Effect of Vermicompost on Soil and Plant Properties of Coal Spoil in the Lusatian Region (Eastern Germany)

WAEL M. NADA,[1] LEON VAN RENSBURG,[2]
SARINA CLAASSENS,[2] AND OSWALD BLUMENSTEIN[1]

[1]Institute of Earth and Environmental Sciences, Potsdam University, Potsdam, Germany
[2]Unit for Environmental Sciences and Management, Northwest University, South Africa

This study was conducted to evaluate the effect of different wood vermicompost application rates on some soil physical and chemical properties as well as on growth parameters of a grass seed mixture (RSM 7.2.1) in tertiary sand contaminated with coal spoil. The experiment was carried out in a greenhouse over a period of 42 days. Soil was mixed with vermicompost at ratios of 0.0, 3.0, 12.5, and 25.0% and sown with the grass seed mixture. Soil samples and plant material were analyzed to determine the effect of different vermicompost application rates on the physical and chemical properties. Results revealed that the physical and chemical properties of the soil improved with increasing application rates of vermicompost. In addition, soil treated with vermicompost showed significant increases in fresh- and dry-matter yields of the grass, as well as enhanced uptake of nutrients by the grass. This indicated that treatment of contaminated soils with vermicompost may be beneficial for reclamation processes by facilitating revegetation of disturbed areas.

Keywords Lusatian tertiary sand, open-cast lignite mining, reclamation, revegetation

Introduction

Open-cast lignite (brown coal) mining operations in the Lusatian district in eastern Germany have left a legacy of almost 1000 km^2 covered by spoil heaps of clastic overburden sediments of the Tertiary and Quaternary ages (Huettl and Weber 2001). These spoil-heap sediments often abound in lignitic components in the form of coal fragments or coal dust (Neumann 1999). The post-lignite-mining landscape is dominated by sandy substrates of Tertiary and Quaternary sediments. These substrates can be identified as lignite- and pyrite-containing substrates stemming from Tertiary sediments and lignite- and pyrite-free substrates stemming from Quaternary sediments. The majority of these substrates are pure sands and loamy sands (Katzur and Haubold-Rosar 1996). These sediments are extremely acidic (pH 2.5–3.0) and contain up to 50 g kg^{-1} carbon derived from lignite (Huettl and Weber 2001). The reason for the extreme acidity of these soils is the presence

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Address correspondence to Leon van Rensburg, Institute of Earth and Environmental Sciences, Potsdam University, Karl-Liebknecht Strasse 24-25, 14476 Potsdam, Germany. E-mail: leon.vanrensburg@nwu.ac.za

and/or possible exposure of pyrite in these substrates to the atmosphere, which generates a high potential for acid production. Another reason is the formation and mobilization of sulfuric acid in these raw soils during the chemical weathering of sulfide minerals (marcasite and pyrite) (Claus 2003). Other negative properties include reduced water-holding capacity of the soil, low nutrient content and pedogenic organic matter, insufficient soil life, and disturbed air–water balances. Reduced infiltration hinders plant growth as soil water is not renewed (Wang et al. 2000). Therefore, it is often difficult to initiate plant growth in the postmining landscape. It is even more difficult to achieve successful revegetation in the sense of establishing new agricultural and forest ecosystems with the same characteristics as before mining disturbances.

