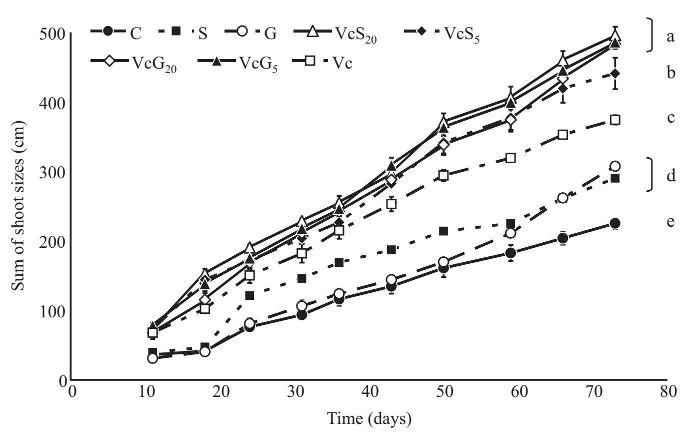

Fig. 2. Mean and s.e. ($n = 4$) of sum of shoot sizes (cm) per week of maize grown in unfertilized soil (Control, C), and soil fertilized with gneiss (G) or steatite (S) powder, vermicompost (Vc) and vermicompost enriched with 5 and 20% of steatite (VcS5 and VcS20) or gneiss (VcG5 and VcG20) during the process of vermicomposting. Means with the same letters were not significantly different at the 0.05 level at the end of the experiment (day 73).

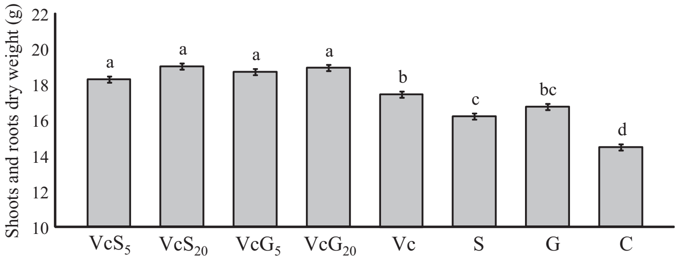

Fig. 3. Mean and s.e. ($n=4$) of dry weights (g) of maize plants (shoots + roots) grown in soil fertilized with vermicompost enriched with 5 and 20% of Steatite (VcS_5 and VcS_{20}) or gneiss (VcG_5 and VcG_{20}) during the process of vermicomposting, fertilized only with vermicompost (Vc), with gneiss (G) or with steatite (S) powder and in unfertilized soil (Control, C). Means with the same letters were not significantly different at the 0.05 level.

VcS_{20}, VcG_5, VcG_{20}) compared to treatments with non-enriched vermicomposts (Vc), with rock powders only (S or G) and without fertilisation (C; Fig. 3). On average, maize biomass in treatments fertilised with vermicompost enriched with rock powder was 12% larger than in the other treatments.

Contrasts C_1 (using gneiss powder) and C_2 (using steatite powder) revealed the effects of the vermicomposting process on nutrient release from rock powders: total average lengths of shoots at the end of the experiment were not significant for C_1 (30.9) but were significant for C_2 (67.1, $p<0.05$).

5. Discussion

The addition of silicate rock powders to the vermicomposting process did not negatively affect earthworm growth and reproduction (Fig. 1), and the addition of 20% gneiss powder increased *E. andrei* fresh mass. Thus, the addition of these materials did not impair the speed of production or the quality of the vermicomposts produced despite the presence of elements potentially toxic to earthworms (Table 2; Karaca et al., 2010).

The results for plant growth (Figs. 2 and 3) show that both gneiss and steatite powders promoted plant growth when compared to plants grown in non-treated soil (control), especially when the rock powders were previously incorporated to the vermicomposting process. To the best of our knowledge, this is the first report of such effects with silicate rocks in vermicomposts. The addition of rock powder to the vermicomposting process, however, has been reported for limestone and natural phosphates. Alvarez et al. (2004), for example, added Araxa rock phosphate and gypsum to vermicompost, and the addition of phosphate-enriched vermicomposts contributed to an increase in dry matter production and accumulation of P by maize plants.

