Laboratory based experiments to assess the use of green and food based compost to improve water quality in a Sustainable Drainage (SUDS) device such as a swale.

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Abstract

Many tonnes of compost are generated per year due to door step composting of both garden and kitchen waste. Whilst there are commercial outlets for the finer grade of compost (<10mm) in plant nurseries, there is little demand for the coarser material (>25mm). This paper reports part of a WRAP-sponsored (Waste Resources Action Programme) study which investigated the potential for green (GC) and mixed green and food (MC) composts to be incorporated into Sustainable Drainage (SUDS) devices such as swales, and replace the topsoil (TS) onto which turf is laid or grass seed distributed. However, it is not known whether compost can replace TS in terms of pollutant remediation, both the trapping of polluted particulates and in dealing with hydrocarbons such as oil, but also from a biofilm development and activity perspective. Using laboratory based experiments utilising leaching columns and an investigation of microbiological development in the composts studied, it was found that many of the differences in performance between MC and GC were insignificant, whilst both composts performed better in terms of pollutant retention than TS. Mixed compost in particular could be used in devices where there may be oil spillages, such as the lorry park of a Motorway Service Area due to its efficiency in degrading oil. Samples of GC and MC were found to contain many of the bacteria and fungi necessary for an active and efficient biofilm which would be an argument in their favour for replacement of TS and incorporation in swales.

Key words: Green compost (GC); Mixed compost (MC); topsoil (TS); Sustainable Drainage (SUDS); swale; biofilm; leachate.

1. Introduction

Of the thirty million tonnes of household rubbish generated in the UK every year, half is recyclable. The Landfill Directive requires significant reductions in the amount of waste sent to landfill, and attempts have been made to divert waste using commercial composting. Compost produced in the UK from segregated waste in 2008/09 was “significantly” (Association for Organics Recycling, 2010) increased from the 2007/08 total of 2.7 million tonnes to approximately 2.85 million tonnes, plus a further 105,000 tonnes of digestate product. Much of this compost (47%) was spread on farmland, but some, ironically, was landfilled (WRAP, 2007). Consequently, there is increasing interest in commercial outlets for composted material. The finer particle sizes (~<10 mm) have found an outlet as “peatless” garden compost, but the coarser sizes (>25 mm) have limited commercial potential. This paper details part of a WRAP-funded (Waste Resources Action Programme) project which was carried out in order to determine the potential of coarser grades of green (GC) and mixed green and food composts (MC) to replace top soil (TS) in vegetated Sustainable Drainage (SUDS) devices such as a swale (cf Charlesworth et al., 2003a).

Many studies of the use of compost in pollutant remediation do so by investigating manures and combined wastes such as Municipal Solid Waste (MSW) which are themselves polluted with contaminants such as heavy metals (e.g. Pinamonti et al., 1997; Businelli et al., 2009; Farrell and Jones, 2009; Paradelo et al., 2011). Segregated wastes used in the present study must have conformed to PAS100 guidelines (BSI, 2011) and thus are not contaminated at the outset. Their physicochemical characterisation in the course of the overall project confirmed their adherence to these guidelines and also compared favourably with published background (Macklin, 1992), CLEA SGVs (Defra and EA, 2002) and ICRCL Soil Class A values (ICRCL, 1987).

As described by Farrell and Jones (2009), the production of compost is an aerobic process facilitated by a variety of microorganisms whereby heat is produced either outside in windrows for the production of GC, or in digestion vessels anaerobically. The latter process is used in the production of MC since it contains food waste, a potential source of microbial pollution, and anaerobic digestion at specified temperatures for specified times eliminates these. Microorganisms are therefore an essential part of the production of compost, being involved in the breakdown of the primary source material and will therefore be present in the finished product.