For successful reclamation, high application rates of basic materials are required to neutralize soil acidity and hence create the potential for plant growth. Because of the lack of nutrients in these spoil substrates, mineral fertilizers are conventionally applied as a fundamental reclamation measure. The risk of nutrient losses from mineral fertilizers via seepage water leaching is high because of the sandy texture of these spoil (Wilden 2000). Therefore, an alternative treatment to the addition of mineral fertilizers might be the application of organic residues such as compost or sewage sludge (Wilden, Schaaf, and Huettl 2001). This will lead to the improvement of the soil structure by increasing porosity and reducing the bulk density (BD) of an ameliorated soil as well as improving soil aeration, water-holding capacity (WHC), buffer capacity, and cation exchange capacity (CEC) (Lynch, Voroney, and Warman 2005). The addition of compost with a significant amount of humified organic matter leads to longer lasting effects of this organic matter in the soil, increasing the agricultural value of the composts. Polysaccharides and other polymeric substances present in organic matter act as aggregating compounds (Masciandaro et al. 2000) and increase micropores in the soil. Recently, Pandey and Shukla (2006) studied the effect of composted yard waste on the movement of water in a sandy soil and found that water and phosphorus (P) retention in the soil was increased. Speir et al. (2004) reported that in samples from a field trial, soil total carbon (C), nitrogen (N), P, and Olsen P were increased markedly with increasing compost application rate. Exchangeable cations (EC), CEC, as well as total extractable and ethylenediaminetetraacetic acid (EDTA)–extractable metals were also elevated. Total copper (Cu) reached the allowable limit in biosolid compost–amended soil. The physical properties of the ameliorated soils were improved in all cases as far as the saturated and unsaturated hydraulic conductivity, WHC, BD, total porosity (TP), pore-size distribution, soil resistance to penetration, aggregation, and aggregate stability were concerned (Aggelides and Londra 2000). Composted organic matter can act as a liming agent in agricultural soils. Neutral to slightly alkaline composts can increase the pH in most acidic soils, reducing the potential for aluminium (Al) and manganese (Mn) toxicity (McConnell, Shiralipour, and Smith 1993). Increases in pH are directly proportional to the proton and Al-consumption capacity of the organic matter, specifically of humic and fulvic substances containing high carboxyl, phenolic, and enolic functional groups. As organic anions are adsorbed, a corresponding release of hydroxyls raises the pH of the soil. Vermicompost contains most nutrients in plant-available forms such as nitrates, phosphates, exchangeable calcium (Ca), and soluble potassium (K) (Arancon et al. 2004; Asciutto et al. 2006) and should therefore be beneficial to vegetation growth.

The aim of this study was to evaluate the effect of different vermicompost application rates on some of the physical and chemical properties of tertiary sand contaminated with coal spoil and on grass grown in this contaminated sand.

Materials and Methods

The experiment was carried out in a greenhouse using plastic pots (18.7 cm in diameter, 21.8 cm deep) filled with a mixture of vermicompost and coal-spoil-contaminated Tertiary sand. A completely randomized design was followed. Soil samples ($n = 20$) were obtained from the surface layer of spoil material (0–30 cm) in the Lusatian region. Samples were air-dried, ground, and sieved through a 2-mm sieve before analyses.

The vermicompost used in this study was produced from a composting trial lasting 3 months that employed cocomposting for 1 month followed by vermicomposting for 2 months. Vermicompost was produced using a mixture of woodchips (*Quercus rubra*) and lake mud. *Eisenia fetida* was applied as the earthworm inoculant. Soil was mixed with sieved (2-mm sieve) vermicompost at ratios of 0.0, 3.0, 12.5, and 25.0% (dry weight, w/w). For each of these mixtures, eight pots were filled to a depth of 18 cm. Each pot was sowed with 0.4 g seeds of the RSM 7.2.1. grass seed mixture (Deutsche Rasengesellschaft e.V. [DRG], Bonn, Germany). The mixture consisted of 45% *Festuca ovina duriuscula*, 10% *Festuca rubra commutata*, 15% *Festuca rubra rubra*, 15% *Festuca rubra trichophylla*, and 15% *Lolium perenne*. This is the same grass seed mixture that was used as part of the closure plan of the company (Lausitzer und Mitteldeutsche Bergbau-Verwaltungsgesellschaft mbH). It is the standard mixture for sowing in dry regions, and the optimum sowing quantity is 20 g m^{-2}. The pots were irrigated every 3 days to 60% WHC for each treatment.