Improved plant growth is a result of better plant nutrition with the addition of rock powders, of vermicomposts or of both. Vermicompost stimulates plant growth because it increases nutrient availability and the efficiency of nutrient uptake (Vaughan and Malcolm, 1985). It also contributes to microbial activity with direct and indirect effects on plant health and nutrition (Domínguez et al., 2010a,b). Ingested material undergoes transformations in the digestive tract of earthworms, including the partial decomposition of organic matter and the release of nutrients for plants by the actions of digestive enzymes and microbes (Brown et al., 2000). Benitez et al. (2005) reported the presence of several hydrolytic enzymes in vermicompost, observing that the activity of phosphatase, for example, increased when compared with compost, suggesting that earthworms and microbes involved in the process had consumed the main substrates containing metabolisable P. Clearly, both earthworms and microbes contribute to the physical, chemical and mineralogical properties of the vermicompost, but it is very difficult to experimentally isolate and determine the contribution each of them (microbes vs. earthworms) to mineral weathering and nutrient release (Liu et al., 2011), partly because earthworms depend on gut microbes for their survival and fitness (Edwards and Bohlen, 1996).

Ground silicate rocks also have the potential to release nutrients for plants (Escosteguy and Klamt, 1998; Leonardos et al., 2000; Melamed et al., 2007) and increase plant growth (Hinsinger et al., 1996) although there are no studies that are specific for steatite. In the present study, the addition of only rock powders (gneiss and steatite) to soil resulted in taller plants compared to non-treated soil (Fig. 2), confirming their potential as fertilizers to increase nutrient availability in cultivated soils and soil nutrient reserves (Melamed et al., 2007).

Differences observed between the control, fertilisation only with rocks, fertilisation with vermicompost and fertilisation with enriched vermicompost treatments are likely linked to plant nutrition, given that treatments involving vermicompost received more total nutrients (from manure and rock powder). The low levels of most nutrients in the steatite treatment (Table 2) could explain the differences found between G and S treatments, where plant height was significantly lower with 5% steatite (Fig. 2), resulting in slightly (but not significantly) lower biomass (Fig. 3) than treatments with gneiss or higher dose of steatite (20%).

Plant growth responses, however, indicated that the vermicomposting process acted differently on the two rocks in terms of nutrient availability. Although plants fertilised only with gneiss or steatite showed similar growth, the contrasts of the effect of vermicomposting with steatite (C_2) showed that vermicomposting contributed to the mineral dissolution of steatite, resulting in a larger effect on plant growth than the mere sum of applying non-enriched vermicompost and applying only steatite to the soil. On the other hand, results with gneiss were similar, but non-significant (contrast C1).

The difference between gneiss and steatite may be associated with the lower hardness and lower resistance to chemical weathering of steatite minerals compared to gneiss minerals (Van Breemen and Buurman, 2002). Although this lower resistance did not result in increased biomass for the treatment with steatite compared to that with gneiss (Fig. 3), the effect of earthworms on physical and chemical weathering (Suzuki et al., 2003; Carpenter et al., 2007; Liu et al., 2011) of steatite rock may have been more efficient than for gneiss. Therefore, vermicomposting may amplify the differences resulting from variable susceptibility of rocks to mineral weathering. Further research, including different primary minerals and particle sizes, should clarify this.

When combining vermicomposting and rock powders, special attention must be given to the elements with potential phytotoxity (Al, Ba, Cr and Ni) and to the availability of the macro and micro-nutrients (Si, Fe, Ca, Mg, K, P, Mn, Zn, Co and Cu) present in the rock powders (Table 2). When considering a hypothetically high dissolution of rocks, with the rock powder and vermicompost doses applied, only Al could result in a phytotoxic effect in the soil with the rock powders used here (Alleoni et al., 2005; Karaca et al., 2010).

Like most grasses, maize responds positively to fertilisation with Si, especially in Oxisols (Epstein, 1999). The Si available in the soil, in turn, may also favour phosphate nutrition (Carvalho et al., 2001). Consequently, silicate minerals from steatite could have released more Si than those from gneiss during vermicomposting, and this did not occur in the absence of earthworms. Associated with the lower Al and higher Mg contents of steatite, this resulted in a larger effect of the VcS_{20} treatment than of VcG_{20}. The effect of higher Ca, K and P contents of gneiss thus did not outweigh the effect of higher Si and Mg release induced by earthworms in the steatite treatments.

