CL:AIRE

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subr:im bulletin

CL:AIRE's SUBR:IM bulletins present practical outcomes of research by the SUBR:IM consortium which have direct application to the brownfield and contaminated land communities. This bulletin considers the use of compost in brownfield projects.

The Use of Compost in the Regeneration of Brownfield Land

1. INTRODUCTION

This end user guide is a product of two work-packages of the Sustainable Urban Brownfield: Integrated Management (SUBR:IM) research consortium. The research of work-package F on integrated remediation and greening of urban greenspace examined the use of compost for the establishment of plant growth on remediated soils. This research was conducted at Forest Research. The research of work-package K focused on the development of novel compost for the remediation of metal contaminated land. This research was conducted at the University of Surrey, University of Cambridge and Forest Research.

In 2002 new legislation was introduced restricting the possibilities for the landfilling of waste. This legislation aimed to reduce landfilling of organic waste by 7.3 million tonnes per year in 2009/10 and 10.5 million tonnes per year by 2012/13. As a consequence there has been an increase in the recycling of organic waste through composting and currently about 1.9 million tonnes of composted materials enter the UK market each year. The same legislation also reduced the options for the landfilling of contaminated soil and has encouraged the use of remediation technologies. These reduce the threat of the contaminants to receptors such as humans, animals and groundwater. After remediation, the treated soil is used on site to support land reclamation and site redevelopment. There is a high pressure on land use in urban areas and the UK government has set a target for 72% of new housing to be established on brownfield sites rather than green field. This has also encouraged the development of new on-site remediation techniques.

Composted materials can be used in the reclamation and remediation of brownfield sites. Compost is commonly added to other to soil-forming materials for use on landfill caps and the revegetation of sites where contaminated soil has been removed (Bending *et al.*, 1999). The composts increase the soil organic matter content, raise fertility and improve the soil structure prior to the establishment of vegetation (Kilbride, 2006). Compost can also be used to restore remediated materials as a plant supporting soil (Sellers *et al.*, 2004) and can directly help in the remediation process of contaminated soils (Bardos and van Veen, 1996). Remediation of soils with compost can improve biodegradation of organic contaminants by microorganisms from the compost as well as immobilisation of heavy metals by the compost itself.

The Waste Resource Application Program (WRAP) has estimated that between 2006 and 2010 more than 100,000 tonnes of compost could be used in the regeneration and reclamation of brownfield and derelict sites across the UK. To improve confidence in composted materials among end-users and to define quality, WRAP has, in cooperation with the Composting Association and the British Standards Institution (BSI), developed a specification for the production of composts, called PAS100 (Publicly Available Specification 100; BSI, 2005). This bulletin examines the potential of PAS100 and non-PAS100 composts for brownfield reclamation and summarises experimental results from the following studies:

- The revegetation of remediated soils amended with green waste compost;
- The effect of compost amendment on heavy metal mobility;
- The effect of amendment rate of composts;
- The metal binding capacity of combinations of compost, clay and zeolite.

2. COMPOST FOR REVITALISATION OF REMEDIATED MATERIALS

The remediation of contaminated soils is quite often a destructive process leaving a soil that might be clean according to guideline values but which is generally not suitable for vegetation establishment. Current remediation technologies fall into four basic categories, namely: physical, chemical, biological and thermal. Thermal treatment will remove contaminants but will destroy other soil characteristics beneficial for plant growth. Chemical extraction and soil washing can also degrade the quality of the soil. To study the restoration of remediated soils, the effect of amending a low heat treated soil and two bioremediated soils with green waste compost and their subsequent ability to support the growth of grass and trees has been assessed (Sellers *et al.*, 2004).