Physical and chemical analyses of soil samples before and after treatment with vermicompost were conducted according to standard procedures. Organic matter was measured by weight loss on ignition at 550 °C (DIN 2000). Electrical conductivity (EC) and pH were measured according to the procedures of DIN ISO (1997) and DIN ISO (2002), respectively. For determination of total P, K, Ca, Mg, Fe, Cu, Zn, and Mn, a sulfuric acid (H_2SO_4) and perchloric acid ($HClO_4$) extraction procedure was followed (Jackson 1967). Quantification was done by means of atomic absorption spectrometry (AAS 1100B, Perkin-Elmer, Waltham, Mass.) according to the methods described by Havezov (1996). The exchangeable cation concentration was measured by replacement of the exchangeable cations with ammonium (Cottenie et al. 1982) and analyzed by atomic absorption spectrometry (Havezov 1996). Available N was determined by extraction with potassium chloride (KCl) and analyzed colorimetrically (Dahnke 1990) and available P was determined by a Bray 1 analysis (Bray and Kurtz 1945).

At the end of the experiment (42 days from sowing), the plants in each pot were harvested. The harvested plants were washed with distilled water until free from any soil particles. The plants of each pot (roots and aboveground biomass) were weighed to measure the fresh weight. Above- and belowground biomass were separated, air dried, and then oven dried at 70 °C for 48 h to determine dry-matter yield. Plant material was ground before analysis. Macro- and micronutrients in plant material were extracted by H_2SO_4-$HClO_4$ acid digestion (Jackson 1967) followed by atomic absorption spectrometry (Havezov 1996). Total N in plant material was determined according to Tabatabai and Bremner (1991).

Relative increase (R_I, %) and agronomic efficiency (A_E) of the plants were calculated using Eqs. (1) and (2), respectively:

$$RI = 100\,(RT - RC)/RC \tag{1}$$

where RT is fresh- or dry-matter yield weight of treated plants and RC is fresh- or dry-matter yield weight of control.

$$A_E = (A_T - A_C)/P \quad (2)$$

where *AT* is fresh- or dry-matter yield weight of treated plants, *AC* is fresh- or dry-matter yield weight of control, and *P* is application rate of vermicompost (%).

After harvesting, the soil in each pot was sampled, air dried, ground, and sieved (2-mm sieve) before analysis. The following properties were determined: WHC (Dewis and Freites 1970), total exchangeable acidity (TEA) (Carter and Gregorich 2003), dry BD (Blake 1965), dry particle density (PD) (Blake and Hartage 1986), and TP [(Eq. (3)]:

$$TP = 100\,(PD - BD)/PD \quad (3)$$

Soil acid–base buffering capacity was measured, and buffer curves were drawn according to Arrhenius with Brenner and Kappen modification (Ostrowska, Gawliński, and Szczubiałka 1991) by adding increasing amounts of 0.1 M hydrochloric acid (HCl) dm^{-3} and 0.1 M sodium hydroxide (NaOH) dm^{-3} to soil samples, followed by potentiometric pH measurements after 24 h. The potential and effective cation exchange capacities (PCEC and ECEC, respectively) were determined by the barium chloride method (Hendershot and Duquette 1986).

All analyses of soil, vermicompost, and plant material were carried out in triplicate, and these data were statistically analyzed according to the method described by Snedecor and Cochran (1989). The least significant difference (LSD) range test was used to compare different treatment means. Mean values within each column followed by the same letter(s) are not significantly different at a 5% level of probability.

Results and Discussion

Effects of Different Vermicompost Application Rates on Soil Physical and Chemical Properties

Physical and chemical properties of soil and vermicompost used in the experiment are presented in Table 1. A clear difference was observed between the properties of soil compared to vermicompost, with the vermicompost containing greater amounts of all elements and organic matter. Soil pH was lower than the pH of the vermicompost.

The effects of different vermicompost application rates (VARs) on various soil physical and chemical properties are presented in Table 2. Soil WHC and TP (%) increased with an increase in the ratio of vermicompost applied. Vermicompost itself has a high WHC and increases porosity because it creates larger particles with larger air spaces in between them when it is mixed with soil. Moreover, the greater porosity in the soil treated with wood vermicompost can be attributed to an increase in the amount of rounded pores. Rasool, Mousa, and Rahim (2008) reported that the increase in porosity has been attributed to an increased number of pores in the 30- to 50-µm and 50- to 500-µm size ranges and a decrease in the number of pores greater than 500 µm. The DBD and DPD of the soil decreased with an increased rate of vermicompost application. The lowest DBD and DPD were found in the treatment with 25.0% vermicompost, whereas the greatest values were noted in the control treatment. Electrical conductivity increased with an increase in the ratio of vermicompost applied, and statistically significant differences were observed between the different treatments. Soil pH also increased with greater VAR, although there were