As part of the SUDS triangle (Charlesworth et al., 2003a; Charlesworth, 2010), devices such as swales place equal emphasis on reducing water quantity, enhancing biodiversity and amenity, and also improving water quality. There are distinct advantages to the use of coarse grades of substrate for water quality improvement purposes since hydraulic conductivity is increased and bulk density decreased allowing easy ingress of stormwater; the open spaces within the compost also allow for increased oxygen levels which encourages increased diversity in the microbial population (Park et al., 2011). Swales are vegetated devices; the plants trap pollutants in their stems and leaves and also take them up systemically, therefore improving water quality. Stormwater infiltration into the soil improves water quality by trapping particulate associated pollutants in the soil interstices but also by treatment in the biofilm which is found naturally within the soil (Burmølle et al., 2007). Biofilms are organized microbial systems including bacteria, fungi, protists and animals which develop in association with surfaces (Newman et al., 2006). They are complex and dynamic systems (Battin et al., 2007) and as they grow and reproduce they can biodegrade pollutants such as oil (White et al., 1995). Their rate of activity can be measured indirectly by analysing carbon dioxide evolution (Coupe *et. al*, 2006).

The construction of swales (essentially grassed ditches) and filter strips (grassed slopes) usually requires careful excavation and the importation of TS before grass seeds are broadcast or turf is laid. Compost could be used in place of the TS, but its pollution mitigation abilities in a swale environment are unknown. Whilst there are studies of the use of compost filled “socks” in the treatment of stormwater (e.g. USCC, 2008; Faucette et al., 2009; Faucette et al., 2008; USEPA, nd), these have mostly utilised smaller grades (< 25mm) of compost. These studies have shown high metal and hydrocarbon removal efficiencies since materials such as compost contain high concentrations of humus which aid in the degradation and trapping of typical urban pollutants (Faucette et al., 2008). If compost is to be used in a SUDS system, to either wholly or partially replace TS, it must perform at least as well in terms of its pollution remediation properties.

The aims of the part of the overall WRAP project reported here were therefore:

1. To assess the pollution remediation potential of coarse grade (>25 mm) green (GC) and mixed compost (MC) in laboratory experiments by applying pollutants to leaching columns of the compost and TS as a comparison, to assess their relative performance in remediating contamination.
2. To assess the potential for biofilm development in composts, specifically in supporting those microbes identified in the literature which trap and biodegrade pollutants such as heavy metals and hydrocarbons, by investigating the microbiology of the compost in a swale-like environment using small-scale models.

2. Materials and methods

Whilst it is accepted that small-scale laboratory experiments are an approximation of the functioning of the systems under study, nonetheless, simulations using model rigs are frequently used to study specific aspects of their performance (e.g. Fernández-Barrera et al., 2010a and b; Rodriguez-Hernandez et al., 2010). Thus, two approaches were taken to address the aims outlined above: the first assessed the ability of the composts and also TS to deal with pollutants applied in amounts commonly found in urban environments by measuring contaminants in the effluent from leaching columns. The second approach utilised microbiological techniques in order to count and identify known bacterial and fungal hydrocarbon degraders harvested from model rigs (More et al., 2010) in both composts and in TS and also to assess the activity of the biofilm using carbon dioxide (CO_2) production (cf. Coupe et al., 2006).

2.1 Leaching of pollutants through compost columns.

One litre plastic drinks bottles were thoroughly washed in de-ionised water, had their bases removed and were attached to a grid. Tubing and taps were attached and the small rigs filled with composts or TS. Topsoil was used as a continuous reference point during the experiments. Simulated rainfall using mains water was flushed through the rigs three times before pollutant addition was begun to clear any contaminants already present in the leaching columns as well as to wet the material to encourage biofilm development.

The pollutants used were clean lubricating oil (Castrol GTX) which was applied at a rate of 25ml m^{-2} fortnightly and Coventry Street dust (CSD) which was applied at a rate of 21g m^{-2} fortnightly. These rates were used as they represent the equivalent of a month's worth of loading in a typical urban environment (Wilson et al., 2003). The pollutants were chosen as they have been used in previous studies of urban pollutants (e.g. Charlesworth et al., 2003b; Charlesworth and Lees, 1999) so their properties are well known. The CSD was sieved and homogenised using a ball mill prior to use (see Charlesworth et al., 2003b for further details). The rigs were rained on fortnightly at an intensity of 15mm/hr (applied the day after pollutant addition) for 52 minutes (13mm), a UK recurrence interval of 2 years approximately (Andersen et al., 1999). The effluent was collected from each test rig and subsequently analysed using ICP-AES for Cd, Zn, Pb, Cu and Ni. These metals are typically found in the urban environment and are associated with urbanisation and industrialisation (Charlesworth et al., 2003b).

