Can organic amendments be used to improve the properties of bauxite processing residue sand?

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Abstract

The effects of adding of a range of organic amendments (biosolids, spent mushroom compost, green waste compost and green waste-derived biochar), at two rates, on some key chemical, physical and microbial properties of bauxite processing sand were studied in a laboratory incubation study. Addition of all amendments tended to decrease bulk density and macroporosity but increase total porosity, available water holding capacity and water retention at field capacity (-10 kPa). Addition of biosolids, mushroom compost and green waste compost all increased soluble organic C, microbial biomass C and basal respiration. The germination index of watercress grown in the materials was greatly reduced by biosolids application and this was attributed to the combined effects of a high EC and large concentrations of extractable P and NO_3^--N. We concluded that the increases in both water retention and microbial activity induced by additions of the composts is likely to improve the properties of residue sand as a growth medium during revegetation.

Key Words

Residue sand, biosolids, biochar, compost

Introduction

Alumina is extracted from bauxite by the Bayer Process and the material remaining (bauxite-processing residue) is disposed-of in large residue drying areas (RDAs) in a semi-dry state. The coarse-textured material (residue sand) is separated from the bulk of the fine-textured material (residue mud) prior to disposal. At Alcoa, the outer embankment of the RDAs are constructed with residue sand and these are subsequently revegetated with native plant species. In the development of effective closure strategies, minimising drainage from RDAs is critical. At present, drainage from RDAs can be recycled to the refinery but following closure, the drainage will need to be treated prior to release to the environment. The coarse-textured nature of residue sand exhibits little water holding capacity and allows rapid movement of infiltrating water to depth. Effective revegetation is important in this regard since transport of water from residue sand back to the atmosphere via transpiration greatly reduces downward percolation of water. It is therefore important to amend the sand in such a way that water holding capacity is increased, nutrient retention is favoured and sustainable plant growth is promoted.

Limitations to plant growth in residue sand include its highly alkaline (primarily due to NaOH and Na_2CO_3), saline-sodic nature, low water and nutrient retention and supplying capacities, its high leaching potential and negligible soil microbial activity (Jones and Haynes 2009). At present, the sand is amended with phosphogypsum (to help neutralise its saline-sodic nature) and inorganic fertilizers (N, P, K, Ca, Mg, B, Cu, Zn, and Mn) are applied prior to establishing a vegetation cover. Although these materials improve the chemical characteristics for plant growth, residue sand still exhibits low water and nutrient holding capacity and little biotic activity. We believe that adding other amendments such as organic matter would also be desirable since they could increase water holding capacity and nutrient supplying capacity and provide a medium where there is less drainage and better plant growth. In addition, organic matter amendment would stimulate soil biotic activity and the development of a self-sustaining below-ground ecosystem and this, in turn, is likely to increase the success of revegetation efforts, particularly in the long-term (Ussiri and Lal 2005).

The purpose of this study was to investigate the effect that addition of a range of organic matter amendments (biosolids, spent mushroom compost, commercially-produced green waste compost and biochar) to phosphogypsum-amended residue sand would have on key soil chemical, physical and microbial properties of residue sand.

Materials and methods

Materials and experimental design

Freshly deposited residue sand was collected from the residue storage area of the Alcoa Kwinana bauxite refinery, transported to the laboratory and air dried. Sieve analysis showed the material had a particle size distribution of 1-2 mm = 12%, 0.5-1mm = 23%, 0.25-0.50mm = 42%, 0.10-0.25mm = 14% and <0.10mm = 9%. Phosphogypsum, obtained from Alcoa, was ground (<1mm) and thoroughly mixed with the residue sand at a rate of 2% v/v. The sand was rewetted to 70% of water holding capacity and incubated for 6 weeks. At the end of that period the sample was leached with 4 pore volumes of water to remove accumulated soluble salts. Biosolids were collected from the Oxley Creek Wastewater Treatment Plant (Brisbane) and spent mushroom compost was collected from a commercial garden centre. The green waste compost was produced commercially from shredded municipal green waste, shredded pine bark and poultry manure (3:2:1 v/v/v) and was sourced from Phoenix Power Recyclers, Yatala, Queensland. The biochar was supplied by BEST Energies, Australia and was produced by low temperature pyrolysis of municipal green waste. Organic materials were ground/sieved (< 2mm) prior to use. The four organic materials were added to the residue sand (3 replicates per treatment) at 40 and 80 g/L. On a volume basis, this is equivalent to 40 and 80 Mg/ha assuming a depth of 10 cm. Amendments were thoroughly mixed with residue sand samples (1L), placed in 2L plastic containers and rewetted to 70% of water holding capacity. The pots were arranged in a randomized block design and incubated at room temperature (24-30ºC) for 6 weeks. Containers were opened and mixed each week to ensure adequate aeration. At the end of the incubation, samples were split into two subsamples; one was stored at 4ºC for microbial and physical analysis and the other was air-dried and stored for chemical analysis.