The low temperature heat-treated soil came from the Avenue Coking Works near Chesterfield, Derbyshire, a bioremediated sandy loam soil was obtained from a development in Cardiff, and a bioremediated clay from the Channel Tunnel Rail Link development. In addition, an untreated contaminated soil originating from the same source as the heat treated soil was tested and a clean sand was used as a control. All materials were tested unamended, or amended with a green waste compost meeting PAS100 specifications. The amended soils were planted with poplar (*Populus trichocarpa*), alder (*Alnus cordata*) and two different grass mixtures, one for sandy soils, the other for clay soils. The application rates for the green waste compost were 25% and 50% (v/v) for the tree experiments, and a layer of 25 mm and 50 mm of compost incorporated into the top 150 mm for the grass experiments. For the trees, the height was monitored, and for the grass mixtures, the ground cover and above-ground biomass were measured. All trials were monitored for 1.5 years.

The results for the tested trees after 5 months are presented in Figure 1 and show that compost amendment had the best improving effect on tree height when added to the untreated contaminated soil and heat treated soil. Although the growth on the bioremediated soil from Cardiff was also improved in the first 5 months, after 17 months only the contaminated and the heat treated soils were significantly improved by compost addition at both the 25 and 50 mm addition rates. The biomass production of the grass mixtures after 5 months is presented in Figure 2. Similar measurements after 16 and 19 months showed that growth on the sand control, the contaminated soil, the heat treated soil and the bioremediated soil from Cardiff was significantly improved by compost addition. Grass growth on the bioremediated soil from the tunnel development

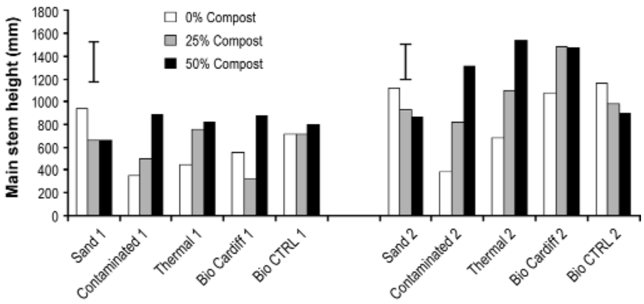

Figure 1. Average height of main stem for alder (1) and poplar (2) taken in September 2004. Bars = least significant difference (from Sellers *et al.*, 2004).

was very poor and stayed so even after compost amendment. This is probably due to the clayey nature of the soil rather than residual contamination or an effect of the remediation process. That the compost did not make much difference to the bioremediated soil is not surprising since this soil was already optimised for microbiological processes which should also result in better conditions for plant growth.

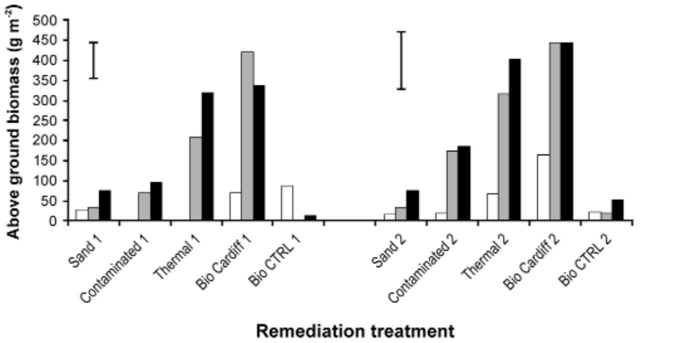

Figure 2. Above ground biomass (g m^{-2}) after 5 months for the sandy soil grass mix (1) and clay soil grass mix (2). Bars = least significant difference (from Sellers *et al.*, 2004).

The results presented cover a relatively short period of time but nevertheless illustrate a few important points. In general, adding compost to the soils improved growth for the tree species and grass mixes tested. Growth was considerably improved on the unremediated soil when compost was added but it remained poor compared to the remediated soils amended with compost. Other research has shown that organic amendments can improve plant growth on incinerated, and burnt soils and fly ash (Castro *et al.*, 2000; Stehouwer and Macneal, 2003; Rai *et al.*, 2004). Land reclamation practitioners have been wary of using remediated soil material in greening and landscape projects, but the results presented here suggest that such material, suitably amended with compost, can support tree and grass vegetation that can enhance the visual appearance and amenity value of local environments. More details of this work can be found in Sellers *et al.* (2004).