Determination of oil and grease in the effluents from the oiled leaching columns was carried out by infra red spectroscopy using a Horiba OCMA 310 oil analyzer (Horiba Co. Ltd, Japan). There were 4 replicates of each treatment for each of the composts and the topsoil, making 36 rigs in total. Standard use of spikes and reference material for quality control was carried out during the analysis. Results from the leaching column experiments were analysed statistically in

SPSS using 2-way ANOVA on the cumulative values with *post hoc* LSD tests to separate relative performance of different media and added contaminants.

2.2 Microbiobiology

Pure cultures of bacteria (using saline and nutrient agar) and fungi (using saline and Rose-Bengal Chloramphenicol agar) were grown from samples taken from the composts and topsoil and used for both enumeration and identification purposes. The method of sampling was that detailed in Singleton, 2004, whereby 1g of sample was shaken in saline and the original solution serially diluted 5 times, 0.1ml of each dilution was then spread onto a nutrient agar plate and inclubated at 25^{o}C for 48 hours. Aseptic technique was followed throughout. In order to identify the bacteria, their morphology, motility, reaction to Gram stain, ability to form endospores, and ability to produce catalase (an enzyme produced by most aerobic bacteria which decomposes hydrogen peroxide produced during aerobic metabolism) were observed and noted (Singleton, 2004). Biochemical tests were carried out to distinguish between bacteria of different genera and species, based on metabolic differences. These tests included the oxidase test, nitrate reduction test, oxidation-fermentation test (Hugh and Leifson test), arginine test and gelatin liquefaction (Singleton 2004; HAS, 2010). Individual fungal colonies were examined under a lens and light microscope (magnification up to x1000) to identify vegetative parts and spores. Spores were examined after incubating the nutrient plates for 5 days. Small test rigs containing 3 litres of compost were also set up (see Fig 1) and the rate of evolution of CO_2 monitored in order to assess the activity of the biofilm which developed. Gas evolution in the light, in the dark, under dry and saturated conditions over a 9 week period was monitored to simulate conditions which might occur in a swale. The rigs were sealed using thin plastic food wrap and gas samples were extracted once a week with a 1ml syringe. Measurement of CO_2 evolution was undertaken using infra red gas analysis (IRGA: ADC-225-MK3, UK) (Coupe et al., 2006). The IRGA was calibrated with 3% ppm CO_2 at a standard volume of 0.2ml.

3. Results

3.1. Leaching tests

Table 1 shows the total and dissolved concentrations of metals in CSD and composts as well as dissolved metal concentrations in the oil and mains water used as artificial rain prior to the start of the leaching tests. The results of total digestion of the composts were found to be well within PAS100 (2011) guidance concentrations. The TS, however, had relatively high concentrations of Pb, which is not explainable at this time. In comparison with dissolved elements in the compost, the unused oil had relatively high Zn and Cd concentrations. Zinc in particular is an anti-wear additive in motor oil, so its high concentrations were not surprising. The artificial rain water had levels of Ni and Pb above WHO (2008) potable water levels (see Table 1). The polluting potential of the additives is therefore clear.

Cadmium, Ni and Zn are not reported in detail here since Cd was consistently below the limits of detection and the average concentration for Ni was 0.01 mg l^{-1} for the duration of the experiment. There was very little difference in the levels of Zn in the effluent once the pollutants were added and all concentrations were well below WHO (2008) guidelines for potable water. Figs 2A-D therefore show Cu, Pb, oil and grease only. Background measurements were taken using leaching columns with no pollutant addition throughout the experiment; these are represented by MC, GC and TS for Cu and Pb (Figs 2A and B). For oil and grease (Fig 2C), a background measure is represented by the first value on the graph which is the average of the effluent collected from 3 simulated rainfall events analysed before pollution addition.