Analyses

Organic C was measured by automated dry combustion using a Carlo Erba C, H, N analyser. Soluble C was measured in K_2SO_4 extracts using a Shimadzu 5000A soluble C/N analyser. Available P was extracted with 0.5 M $NaHCO_3$ (pH 8.5) (1:100 w/v for 16 h) (Colwell 1963) and measured colorimetrically. Extractable mineral N was extracted with 2 M KCl (1:100 ratio for 1 h) followed by colorimetric analysis of NH_4^+ and NO_3^--N. Microbial biomass C was estimated based on the difference between organic C extracted with 0.5 M K_2SO_4 from chloroform-fumigated and unfumigated soil samples using a K_C factor of 0.38. Basal respiration was determined by placing 30 g oven dry equivalent of moist soil in a 50-ml beaker and incubating the sample in the dark for 10 days at 25ºC in a 2-l air-tight jar along with 10 ml 1M NaOH. The CO_2 evolved was determined by titration. Bulk density was determined on naturally compacted samples, particle density by the pycnometer method and total porosity by the difference. Soil water content in samples was determined at -10 and -1500 kPa using a pressure plate apparatus. Pore size distribution was calculated as macropores (> 29 µm diameter; air-filled porosity at -10 kPa), mesopores (0.2-29 µm diameter; drained between -10 and -1500 kPa) and micropores (< 0.2 µm diameter; water filled pores at -1500 kPa).

Table 1. Some chemical and microbial properties of bauxite residue sand amended with organic materials at 40 or 80 Mg/ha.

Treatment[1]	Extractable P (mg/kg)	NH_4^+-N (mg/kg)	NO_3^--N (mg/kg)	Organic C (gC/kg)	Soluble organic C (gC/kg)	Microbial biomass C (mgC/kg)	Germination index (GI)
Control	11.8^a	5.4^a	1.0^a	0.27^a	nd	nd	83.4^b
Biosolids (40)	460.6^b	25.4^d	296.6^b	10.0^b	126.8^b	8.4^a	47.6^a
Biosolids (80)	966.1^c	21.1^{cd}	557^c	16.9^c	412.4^c	20.4^c	53.7^a
Mushr. Comp. (40)[2]	50.2^a	11.4^{abc}	1.0^a	9.0^b	53.9^a	16.0^b	83.1^b
Mushr. Comp. (80)	41.4^a	17.9^{bcd}	0.8^a	14.6^{bc}	145.1^b	24.9^d	86.6^b
Greenw. Comp. (40)	27.3^a	9.9^{abc}	6.2^a	10.8^b	63.2^a	11.5^a	95.0^b
Greenw. Comp. (80)	45.5^a	13.3^{abc}	12.4^a	16.7^c	95.5^b	25.5^d	73.2^b
Biochar (40)	11.8^a	11.8^{abc}	1.3^a	18.3^c	nd	nd	78.7^b
Biochar (80)	11.7^a	7.6^{ab}	1.8^a	35.5^d	nd	nd	83.6^b

[1] Means followed by the same letter in a column are not significantly different at $P \leq 0.05$

[2] Mushr. Comp. = mushroom compost, Greenw. Comp. = Greenwaste compost

A germination test was carried out (in quadruplet) on filter paper in petri dishes. Two ml of aqueous extract (1/10 w/v) from each of the treatments was added to dishes. Ten seeds of watercress (Lepidium sativum) were placed on the filter paper and dishes placed in the dark at 28ºC. The germination index percentage with respect to control (distilled water) was determined after 5 days. The control GI value was considered as 100%.

The statistical significance of experimental treatments was determined by Analysis of Variance Analysis using the Minitab Statistical Software Package and differences were calculated at the 5% level using Tukey's test.

Results and discussion

Very little research has addressed revegetation of residue sand although a large body of research has been concerned with revegetation of residue mud (Fuller *et al.* 1982; Wong and Ho 1993; Xenidis *et al.* 2005; Courtney *et al.* 2008). Although residue sand has similar chemical properties to residue mud, it has a lower buffering capacity and a much greater particle size (Jones and Haynes 2009). The initial treatment of the residue sand with phosphogypsum was successful in reducing ESP from about 75% down to 15-20% and pH from 11.1 down to 8.1 (data not shown).

