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A Greenhouse Trial on the Effects of Spent Mushroom Compost on the Microaggregate Fraction of Lead-Zinc Tailings

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ABSTRACT

Particle size analysis was carried out on the microaggregate fraction (<53 µm) of spent mushroom compost (SMC) amended pyritic lead-zinc tailings using laser diffraction. A randomized factorial greenhouse trial of six-month duration was established using tailings originating from the surface (20 to 30 cm) of the partially vegetated 76-ha tailings management facility (TMF) in Gortmore, Silvermines, Co. Tipperary, Ireland. SMC was incorporated at application rates of 0, 50, 100, 200 and 400 t ha^{-1} and *Lolium perenne* sown at a rate of 200 kg ha^{-1}. Following trial dismantlement, the effects of SMC treatment on the microaggregate fraction of the tailings was investigated using optical laser diffraction on a Malvern Mastersizer 2000®. At SMC applications of 200 t ha^{-1} and 400 t ha^{-1} an increase in clay dispersion was observed as represented by low d(0.10) values, while a reduction in clay dispersion was noted at SMC applications of 50 t ha^{-1} and 100 t ha^{-1}. Furthermore, microaggregate stability generally decreased with increasing SMC application as noted by a decrease in d(4,3) values. This is probably explained by the change in surface charge following SMC amendment, the low clay concentration and the mineralogy of the lead zinc-tailings, all of which did not prove favorable in the stabilization of the microaggregates present in pyritic lead-zinc tailings. Laser diffraction gave rapid, reliable and consistent results and for the most part showed a shift in particle size distribution between each SMC treatment.

Keywords: laser diffraction, micro-aggregate stability, tailings

INTRODUCTION

The addition of compost to contaminated soils has, in the past proved successful in terms of reclaiming such soils, as it primarily improves the structure of the soil and encourages development of a higher infiltration rate. Composts are particularly abundant sources of xenobiotic-degrading microbes such as bacteria, lignolytic fungi and actinomycetes, which successfully disintegrate contaminants into harmless substances such as carbon dioxide and water (Semple *et al*. 2001). Spent mushroom compost, an abundant waste product of the mushroom industry, is reported to have a positive impact on the physical, chemical and biological properties of pyritic lead-zinc tailings on a short-term basis (Jordan *et al.* 2008). In view of this fact, the research reported here investigated the effects of SMC amendment on the micro-fraction of lead-zinc tailings, from Gortmore TMF, Silvermines, Co. Tipperary, Ireland, using laser diffraction on a Malvern Mastersizer 2000®. The microaggregate stability of tailings is often overlooked in evaluating the success of remedial schemes and is a particularly important consideration as 11.7% of the tailings at Gortmore TMF are composed of dioctahedral clay (Jordan and Mullen 2006).

MATERIALS AND METHODS

Lead-zinc tailings from Gortmore TMF were amended with SMC at five application rates, replicated 10 times, in a randomized factorial greenhouse pot trial as described by Jordan *et al.* (2008). The trial was terminated after its six-month duration and the amended tailings were air-dried and sieved through a 2 mm sieve.

The microaggregate stability of the SMC-amended tailings was determined on samples <53 µm using optical laser diffraction on the Malvern Mastersizer 2000® (Malvern Instruments Ltd., Malvern, UK). The Malvern instrument was equipped with a 2 mV Helium-Neon laser with a wavelength of 0.63 µm as the light source and a photosensitive silicon detector (Anonymous 2000). The values reported for microaggregate stability are (i) the d(0.10) values, which are illustrative of 10% of the total particles suspended in the soil solution, with the d(0.10) value evocative of clay dispersion, with low d(0.10) values representing an increase in the presence of dispersible clay and (ii) the d(4,3) values, which correspond to the volume mean diameter of particles and incorporates the number and volume of particles in a specific medium, with larger d(4,3) values characteristic of the presence of more durable/stable aggregates as described by Courtney *et al*. (2009).