Table 1
Properties of soil and vermicompost used in the study

Properties	Soil	Vermicompost
Electrical conductivity (dS m^{-1})	0.19	3.19
pH	3.60	7.48
Organic matter (%)	2.43	27.18
Total C (g kg^{-1})	12.40	150.50
Total N (g kg^{-1})	0.40	12.50
C/N ratio	31.00	12.04
P (mg kg^{-1})	298.29	432.67
K (mg kg^{-1})	6725.15	11034.28
Ca (mg kg^{-1})	3312.60	12023.00
Mg (mg kg^{-1})	1966.03	2235.00
Fe (mg kg^{-1})	803.10	6593.75
Cu (mg kg^{-1})	11.50	18.25
Zn (mg kg^{-1})	75.70	93.75
Mn (mg kg^{-1})	269.50	515.00

no significant differences between the 12.5 and 25.0% vermicompost-containing mixtures. These observations can be attributed to compost containing high amounts of nutrients, buffering capacity due to a high base content, and the capacity to absorb free protons (H^+) in the soil (Cox, Bezdicek, and Fauci 2001). Furthermore, increases in the percentage of organic matter and the amounts of total C and N in the soil were also observed consistent with an increase in the VAR. No significant differences existed between the 0.0 and 3.0% treatments for organic matter and total C content. The C/N ratio decreased with an increased VAR.

The exchangeable bases (EB) increased significantly with an increase in the VAR, with the exception of K^+ and Na^+ at an addition rate of 3.0%. The greatest value of the exchangeable bases was recorded for Ca^{2+} followed by Mg^{2+}, K^+, and Na^+. The greatest amount of exchangeable cations was associated with the application of 25.0% vermicompost, while the lowest amount of exchangeable cations was recorded in the control. Increased amounts of these bases may be due to their high proportion in vermicompost compared to the untreated soil. The total EB show the same trend of being increased significantly with increasing VAR and corresponds to the results of Renato et al. 2003. An increase in the VAR led to decreased TEA, with the greatest TEA value observed in the control and the lowest in the soil treated with 25.0% vermicompost. This may be attributed to the reaction of the compost with the exchangeable acids, which reduces their activity.

The ECEC and PCEC and subsequently the percentage base saturation (BS) were significantly increased with the increase of VAR. The soil treated with 25.0% vermicompost showed the greatest values for all three properties, while the lowest values were recorded in the untreated soil. Vermicompost is characterized by the production of functional groups, which are responsible for surface changes, as well as a high proportion of fine particles and organic matter, which will increase the number of exchange sites for mineral nutrients. These characteristics of vermicompost will lead to the observed changes when added to soil in sufficient amounts (McConnell, Shiralipour, and Smith 1993; Pandey and Shukla 2006).

Table 2
Effect of different vermicompost application rates on physical and chemical soil properties

Properties	Vermicompost application rates (%) 0.0	3.0	12.5	25.0	LSD (0.0)
Water-holding capacity (%)	30.83 c	32.70 c	58.22 b	72.60 a	2.91
Dry bulk density (g cm^{-3})	1.33 a	1.31 a	1.18 b	1.04 c	0.04
Dry particle density (g cm^{-3})	2.39 a	2.36 a	2.28 b	2.19 c	0.04
Total porosity (%)	44.29 c	44.34 c	48.17 b	52.59 a	2.54
Electrical conductivity (dS m^{-1})	0.23 d	0.35 c	0.66 b	0.83 a	0.09
pH	3.73 c	5.22 b	7.39 a	7.61 a	0.38
Organic matter (%)	2.78 c	2.87 c	4.27 b	6.97 a	0.54
Total N (g kg^{-1})	0.39 d	0.52 c	1.12 b	2.13 a	0.07
Total C (g kg^{-1})	12.20 c	12.97 c	24.37 b	39.47 a	2.18
C/N ratio	31.28 d	24.94 c	21.76 b	18.53 a	1.29
Exchangeable bases (cmol kg^{-1})					
Ca^{++}	0.73 d	1.08 c	3.85 b	5.90 a	0.19
Mg^{++}	0.69 d	0.89 c	1.17 b	2.06 a	0.08
K^{+}	0.62 c	0.68 c	0.97 b	1.44 a	0.09
Na^{+}	0.59 c	0.62 c	0.91 b	1.42 a	0.07
Total exchangeable bases (cmol kg^{-1})	2.64 d	3.27 c	6.90 b	10.81 a	0.29
Total exchangeable acidity (cmol kg^{-1})	0.52 a	0.36 b	0.28 c	0.20 d	0.05
Effective CEC (cmol kg^{-1})	3.16 d	3.63 c	7.18 b	11.01 a	0.19
Potential CEC (cmol kg^{-1})	3.43 d	4.66 c	10.34 b	14.37 a	0.2
Base saturation (%)	83.55 d	90.08 c	96.10 b	98.18 a	0.21