3. COMPOST FOR REMEDIATION OF METAL CONTAMINATED SOILS

Organic materials such as compost are often proposed as suitable materials for the remediation of contaminated brownfield sites intended for soft end-use. Composts are known to improve the vitality of soil through improving the soil fertility, increasing the water and nutrient holding capacity, stabilising the soil pH, improving soil aeration and enhancing revegetation. In addition to vitalising the soil, they are also believed to immobilise metals thereby breaking contaminant-receptor pathways and reducing the ecotoxicity of the contaminants. In order to study the latter claim four different composts on three different metal contaminated soils have been tested to determine if metals are really immobilised and plant uptake is reduced (van Herwijnen *et al.*, 2007a).

The leaching of metals from compost amended soils as well as performance and metal concentrations of Greek cress (*Lepidium sativum*) were studied (van Herwijnen *et al.*, 2007a). The composts used in this study were a commercially available green waste compost (GWC), spent mushroom compost (SMC), a commercially available sewage sludge compost consisting of a mixture of composted sewage sludge and wood chips (SC), and a commercially available coir compost made from composted coconut husks (CC). The green waste compost was produced according to PAS100 guidelines but the coir compost and spent mushroom compost also conformed to the PAS100 standard for concentrations of heavy metals. Only the composted sewage sludge exceeded these levels. The contaminated soils used in the study were collected at former zinc smelter in Avonmouth near Bristol, a mine spoil in the Tamar Valley in south Devon and foundry sand from a former arsenal in Thamesmead, London. The Greek cress was grown on amended soils for 14 days and at the end of the trial the plants were harvested for chemical analysis, and the above-ground biomass was determined. The leaching tests were carried out according to a standard European test (EN 12457-2:2002).

The results demonstrate that the leaching behaviour of copper and zinc is dependent on both soil type and the type of compost. Figure 3 shows a few extreme cases for the leaching of copper and zinc. Composted sewage sludge and spent mushroom compost both increased the leaching of zinc, originally bound to the soil, by a factor of 1.8 and 2.0 respectively while green waste compost and coir compost reduced the leaching of zinc by factor of 0.15 and 0.6 respectively. However, an increase in the leaching of zinc was observed for all composts mixed with the Thamesmead soil; although the zinc most likely originates from the composts rather than the soils. It was also observed that the magnitude of the effects of composts differed between the soils. In the case of the Avonmouth soil for example, the effect of composted sewage sludge was almost 10 times higher in magnitude than that of green waste compost while on the Thamesmead soil the effect of composted sewage sludge and green waste compost were comparable. In the Avonmouth soil all compost amendments increased the leaching of the soil bound copper. Even green waste compost which reduced the leaching of zinc from this soil increased the leaching of copper at relatively the same order of magnitude as composted sewage sludge. In contrast, all amendments apart from spent mushroom compost reduced the leaching of copper on Tamar valley soil significantly with a factor of 0.1. The observed increased leaching of metals after compost amendment has been reported for arsenic (e.g. Cao *et al.*, 2003; Cao and Ma, 2004; Clemente *et al.*, 2003) but is rarely reported for metals such as zinc, copper, cadmium and lead (Kiikkilä *et al.*, 2002). More details on the work presented here are given in van Herwijnen *et al.* (2007a).