6. Conclusions

Fertilisation with vermicomposts obtained from substrates enriched with rock powders may result in benefits to plants greater than those derived from the isolated use of vermicomposts or rock powders. Based on our results, we suggest that at least 20% of gneiss and steatite powders (which increased the growth of maize and did not negatively affect the growth of earthworms) could be added to manure to be vermicomposted. Our results furthermore suggest that the effect of the vermicomposting process on the optimisation of the release of nutrients from silicate rocks depends on the rock type. Therefore, further medium- and long-term studies under field conditions are needed to obtain more reliable results on the agronomic effectiveness of this apparently promising technology. The improvement of this technology may expand the horizon for greater viability for use of ground silicate rocks in agriculture.

Acknowledgements

The authors thank CAPES for the scholarship to M.E.P Souza and CNPq for scholarships to A.M.X. Carvalho and D.C. Deliberali and a fellowship to G. Brown. CNPq and FAPEMIG financially supported the research. Prof. J.C. Galvão and Prof. E. Montovani are acknowledged for the maize seeds and seed analyses. Marcela and Tiago helped with the laboratory and greenhouse experiment, Arne Janssen improved the text and two anonymous referees provided helpful comments.

References

Aira, M., Domínguez, J., 2010. Lombrices de tierra y los microorganismos: desentrañando la caja negra del vermicompostaje. Acta Zool. Mex. (n. s.) 26 (no. especial 2), 385–395.

Alleoni, L.R.F., Borba, R.P., Camargo, O.A., 2005. Metais pesados: da cosmogênese aos solos brasileiros. Tópicos em Ciência do Solo 4, 1–42.

Alvarez, V.V.H., Ruiz, H.A., Martins Filho, C.A.S., Guarçoni, M.A., Rodrigues, D.T., 2004. Crescimento de plantas de milho pela adição de vermicomposto enriquecido ou não com fosfatos e com gesso. Rev. Ceres 51, 635–647.

Aquino, A.M., Assis, R.L. (Eds.), 2005. Agroecologia: princípios e técnicas para uma agricultura orgânica sustentável. Embrapa Informação Tecnológica, Brasília.

Aquino, M.A., Nogueira, E.M., 2001. Fatores limitantes da vermicompostagem de esterco suíno e de aves e influência da densidade populacional das minhocas na sua reprodução. Embrapa Agrobiologia, Documentos No. 147, Seropédica.

Barois, I., Lavelle, P., 1986. Changes in respiration rate and some physicochemical properties of a tropical soil during transit through *Pontoscolex corethrurus* (Glossoscolecidae, Oligochaeta). Soil Biol. Biochem. 18, 539–541.

Bartz, M.L.C., Costa, A.C., Souza Jr., I.G., Brown, G.G., 2010. Sobrevivência, produção e atributos químicos de coprólitos de duas espécies de minhocas (*Pontoscolex corethrurus*: Glossoscolecidae e *Amynthas gracilis*: Megascolecidae) em solos sob diferentes sistemas de manejo. Acta Zool. Mex. (n. s.) 26 (no. especial 2), 261–280.

Benitez, E., Sainz, H., Nogales, R., 2005. Hydrolytic enzyme activities of extracted humic substances during the vermicomposting of a lignocellulosic olive waste. Bioresour. Technol. 96, 785–790.

Brown, et al., Barois, I., Lavelle, P., 2000. Regulation of soil organic matter dynamics and microbial activity in the drilosphere and the role of interactions with other edaphic functional domains. Eur. J. Soil Biol. 36, 177–198.

Carpenter, D., Hodson, M.E., Eggleton, P., Kirk, C., 2007. Earthworm-induced mineral weathering: preliminary results. Eur. J. Soil Biol. 43, 176–183.

Cardoso, I.M., Boddington, C., Janssen, B., Oenema, O., Kuyper, T., 2004. Double pot and double compartment: integrating two approaches to study nutrient uptake by arbuscular mycorrhizal fungi. Plant Soil 260, 301–310.

Carvalho, R., Furtini Neto, A.E., Santos, C.D., Fernandes, L.A., Curi, N., Rodrigues, D.C., 2001. Interações silício-fósforo em solos cultivados com eucalipto em casa de vegetação. Pesq. Agropec. Bras. 36, 557–565.

Domínguez, J., Lascano, C., Gómez-Brandón, M., 2010a. Influencia del vermicompost en el crecimiento de las plantas, Aportes para la elaboración de un concepto objetivo. Acta Zool. Mex. (n. s.) 26 (no. especial 2), 359–371.