Fig 2A shows the concentration of Cu in the effluent from the leaching columns and, whilst concentrations increased for all of the rigs, they did not exceed 0.12 mg l^{-1} which is well below the WHO (2008) guideline value of 2 mg l^{-1}. After initially registering a rise in Cu levels in the effluent, after addition 7, this appeared to fall to a level of between 0.08 and 0.02 mg l^{-1}. The lowest concentrations were consistently found in association with GC, the highest with MC. There would not appear to be any difference between the samples which had oil or street dust added to them, in fact the highest concentration of Cu was that of MC during weeks 4-7 in samples where no pollutants were added.

Figure 2B shows that the concentration of Pb in the effluent after pollutant addition did rise and for TS and GC, this was slightly above the WHO (2008) guidance concentration. For MC after pollutant addition, levels of the contaminants were higher, particularly with the addition of oil.

Figure 2C shows the results of oil additions to the substrates and by comparing the amount of oil applied with that found in the effluent, the concentration of oil and grease in the effluents has been converted into recovery or degradation percentages (Fig 2D). Both of these sets of data show that TS performed least well, with MC degrading the most oil and therefore yielding the least oil and grease in the effluents from the leaching columns.

3.1.1. Statistical analysis of leaching experiments

From 2-way ANOVA statistical testing, it was found that the type of medium was very significant ($p<0.001$) in explaining differences in the levels of Zn, Cu and Pb in the collected effluent (Table 2). In the case of Ni, there was a significant interaction between the type of medium and pollutant. *Post hoc* testing showed that across all pollutants MC resulted in significantly ($p<0.001$) higher levels of all metal species in effluent compared to GC and significantly ($p<0.001$) higher levels of Zn, Pb and Ni compared to TS. Overall Cu levels were not significantly different between MC and TS. Green compost produced significantly higher levels of Zn ($p<0.001$) but significantly ($p<0.001$) lower levels of Cu compared to TS. There was no significant difference in the levels of both Pb and Ni between GC and TS.

The type of pollutant added to each treatment was a significant (p<0.05) factor in independently explaining the differences in the levels of Cu collected in the effluent from the different treatments (Table 2). There was a significant interaction between pollutant and medium in the case of Ni and no significant effects with Zn and Pb. *Post hoc* tests demonstrated that across the different growing media application of oil resulted in significantly higher levels of Cu (p<0.05) and Ni (p<0.001) in effluent compared to application of dust and significantly higher levels of Cu (p<0.05) and Ni (p<0.001) compared to topsoil. There was no significant difference in levels of metal species between treatments to which dust was applied and those to which no pollutant addition was made. However, compost is a dynamic system, not only comprised of physico-chemical components, but biological ones also. The next section therefore gives the results of the biofilm investigation.

3.2 Microbiology

3.1.2. Identification and enumeration of bacterial and fungal species present in composts and topsoil harvested from model rigs.

Table 3A shows that MC had the highest number of bacteria and fungi, while TS had the least. The high numbers for MC can be explained by the mixture of kitchen and garden waste from which it is made and on which microorganisms live. Whilst lower than MC, the count for GC was higher than that for topsoil which may be due to the decay of garden waste releasing nutrients which would support microorganisms. Table 3B shows that both GC and MC had a reasonable selection of both fungal and bacterial oil degraders, whereas TS only had bacteria and did not have the fungal degraders which were present in the composts.

3.3.2 Microbiological activity in composts and topsoil under swale-like conditions

Figure 4A shows CO_2 measurement as a proxy for microbial activity without addition of water. The trend for all materials was a gradual decrease in activity, and hence number of microbes, over the course of the experiment. Maximum activity for all three substrates was achieved in the second week. The least microbial activity throughout the whole trial under all conditions was found in TS, whereas activity overall for MC and GC was not very different. Figure 4B shows microbial activities in the dark under saturated conditions. Microorganisms in all 3 substrates exhibited highest activity towards the end of the experiment with concentrations of CO_2 levelling out in weeks 7-9. Figure 4C shows microbial activities in the light under saturated conditions. Activity for GC was similar in the dark and in the light, whereas biofilm development appeared much more efficient for MC in the light.