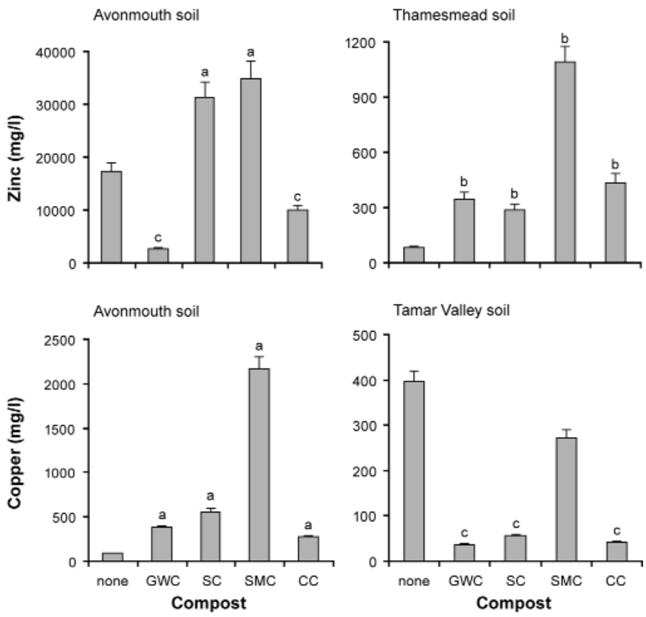

Figure 3. Mean concentrations (mg l^{-1}) of zinc and copper in leachates from compost amended soils. Error bars are standard error of the means. a, b, and c indicates where values are statistically significantly different from each other (from van Herwijnen *et al.*, 2007a). For an explanation of the sites and composts, see text.

It is commonly assumed that the leachability of a metal can be taken as an indication of its bioavailability. Greek cress was grown on compost-amended Avonmouth soil and Figure 4 shows the concentrations of copper and zinc in these plants (van Herwijnen *et al.*, 2007a). Both the green waste compost and spent mushroom compost reduced concentrations of copper and zinc in Greek cress in contrast to the leaching results presented in Figure 3. Other workers have found little or no relationship between extractability of metals and plant uptake. Extraction with EDTA solution has been proposed to be most representative for plant availability (Madyiwa, 2003) but weak salt solutions have also been suggested to give the best correlation with metal uptake (Aten and Gupta, 1996). Since leaching results do not correspond with plant uptake or plant availability, care should be taken before applying these types of materials at an operational scale in the field. These results suggest that each time a material is proposed for remediation of metal contaminated soils it should be tested with the proposed soil using appropriate leaching and plant uptake tests to ensure that potential risks of toxic metals reaching potential receptors in the environment are fully quantified (van Herwijnen *et al.*, 2007a).

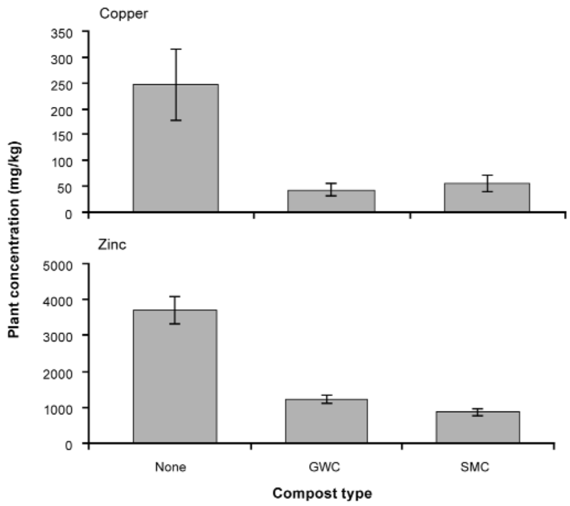

Figure 4. Shoot concentrations of zinc and copper in shoots of Greek cress growing on Avonmouth soil amended with two different types of compost: green waste compost (GWC) and spent mushroom compost (SMC). Error bars are standard error of the means (from van Herwijnen *et al.*, 2007a).