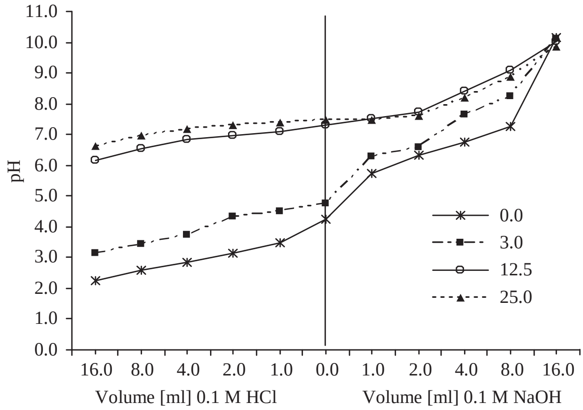
Notes. Means in the same category followed by different letters are significantly different at the 0.05 level of probability. CEC, cation exchange capacity; ECEC = TEB + TEA; base saturation = (TEB / ECEC) × 100.

Soil acid- and base-buffering capacities can be expressed by the slope of buffer curves, according to the algebraic equation presented in Eq. (4):

$$Slope = (y_2 - y_1)/(x_2 - x_1) \quad (4)$$

where x_2 and x_1 are the volumes (ml) of HCl (16 ml) and NaOH (0 ml), respectively, added to the sample and y_2 and y_1 are pH values of the sample after adding HCl or NaOH.

The data presented in Figure 1 show that an increase in the independent HCl and NaOH factors caused a decrease and or increase, respectively, in the dependent factor, pH. Generally, rates of change with the addition of acid (HCl) were lower than with the addition of alkali (NaOH), because of the presence of a high proportion of C in the soil (Table 1). In the present work, the untreated soil (control) showed low resistance to alkalization and acidification; the addition of an alkali caused pH changes that varied between 4.23 and 10.13, and the addition of an acidifying agent (HCl) caused pH changes from 4.23 to 2.24. Similarly, considerable changes in the curve slopes were recorded in the soil treated with 3.0% vermicompost. The addition of HCl and NaOH caused a 1.60-unit pH decrease and 5.45-unit pH increase, respectively. On the other hand, the addition of vermicompost increased soil resistance to pH changes. The greatest resistance was recorded



Slope value using acid and alkali solutions as affected by different VAR

VAR [%]	ACS HCl	BCS NaOH
0.0	–0.10	0.31
3.0	–0.10	0.29
12.5	–0.07	0.17
25.0	–0.05	0.16

ACS: acid curve slope, BCS: base curve slope

Figure 1. Effect of base (NaOH) and acid (HCl) additions on changes in buffering capacities of soil treated with vermicompost.

for the treatments with greater addition rates of vermicompost (12.5 and 25%). The difference between the impact of 12.5 and 25.0% VAR, expressed by the area between the two curves, was small. Treatments with 12.5 and 25.0% VAR exhibited notable resistance to acid impact, and a greater amount of acid (up to 16 cm^3) caused only a slight pH change (up to 1.14 and 0.83 pH units respectively). When considering this data, it is evident that there is an inverse relationship between the curve slope and the soil resistance to change in pH, where the decrease in slope value means increasing soil resistance. The high resistance of treated soil may be due to the high organic C content and the presence of carbonates in vermicompost, which act as a sink for acid protons. Moreover, the addition of vermicompost led to increased soil resistance to change in pH by increasing the total surface available for cation exchange sites (Cox, Bezdicek, and Fauci 2001).

