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Utilization of spent mushroom compost for the revegetation of lead–zinc tailings: Effects on physico-chemical properties of tailings and growth of *Lolium perenne*

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ABSTRACT

In an attempt to promote sustainable vegetation cover on metalliferous tailings, a randomized factorial greenhouse trial of six-month duration was established to determine the effect of spent mushroom compost (SMC) amendment on the physical and chemical properties of the predominantly lead/zinc tailings. The tailings originated from the surface (20–30 cm) of the partially-vegetated 76 ha tailings management facility (TMF), where more than nine million tonnes of pyritic metalliferous material were deposited in an unlined land impoundment. SMC was incorporated at application rates of 0, 50, 100, 200 and 400 ton ha^{-1}, with each treatment replicated 10 times and *Lolium perenne* sown at a rate of 200 kg ha^{-1}. The addition of SMC was beneficent as a growing medium through improvement of the structural status of the tailings and ultimately through the provision of plant nutrients and reduction in metal concentrations. However, this improvement in the structural and chemical status of the tailings is not adequate in maintaining a sustainable vegetation cover and therefore other remedial options such as introducing a capillary break on the surface of the tailings facility are necessary.

1. Introduction

The Silvermines district is located on the northern flank of Slieve Phelim-Keeper Hill (N52°4′36″, W8°19′), which extends from O'Brien's Bridge in County Clare, to Roscrea in Co. Tipperary, Ireland (Andrew, 1986). The Silvermines area has a long and extensive history of mining, with the earliest records of argentiferous galena mining by the Danes dating back to the 9th century (Andrew, 1986). Waste material from lead–zinc mining ore of an underground lead/zinc deposit mined from 1967 to 1982 is stored *in situ* at the TMF impoundment in Gortmore. An attempt was made to revegetate the area with self-sustaining grassland in 1985, following a series of lethal dust blows from the impoundment; however, acid generation, nutrient deficiencies and the high salinity of the tailings hindered this endeavor (DAFRD, 2000).

Spent mushroom compost, a relatively abundant waste product of the mushroom industry, can be utilized successfully for the stabilization of disturbed and/or commercial sites, such as abandoned coalmines, pipeline construction sites and industrial sites as it acts as a slow-release fertilizer, and provides small quantities of $CaCO_3$, which lead to an elevation of soil pH (Rupert, 1995). SMC is also a novel biosorbent of heavy metals, where it is reported to have a vast sorption capacity for cadmium, lead and chromium owing to the presence of hydroxyl, phosphoryl and phenolic functional groups on the surface of the SMC (Chen et al., 2005). The research reported here was designed to investigate the effects of SMC incorporation on selected physical, physico-chemical and chemical properties of lead–zinc tailings and to determine if application of SMC is useful for promoting vegetation growth on lead/zinc mine tailings.

2. Methods

2.1. Experimental set-up

Mine tailings were collected from a partially-vegetated area in the tailings management facility (TMF) at Gortmore, Silvermines in May 2004 from a depth of 20–30 cm. The tailings material was partially dried and then passed gently through an 8-mm aperture sieve, in order to minimize structural damage (Rowell, 1994). One-litre plastic pots were packed to a dry bulk density value of 1.12 g cm^{-3}, which was the actual bulk density of the area where the tailings material was collected. Spent mushroom compost was incorporated into the tailings at five different application rates (treatments); 0, 50, 100, 200 and 400 ton ha^{-1} SMC, with ten replicates of each treatment ($n = 50$).

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The pots were then placed in saucers on a bench in a plastic tunnel and allowed to sit in distilled water for two days to ensure that equilibrium moisture content was achieved prior to seeding. *Lolium perenne* was sown in all pots at a rate of 200 kg ha^{-1}, taking into account the purity of the seed, as recommended by Williamson et al. (1982) for mine spoil. The pot trial was performed over one growing season, in effect 6 months (June–December 2004), and the consequent biomass amounts were determined on two occasions; after 6 weeks and after 12 weeks. Deterioration in herbage growth after 12 weeks ensured that no biomass could be collected at the end of the trial.

2.2. Organic matter and physical analyses performed

Organic matter content was determined using the loss on ignition method as per Rowell (1994), while moisture content was also determined according to Rowell (1994), where the amended tailings were dried to constant weight in a Gallenkamp® fan oven at 105 °C. The bulk density of the tailings was determined using a method described by Blake (1965), in which clods were weighed, coated with paraffin wax and then suspended in water, according to Archimedes' principle. The Blake and Hartage method (1986) was employed in measuring the particle density (ρ_p) of the amended tailings substrate. The procedure involved the use of a pycnometer (specific-gravity flask), where the soil particles were dispersed in water and the air expelled from the suspension through boiling (Rowell, 1994). Finally, the total porosity was calculated as per Danielson and Sutherland (1986), using the values obtained for the bulk and particle densities. All parameters were determined in duplicate and were carried out on amended tailings at the end of the study.