Domínguez, J., Gómez-Brandón, M., Lascano, C., 2010b. Propiedades bioplaguicidas del vermicompost. Acta Zool. Mex. (n. s.) 26 (no. especial 2), 373–383.

Edwards, C.A., Bohlen, P.J., 1996. Biology and Ecology of Earthworms, 3rd ed. Chapman & Hall, London.

Edwards, C.A., Fletcher, K.E., 1988. Interactions between earthworms and microorganisms in organic-matter breakdown. Agr. Ecosyst. Environ. 24, 235–247.

Environmental Protection Agency (EPA) 3052, 1996. Microwave assisted acid digestion of siliceous and organically based matrices. Washington, USA: Revision, December, CD-Rom. Windows 95/XP.

Epstein, E., 1999. Silicon. Annu. Rev. Plant Phys. 50, 641–664.

Escosteguy, P.A.V., Klamt, E., 1998. Basalto moído como fonte de nutrientes. Rev. Bras. Ciênc. Solo 22, 11–20.

Golfari, L., 1975. Zoneamento ecológico do Estado de Minas Gerais para reflorestamento. Série Técnica, 3. CPFRC, Belo Horizonte.

Hartenstein, R., Hartenstein, F., 1981. Physicochemical changes affected in activated sludge by the earthworm *Eisenia foetida*. J. Environ. Qual. 10, 377–382.

Hinsinger, P., Bolland, M.D.A., Gilkes, R.J., 1996. Silicate rock powder: effect on selected chemical properties of a range of soils from Western Australia and on plant growth as assessed in a glasshouse experiment. Fert. Res. 45, 69–79.

Janssen, B.H., 1990. A double-pot technique as a tool in plant nutrition studies. In: Van Beusichen, M.L. (Ed.), Plant Nutrition-Physiology and Application. Kluwer Academic, The Netherlands, pp. 759–763.

Karaca, A., Kizilkaya, R., Turgay, O.C., Cetin, S.C., 2010. Effects of earthworms on the availability and removal of heavy metals in soil. In: Sherameti, I., Varma, A. (Eds.), Soil Heavy Metals. Springer, Berlin, pp. 237–262.

Leonardos, O.H., Theodoro, S.C.H., Assad, M.L., 2000. Remineralization for sustainable agriculture: a tropical perspective from a Brazilian viewpoint. Nutr. Cycl. Agroecosys. 56, 3–9.

Liu, D., Lian, B., Wang, B., Jiang, G., 2011. Degradation of potassium rock by earthworms and responses of bacterial communities in its gut and surrounding substrates after being fed with mineral. PLoS ONE 6 (12), e28803, http://dx.doi.org/10.1371/journal.pone.0028803.

Longo, A.D., 1995. Minhoca: de Fertilizadora do solo a Fonte Alimentar. Ícone, São Paulo.

Melamed, R., Gaspar, J.C., Miekeley, N., 2007. Pó-de-rocha como fertilizante alternativo para sistemas de produção sustentáveis em solos tropicais, CETEM/MCT, Série Estudos e Documentos.

Michel, C., Devillez, E.J., 1978. Digestion. In: Mill, P.J. (Ed.), Physiology of Annelids. Academic Press, London, pp. 509–554.

Ribeiro, A.C., Guimarães, P.T.G., Alvarez, V.V.H., 1999. Recomendações para o uso de corretivos e fertilizantes em Minas Gerais, 5ª aproximação. CFSEMG, Viçosa.

Suzuki, Y., Matsubara, T., Hoshino, M., 2003. Breakdown of mineral grains by earthworms and beetle larvae. Geoderma 112, 131–142.

Van Breemen, N., Buurman, P., 2002. Soil Formation, 2nd ed. Kluwer Academic Publishers, The Netherlands.

Vaughan, D., Malcolm, R.E., 1985. Influence of humic substances on growth and physiological processes. In: Vaughan, D., Malcolm, R.E. (Eds.), Soil organic Matter and Biological Activity. Martinus Nijhoff Junk Publisher, Dordrecht, pp. 37–75.

Whittig, L.D., Allardice, W.R., 1986. X-Ray diffraction techniques. In: Klute, A. (Ed.), Methods of Soil Analysis – Physical and Mineralogical Methods. , 2nd ed. American Society of Agronomy, Madison, pp. 331–362.