4. COMPOST APPLICATION RATES

Under Waste Management Licensing Regulations (1994), it is permitted to apply relatively large amounts of composts to soils. The research presented here shows that growth can be significantly improved by compost amendment (van Herwijnen *et al.*, 2007b). Figure 5 shows ryegrass growing on soil highly contaminated with heavy metals from Avonmouth amended with increasing levels of compost. The growth of the plants is clearly improved with every increment of green waste compost or composted sewage sludge added to the soil. However, higher addition rates can affect the growth performance of plants. A clear example is given in Figure 6, which shows impaired growth of ryegrass after amendment of green waste compost to a soil contaminated with heavy metals at a low level. Composted sewage sludge added to the same soil improved growth at the lower rates of 7% and 14% but the higher rate of 20% also inhibited growth, as was also observed for green waste compost amendment. Similarly, plant growth improved after the amendment of green waste compost at 25% to remediated soils but the higher level of 50% did not give any additional improvement for plant growth. Figures 1 and 2 also show that in some cases, the level of 50% compost reduced the plant growth compared to 25% while in other cases plant growth was improved.

Figure 5. Ryegrass growing on high level contaminated soil amended with different rates of compost. Top: Green waste compost, bottom: composted sewage sludge. From left to right: 0%, 7%, 14% and 20% compost amended to the soil.

Like the results for leaching and plant uptake, these observations vary between soils and a recommendation about the level of compost to be applied cannot be given without performing plant tests on the soil in question. In general, immature composts should not be used because during the continuing composting process nitrogen, which is essential for plant growth, can be immobilised by the compost (Chaves *et al.*, 2005). Compost materials should have sufficient carbon to nitrogen ratio. At ratios above 25 to 1, similar nitrogen immobilisation processes may occur. Nevertheless only mature composts were tested in these studies which had a carbon to nitrogen ratio below 25 to 1 so nitrogen immobilisation should not have played a big role.

Figure 6. Ryegrass growing on low level contaminated soil amended with different rates of compost. Top: Green waste compost, bottom: composted sewage sludge. From left to right: 0%, 7%, 14% and 20% compost amended to the soil.

5. AMENDMENT OF COMPOSTS WITH METAL IMMOBILISING MINERALS

When compost is used to immobilise heavy metals and enable revegetation of a polluted soil, there is always the risk that degradation of the compost will release the metals in the longer term. The results presented here also show that there is a limit to the total amount of compost that can be added before plant performance suffers, which can be problem if higher rates of compost addition would be necessary for effective metal immobilisation. For these cases it can be useful to combine compost with minerals that can also immobilise heavy metals such as zeolites. In addition, zeolites could provide longer term metal immobilisation because they are more resilient than compost additions to soil weathering and mineralization processes. So far, most research on combined use of composts and minerals focused on the immobilisation of metals originating from compost (Larchevêque *et al.*, 2006; Schwab *et al.*, 2006) or the stabilisation of nutrients during the composting of manure (Leggo and Ledesert, 2001).

A combined amendment of compost and zeolite (clinoptilolite) has also been tested to ascertain whether an increase in the metal immobilisation capacity of the compost can be achieved by combining the two materials (Ouki *et al.,* 2007). Figure 7 shows the metal concentrations in leachates from highly contaminated Avonmouth soil amended with green waste compost and/or zeolite. Metal concentrations in leachates were effectively reduced for cadmium, copper, lead and zinc for the individual amendments by maximum factors of 0.3, 0.7, 0.4 and 0.6 respectively. Combining the compost with the zeolite as soil amendment worked very well for cadmium and zinc. For both metals, the reduction of the leachate concentration was significantly lower for the combined amendments (compost and zeolite) compared to the individual amendments. For cadmium the maximum reduction by the combined mixture was 0.2 and for zinc 0.5. Addition of compost and the zeolite individually was found to reduce the leachate concentrations of lead but in general the combination of compost with zeolite was as effective as the compost on its own. The leachate concentrations of copper showed similar results to those for lead but in this case the combination of compost and zeolite appeared to be less effective than either the compost or the zeolite as sole amendment.

Overall, it can be concluded that the combination of zeolite and composts demonstrated a very good potential for metal containment but these and earlier results have shown that the efficiency depends on both the type of soil and the metal of concern. Further information on this work can be found in van Herwijnen *et al.* (2007a, b, c) and Ouki *et al.* (2007).