The effects of different application rates of vermicompost on the available macro- and micronutrients in the soil are presented in Table 3. Available N, P, K, Ca, Mg, Cu, zinc (Zn), and Mn increased significantly with an increased VAR. Significant differences in P, Mg, Cu, and Zn were only noted with application rates of 12.5 and 25% vermicompost. These effects can potentially be attributed to the presence of these elements in the vermicompost (Table 1). The availability of nutrients may also be affected by the change in pH caused by the addition of vermicompost to the soil (Table 2). In contrast to the other micronutrients, iron (Fe) was lower in the treatments with vermicompost compared to the control, and no significant differences were observed with an application rate of 3.0% vermicompost. The decrease in Fe may be due to the change in pH caused by the vermicompost, because the bioavailability of Fe will decrease at pH levels near neutral or higher (Im-Erb et al. 2004).

Effects of Different Vermicompost Application Rates on Vegetation Properties

Concentrations of macro- and micronutrients in plant material after treatment with varying amounts of vermicompost are presented in Table 4. All macro- and micronutrient concentrations increased with greater vermicompost application rates, except for Fe, which was lower with a greater VAR, as in the case of soil samples analyzed (Table 3). All increases observed were statistically significant, with the exception of Cu, which only showed a

Table 3

Effect of different vermicompost application rates on available macro- and micronutrients in soil

VAR (%)	Macronutrients					Micronutrients			
	KCl-N (mg kg^{-1})	Bray[1] P (mg kg^{-1})	K (EDTA mg kg^{-1})	Ca (EDTA mg kg^{-1})	Mg (EDTA mg kg^{-1})	Fe (EDTA mg kg^{-1})	Cu (EDTA mg kg^{-1})	Zn (EDTA mg kg^{-1})	Mn (EDTA mg kg^{-1})
0.0	14.05 d	7.32 c	186.84 d	315.46 d	255.52 c	724.43 a	0.49 c	0.84 c	1.05 d
3.0	97.66 c	8.11 c	215.20 c	362.50 c	264.37 c	703.11 a	0.52 c	1.40 c	4.58 c
12.5	394.69 b	11.61 b	274.12 b	630.86 b	322.56 b	553.53 b	0.82 b	3.31 b	23.43 b
25.0	753.25 a	16.35 a	387.15 a	820.73 a	394.60 a	477.17 c	1.28 a	7.03 a	44.51 a
LSD (0.05)	24.85	0.83	10.96	22.73	9.46	29.65	0.05	0.64	1.25

Notes. Means in the same category followed by different letters are significantly different at the 0.05 level of probability.

Table 4

Effect of different vermicompost application rates on macro- and micronutrients in plant material

	Macronutrients (g kg^{-1})					Micronutrients (mg kg^{-1})			
VAR (%)	N	P	K	Ca	Mg	Fe	Cu	Zn	Mn
0.0	1.69 d	0.38 b	0.87 d	0.68 d	0.43 d	439.21 a	10.30 a	31.77 c	53.50 b
3.0	10.90 c	1.04 b	3.75 c	1.34 c	0.99 c	410.63 b	10.50 a	32.18 c	125.03 a
12.5	33.59 b	3.97 a	12.56 b	6.72 b	2.79 b	328.10 c	10.50 a	62.91 b	125.76 a
25.0	36.99 a	4.48 a	13.72 a	7.15 a	3.13 a	316.70 c	10.63 a	67.79 a	126.25 a
LSD (0.05)	1.63	1.12	0.79	0.26	0.23	12.56	0.50	1.49	1.45

Notes. Means in the same category followed by different letters are significantly different at the 0.05 level of probability.

slight increase with greater VAR. Levels of Mn were found not to differ among vermicompost treatments but were significantly greater than in the control treatment. In plants, the Mn concentration is usually between 40 and 120 mg kg^{-1} (Mengel and Kirkby 1987). The uptake of various plant nutrients depends on soil pH, and nutrients are taken up at greater rates in slightly acidic conditions. Thus, a greater soil pH may lead to less uptake of nutrients. However, in some cases, ion competition, antagonism, or synergism among or between ions may occur, resulting in unusual uptake patterns (Asciutto et al. 2006).