This turbidimetry methodology was adapted from Pojasok and Kay (1990) and entailed mechanically shaking 1 g of <2 mm of air-dried amended tailings with 25 ml of distilled water using a reciprocal shaker for 30 min. The ensuing suspension was then allowed infiltrate through a 53 µm sieve and made up to a 50 ml volume. A fraction of this tailings suspension was transferred to a Hydro 2000S dispersion unit, which uniformly diffused the suspension at 1750 rpm. Suspension concentrations were adjusted until the obscuration of the primary beam was approximately 15% for each sample, in accordance with the Malvern Mastersizer 2000® standard operating procedures (Anonymous 2000). This specific obscuration should optimize the best signal/noise ratio and slight multiple scattering effects (Bittelli *et al.* 1999). As soon as the particles enter the laser beam, they are dispersed away from the obscuration detector and the scattered particles are collected on a reverse Fourier lens, therefore detecting the relationship between light intensity and particle size distribution (Anonymous 2000). The Malvern Mastersizer 2000® is based on the Mie theory, which completely solves the Maxwell's equations for interaction of light with matter and therefore permits precise particle volumes over the size range of 0.1 to 2000 µm (Anonymous 2000). Five successive measurements of 10 seconds duration, with 10 seconds pause between each measurement were determined and the average particle size as represented by the d(4,3) and d(0.10) values were subsequently calculated.

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Short Communication

RESULTS

The effect of SMC application on the microaggregate stability measurements d(4,3) and d(0.10) are summarized in **Table 1**. Evidently, the largest d(4,3) value was recorded for the control sample indicating that these microaggregates are more stable than those amended with SMC. Consequently, the impact of SMC application on the microaggregate fraction of clay and silt particles is negative as the d(4,3) values decrease with increasing application rate. The suspensions dispersed to varying degrees, with overall values for d(4,3) ranging from 20 to 25 µm, which are within the fine silt range (Rowell 1994).

Table 1 Mean physical properties of tailings amended with SMC.

Application Rate	d(4,3)	d(0.10)
Control	24.40 e	4.61 bcd
SD	0.810	0.321
50 t ha^{-1}	23.18 cd	4.91 de
SD	0.680	0.511
100 t ha^{-1}	22.98 c	4.69 cd
SD	1.340	0.550
200 t ha^{-1}	22.11 b	4.29 ab
SD	0.673	0.420
400 t ha^{-1}	21.17 a	4.12 a
SD	1.102	0.434

Means represented by the same letter (a to e) in each column are not significantly different (P<0.05) in accordance with Duncan's *post hoc* test. **SD:** Standard deviation; **d(4,3)** and **d(0.10)**: Microaggregate measurements (µm); Each parameter was statistically analyzed independently. n=10 in all cases.

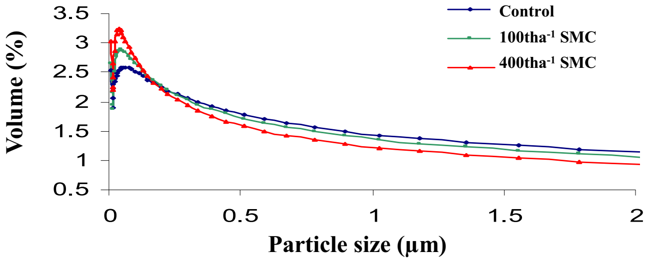

Fig. 1 Comparative volume-size distributions for clay-sized tailings (<2.0 µm) amended with selected varying applications of SMC.

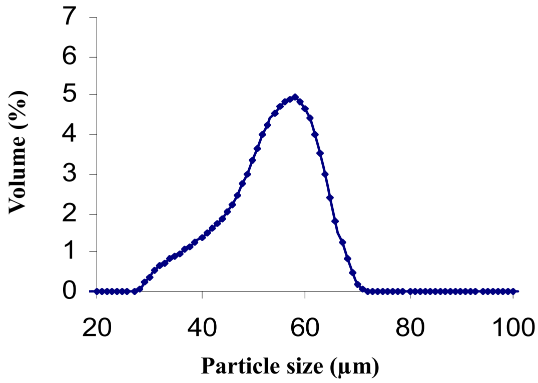

Fig. 2 Comparative volume-size distributions for spent mushroom compost (<100 µm).

DISCUSSION

The negative impact of SMC on microaggregate stability is probably due to the lack of clay and iron and aluminium oxides in the tailings material, which therefore lack appropriate sites for the sorption of organic colloids arising from the decomposing SMC. Humic substances and polysaccharides attach predominately onto clay and iron and aluminium oxides to form organo-mineral complexes (Haynes and Beare 1995).