2.3. Chemical analyses

2.3.1. Chemical analyses performed on tailings

The chemical analyses of the tailings included total lead, zinc, copper and cadmium concentrations, which were determined by atomic absorption spectrophotometry (Varian, 1989). Each sample (<2 mm) was dried at 105 °C for 24 h, allowed to stand overnight with 10 ml of concentrated analar nitric acid and then heated gently to 125 °C on a heating block for 3 h (McCarthy, 2002). Samples were then filtered, diluted and concentrations of each metal were determined by AAS in accordance with the optimum working conditions (Varian, 1989). Similarly, exchangeable lead, zinc, copper and cadmium fractions were determined by AAS, using a 1 M-ammonium acetate extraction methodology as described by Simard (1993). A certified reference material digest (GEW 07604) was also analysed to ensure the precision of the procedure. The nitrogen content of the amended tailings was determined using a macro-Kjeldahl method according to IDF (1993), while the pH and electrical conductivity were determined using a 5:1 ratio as detailed by Bower and Wilcox (1965).

2.3.2. Chemical analysis performed on SMC

The SMC utilized in this research was analyzed for organic matter, total metal content, pH, EC and nitrogen as described above. Additionally, total phosphorus was determined using a procedure described by Rowell (1994), and concentrations were read at 712 nm by UV spectrophotometry (Ultra Spect 2000). Furthermore, the cation content (K, Ca, Mg, Na) was also determined on the SMC sample using AAS as per Rowell (1994) for plant material, while the C/N ratio was calculated from the percent total nitrogen and organic matter content on the assumption that organic matter contains 58% carbon (Haug, 1993).

2.4. Biological analyses by crop yield and phytotoxicity

When some grass heights exceeded 20 cm, all herbage was cut back to a height of about 2 cm; this occurred 6 and 12 weeks after trial establishment. The grass was then thoroughly washed with deionised water before being dried to a constant dry weight in a Gallenkamp fan oven at 70 °C and the vegetation biomass determined, while the phytotoxicity of the amended tailings was determined using the germination index test as outlined by Tiquia and Tam (1998).

2.5. Statistical analysis

The data generated were analysed statistically using analysis of variance, descriptive measures and Pearson's bivariate correlations on SPSS, version 11.0 (SPSS, 2002). Following the implementation of Kolmogorov–Smirnov one-sample normality tests on SPSS, all poorly skewed data were transformed using $\log_{10}$ (Daniel, 1999). Differences between the effects of SMC application rates on the tailings properties were individually determined using Duncan's post hoc tests on one-way ANOVA (SPSS, 2002) and the overall effect of SMC amendment on the various properties of the tailings and biomass was individually investigated using redundancy analysis (RDA) on CANOCO 4.5 (ter Braak and Šmilauer, 2002), where the application rates of SMC were entered as environmental variables, while the various characteristics of the tailings were entered as the species data.

3. Results

Elemental analysis of the SMC utilized in this study had an average N/P/K ratio of 21:1:20. The sample had a moisture content of 50.6% and a high soluble salts content; which is characteristic of SMC owing primarily to the high potassium content (Maher et al., 2000; Lohr et al., 1984), while the detected heavy metal content was relatively low. The effects of SMC amendment on the physical and chemical properties of the lead–zinc tailings are presented in Tables 1 and 2, where the tailings showed a varied response to SMC supplementation.

4. Discussion

4.1. Physical properties of amended tailings

Evidently, all physical characteristics differed significantly ($P < 0.05$) with varying SMC application (Table 1), with the notable exception of total porosity values. The initial coarseness of the tailings may have been fundamental in this regard as the ability of such substrates to retain water is poor, resulting in swift desiccation patterns (Davies, 1983).

The overall values obtained for bulk density are quite high and are representative of poorly-structured substrates with low organ-

Table 1
Mean physical properties of tailings amended with SMC

Application rate	MC (%)	OM (%)	S_t (%)	ρ_b (g cm^{-3})	ρ_p (g cm^{-3})
Control	22.9^{bcd}	1.64^{a}	51.62^{a}	1.55^{cd}	3.25^{b}
50 ton ha^{-1}	20.99^{d}	4.99^{a}	46.75^{a}	1.52^{bcd}	2.93^{a}
100 ton ha^{-1}	22.27^{cd}	6.39^{ab}	49.91^{a}	1.48^{abc}	3.02^{ab}
200 ton ha^{-1}	24.83^{abc}	7.92^{bc}	50.76^{a}	1.43^{a}	2.96^{a}
400 ton ha^{-1}	24.90^{abc}	8.84^{c}	47.82^{a}	1.45^{ab}	2.89^{a}

Means represented by the same letter in each column are not significantly different ($P < 0.05$) in accordance with Duncan's post hoc test where a = lowest mean. MC, moisture content; OM, organic matter; S_t, total porosity; ρ_b, bulk density; ρ_p, particle density; n = 10 in all cases.