Vegetation yield parameters showed significant differences among treatments (Tables 5 and 6) with a positive response from plants to the application of vermicompost. Under different application rates of vermicompost, the fresh and dry weights (g pot^{-1}) for aboveground biomass and roots were increased significantly compared to the control. The application of 25.0% vermicompost gave the greatest fresh yield of aboveground biomass and roots, while the lowest values were recorded for the control treatment (Table 5). The lowest fresh-matter yield was recorded for the control for aboveground biomass and roots respectively. Similarly, the greatest dry weight of aboveground biomass and roots were observed for the soil treated with 25.0% vermicompost (Table 6) and the lowest dry weight

Table 5
Effect of different application rates of vermicompost on vegetation properties (fresh matter)

	Aboveground biomass			Roots		
VAR (%)	Fresh-matter yield (g pot^{-1})	R_I (%)	A_E	Fresh-matter yield (g pot^{-1})	R_I (%)	A_E
0.0	0.85 d			0.30 d		
3.0	1.94 c	128.24	0.36	0.72 c	140.00	0.14
12.5	7.26 b	754.12	0.51	2.51 b	736.67	0.18
25.0	9.12 a	972.94	0.33	3.05 a	916.67	0.11
LSD (0.05)	0.85 d			0.30 d		

Notes. Means in the same category followed by different letters are significantly different at the 0.05 level of probability. R_I, relative increase; A_E, agronomic efficiency [see Eqs. (1) and (2)].

Table 6
Effect of different application rates of vermicompost on vegetation properties (dry matter)

	Aboveground biomass			Roots		
VAR (%)	Dry-matter yield (g pot^{-1})	R_I (%)	A_E	Dry-matter yield (g pot^{-1})	R_I (%)	A_E
0.0	0.15 d			0.06 d		
3.0	0.33 c	120.00	0.06	0.12 c	100.00	0.02
12.5	1.33 b	786.67	0.08	0.44 b	633.33	0.03
25.0	1.56 a	940.00	0.06	0.53 a	783.33	0.02
LSD (0.05)	0.09			0.03		

Notes. Means in the same category followed by different letters are significantly different at the 0.05 level of probability. R_I, relative increase; A_E, agronomic efficiency [see Eqs. (1) and (2)].

for the control treatment. Vermicompost is rich in all the nutrients necessary for vegetation growth and enhances the soil physical and chemical properties and subsequently the growth and yield of vegetation. For both fresh and dry weights in the control treatment, a high relative increase (R_I, %) was recorded for aboveground biomass and roots in the 25.0% and 12.5% vermicompost followed by the 3.0% vermicompost (Tables 5 and 6). Increases in the biomass yield can be expected when plants are grown in soil where the levels of nutrients are greater. The R_I values in the treatments were inflated because of the low biomass yield of plants grown in the control treatment.

Agronomic efficiency (A_E) is the best way to express nutrient efficiency under field conditions and indicates the crop yield increase per unit nutrient added (Gowariker et al. 2009). The A_E of all treatments was calculated [Eq. (2)] and showed that the 12.5% VAR had the greatest effect on this parameter (Tables 5 and 6). Thus, 12.5% VAR had the greatest efficiency on crop yield.

Conclusions

The successful reclamation of postmining areas remains a great concern. The results obtained during this study demonstrated that increasing vermicompost application to coal mine soil altered physical and chemical soil properties in such a way as to aid vegetation growth. Soil treated with vermicompost showed significant increases in RSM grass biomass (fresh- and dry-matter yield) as well as enhanced plant uptake of macro- and micronutrients. This shows that vermicompost may be beneficial in the reclamation of soil contaminated with coal spoil by facilitating revegetation of disturbed areas. Further investigations into the long-term effects of vermicompost in this context should be carried out as part of a field experiment.

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