Furthermore, clay-size particles usually comprise of less than 10% of tailings and are derived from weathered secondary minerals such as illite, kaolinite, vermiculite and montmotillonite, which tend to amplify with time (Williamson *et al*. 1982). In Gortmore TMF, 11.7% of the tailings is comprised of dioctahedral clay particles (Jordan and Mullen 2006). This suggests that the tailings are probably improving in structure over time owing to the limited weathering process and this ultimately may result in an improvement in moisture and nutrient retention (Williamson *et al*. 1982). More significantly, clays have reactive surfaces that contain sites responsible for physico-chemical reactions that initiate flocculation and cementation (Harris and Megharaj 2001) and many mine wastes are dominated by fine-textured single-grained structures owing to the various extraction processes (Whyte and Sisam 1949). Therefore, this increase in clay-size particles may ultimately lead to the increase in stable microaggregates through the development of clay-humic compounds by bridging polyvalent cations (Piccolo and Mbagwu 1994), such as Al^{3+}, Fe^{3+} and Ca^{2+} being adsorbed on clay surfaces (Haynes and Beare 1995).

In contrast, the particle size values for d(0.10) range from 4 to 5 µm and represent 10% of the total particles enumerated in the soil suspension, where the lower d(0.10) values characterize a high level of clay dispersion. At SMC application rates of 50 and 100 t ha^{-1}, clay dispersion was favorably reduced and this is most likely caused by the increase in organic carbon fractions (Haynes 2000). However, at the higher SMC applications of 200 and 400 t ha^{-1}, clay destabilization was significantly promoted (P<0.05) as outlined in **Table 1**. Therefore, organic carbon fractions may not be the major binding agent responsible for stabilizing microaggregates present in pyritic tailings as suggested by Tisdall and Oades (1982).

Additionally, the increase in dispersible clay at high SMC applications may be attributed to the accumulation of salt concentrates in the amended tailings as SMC has high potassium and sodium content (Jordan *et al.* 2008), with Na^{2+} having a known dispersing effect on soil which can cause a reduction in infiltration rates and ultimately the formation of a dense crust upon drying (Berg 1975; Stewart and Meek 1997). Moreover, if the partial oxidation of the organic matter from the SMC amendments increased the carboxylic acid content, the specific adsorption of the carboxyl groups may have induced a further negativity in the clay colloids and have, therefore, promoted dispersion as the dispersing ability of clay particles is related to the charge and charge density of the amended tailings (Durgin and Chaney 1984). This scenario was probable at higher SMC applications, particularly as carboxyl, phosphoryl and phenolic functional groups are abundantly found on the sorption sites of SMC (Chen *et al.* 2005). Furthermore, the complexation of the organic anions with the metal ions in the tailings material favors the dispersion of clays by increasing the negative charge on the colloid surfaces (Oades 1984). Despite SMC playing a probable role in improving the aggregate stability of the tailings material, the effect may have been only temporary as the tailings are a poorly structured material and, once disaggregation transpired, the organic matter may have acted as a deflocculant (Emerson 1983).

Looking more closely at the effect of SMC on clay-sized particles (<2 µm), as represented in **Fig. 1**, a considerably larger quantity of finely-sized particles (<0.25 µm) occurred with increasing SMC application, which was as expected owing to the larger particle size distribution of SMC as illustrated in **Fig. 2**.

The production of chelating agents and subsequent formation of complexes with polyvalent cations during SMC decomposition may have penetrated the clay domain as is evident in **Fig. 1**, and may have resulted in the disintegration of the former bonds within the organo-mineral complexes and ultimately lead to the dispersion of clay particles (Oades 1984). Concomitantly, SMC application reduced the extent of clay-sized particles dispersed in the particle size range of 0.5 to 2 µm.

CONCLUSIONS

The supplementation of SMC improved the physical properties of iron pyrite lead-zinc tailings by reducing d(0.10) values resulting in less dispersion of clay-sized particles at SMC applications of 50 and 100 t ha^{-1}. However, at higher SMC applications of 200 and 400 t ha^{-1} clay dispersion was increased. The overall microstability measurements as represented by d(4,3) values decreased with increasing SMC applications probably owing to the change in surface charge following SMC amendment, the low clay concentration and the mineralogy of the lead-zinc tailings, all of which did not prove favorable in the stabilization of the microaggregates present in pyritic lead-zinc tailings.

IMPLICATIONS FOR PRACTICE

- The supplementation of SMC at applications of 50 and 100 t ha^{-1} will decrease the dispersion of clay-sized particles and therefore the possibility of dust blows from the tailings management facility would be lessened.
- As the microstability of the amended tailings reduced following SMC application, the overall effect of SMC on the micro particles of the tailings is negative and this should be taken into account when implementing remedial measures on tailing ponds.

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