A more-than adequate supply of N and P following land application of biosolids is common (Pierzynski 1994) and in this study extractable P, NH_4^+-N and NO_3^--N were greatly elevated in the biosolids treatments (Table 1). The EC in saturation paste extracts was also elevated being > 1 mS m^{-1} in biosolids treatments and < 0.6 mS m^{-1} in the others (data not shown). The high soluble salts, extractable P and mineral N produced conditions inhibitory to germination and early seedling growth and as a result, germination index was 45-55% in biosolids treatments and >80% in the others (Table 1). The concentrations of extractable P in the biosolids treatments are likely to be inhibitory to growth of many Australian native plants (which are being used for revegetation) since Handreck and Black (2002) suggested optimum P levels were < 10mg kg^{-1} for species sensitive to P and < 40mg kg^{-1} for moderately sensitive species. Additions of both spent mushroom compost and green waste compost increased extractable P and NH_4^+-N levels (Table 1) demonstrating their important effect of improving soil fertility. Green waste biochar had no significant effect on extractable P or mineral N levels. This may be partially due to the source of biochar since Chan *et al.* (2008) showed that biochar produced from animal manure has a much higher nutrient content and greater effect on soil fertility than that produced from plant residues.

For brevity, results for physical properties of treatments are shown only for the 80 Mg ha^{-1} application rate (Table 2). Addition of organic amendments caused a reduction in bulk density and tended to increase total porosity (Table 2). This is characteristic of their effect when added to soils (Khaleel *et al.* 1981; Haynes and Naidu 1998). Their addition also caused a decrease in the percentage of total porosity occupied by macropores with concomitant increases in mesoporosity and microporosity. This is attributable to a greater percentage of small pores in the organic materials, compared to the coarse-textured sand, and/or organic material partially filling large voids previously present between these sand particles. This change in pore size distribution resulted in an increase in plant-available water and in water content at field capacity (i.e. -10 kPa) for all amended treatments. This is of particular practical importance since an increased water storage capacity will provide revegetating plants with a larger supply of water as well as reducing water fluxes down the profile.

As expected, the addition of biosolids, mushroom and greenwaste composts to the residue sand increased organic C, soluble C, microbial biomass C (Table 1) and basal respiration (data not shown). That is, their addition increased substrate C (i.e. soluble C) availability and as a result there was an increase in the size and activity of the microbial community present. Indeed, soluble C and microbial biomass C were below levels of detection in the control treatment. The increases in microbial activity are important in promoting a functioning below-ground ecosystem, the cycling of nutrients through organic pools and improving the fertility of residue sand. Charcoal C is essentially a biologically inert substance and as a result, soluble C and microbial biomass C were below the level of detection in the biochar treatments and basal respiration was very low.

Table 2. Physical properties of bauxite residue sand amended with organic materials (at 80 Mg/ha).

Treatment[1]	Bulk Density ($Mg\ m^{-3}$)	Total Porosity ($m^{-3}\ m^{-3}$)	Pore size distribution (%) Macropores (>29μm)	Mesopores (0.2-29μm)	Micropores (<0.2μm)	Available water ($kg\ m^{-3}$)	Field Capacity ($kg\ m^{-3}$)
Control	1.65^a	0.46^a	76^a	11^a	13^a	51^a	109^a
Biosolids (80)	1.54^b	0.48^{ab}	63^c	14^b	22^c	68^b	177^b
Mushr. Comp. (80)[2]	1.42^c	0.54^c	65^c	19^c	16^{ab}	102^d	190^c
Greenw. Comp. (80)	1.46^c	0.52^{bc}	66^{bc}	16^{bc}	17^b	85^c	174^b
Biochar (80)	1.44^c	0.51^{abc}	61^c	25^d	15^{ab}	126^e	199^c

[1] Means followed by the same letter in a column are not significantly different at P≤0.05

[2] Mushr. Comp. = mushroom compost, Greenw. Comp. = Greenwaste compost

Conclusions

For revegetation of bauxite residue sand, waste organic materials such as biosolids, mushroom and green waste composts are potentially important amendments. Their addition not only improves physical conditions (particularly water storage capacity) of the medium but also increases fertility and stimulates microbial activity. There seems scope to mix, or co-compost, biosolids with some other material (e.g. green wate) in order to reduce its negative effects on soil chemical properties (e.g. excessive accumulation of salts, P and mineral N) to produce an amendment that would be more conductive to plant growth.

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