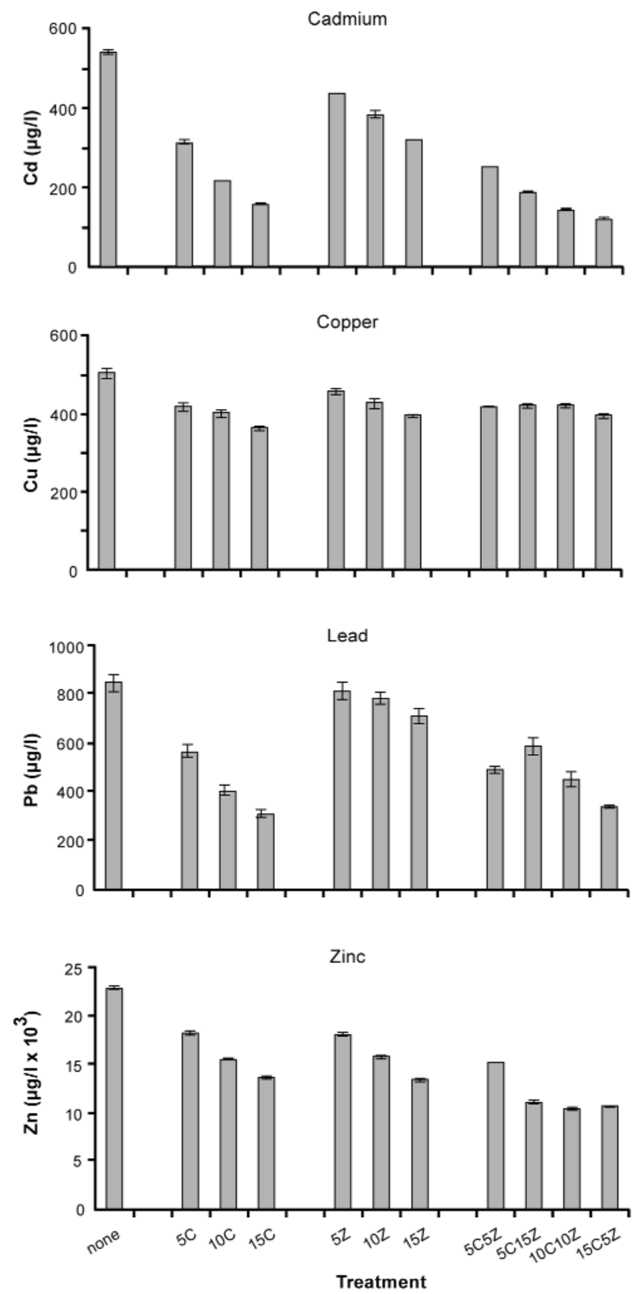

Figure 7. Concentrations of cadmium, copper, lead and zinc in leachates of highly contaminated Avonmouth soil amended with green waste compost (C) and/or zeolite (Z) at 5, 10 or 15% of the soil mixture (w/w). Error bars are standard error of the means (from Ouki *et al.*, 2007).

6. CONCLUSIONS

The research presented here demonstrates that there is a large potential for the use of compost in the regeneration of brownfield land. Remediated soils, where structure has been destroyed during the remediation process, can be improved with compost but unremediated soils can also benefit from compost addition. It has been shown that compost can be used for the remediation of metal contaminated sites but its effectiveness varies according to the type of compost, soil and the metal. There is currently not enough knowledge to accurately predict the effect a given compost and soil combination will have on the mobility of metals. Before the addition of compost to a metal contaminated soil, extensive testing is necessary to establish what the effect on the mobility of metals may be. More research into this area is required and a standard testing procedure should be developed. It has been shown that, although PAS100 produced compost may increase the leaching of toxic metals but this standard will help the use of compost in land regeneration. Through the PAS100 better standardised source segregated composts will be produced enabling a more reliable outcome of the compost addition.

Acknowledgements

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