4. Discussion

Some pollutants were not reported as their concentrations in the effluent, and hence potential release into the environment, were so low, including Cr, Zn, Ni and Cd. The results for Pb, however, revealed concentrations which were slightly higher than the guideline for drinking water given in WHO (2008). However, in an urban environment, these effluents would not be used for potable purposes, but would be allowed to flow into receiving watercourses. In a study of the toxicity of Pb to freshwater organisms, Offem and Ayotunde (2008) found that the mean 24-H LC_{50} for the water flea (*Daphnia* sp.) was 2.51 ± 0.04 mg l^{-1} Pb. Levels of Pb in effluent from the leaching experiments were much lower that this and would therefore be unlikely to present a hazard to biota such as *Daphnia*.

Mixed compost appeared to perform least well, while GC and TS were similar in their potential pollutant remediation ability. Microbiological analysis of the composts revealed that MC had the highest numbers of bacteria and fungi whilst TS had the least. This is reflected in their ability to deal with oil as a pollutant in the leaching columns. This experiment was very small scale and added the equivalent of a month’s oil loading in a typical urban environment every 2 weeks, i.e. double the normal amount, but the composts were still able to degrade between 65% and 80% of the oil added. If a swale were installed in an area likely to suffer significant oil pollution, e.g. a lorry park in a Motorway Service Area, it would seem that MC would be better able to degrade this excess oil than GC or TS.

Statistical analysis showed that in many cases there was no significant effect of adding pollutants to each medium on the resulting level of metal concentration in the effluent. It would therefore appear that the pollutants added to the compost leaching columns have been retained in some way, and that the composts have behaved as effectively as TS in this regard. This complexity may simply represent the very low concentrations of the elements tested for, but may also have been a function of the physicochemical makeup of the substrates. Hence, in terms of physical properties, it is well known that heavy metals are easily adsorbed to clays, carbonates and to organic matter. From previous analysis of the composts, it was found that they were approximately 50% organic matter and between 2 and 5% carbonate. These would provide binding sites for the metals and may explain why in many cases, there is little difference between adding pollutants and adding nothing, since the pollutants have been retained in the substrate by adsorption and are not transported out of the column in the leachate.

Over a period of nine weeks in dry conditions, topsoil produced the least microbial activity as reflected in low microbial numbers found in identification and enumeration, while GC produced the highest activity, closely followed by MC. In dry, anaerobic conditions, the decrease in CO_2 evolved from all the samples as the weeks advanced showed that the microbes were either dying off or forming spores to cope with the adverse conditions. It is likely that the group of organisms left after nine weeks were mesophilic anaerobes, which could survive without moisture over that period of time in anaerobic conditions; these organisms were more abundant in GC than MC or topsoil. This implies that in periods of no rainfall, GC will be best suited for microbial biodegradation of pollutants such as motor oil.

In comparing microbial activity in the dark with microbial activity in the light under saturated aerobic conditions, microbial activity was generally higher in the light than in the dark. At the end of nine weeks, MC produced 90% more CO_2 in the light than in the dark, GC produced

10% more CO_2 in the light than in the dark and topsoil produced 66% more CO_2 in the light than in the dark. Consequently, although MC had the highest initial microbial population, GC was better able to sustain microbial activity under both dark and light conditions in contrast to that of MC which performed better in the light than in the dark. It is possible that photosynthesising algae played a role in the activity taking place in the light, but these were not monitored for.

Topsoil had the most bacterial oil degraders followed by MC and lastly GC. However, for fungi, MC had the highest oil degraders followed by GC. Topsoil contained no fungal oil degraders. Overall, MC had the highest oil degraders followed by topsoil and lastly GC. It is therefore expected that oil degradation should occur faster in MC followed by topsoil and then GC.

5. Conclusions.

The coarse grades of compost tested here would appear to have the potential to replace some of the TS currently used in constructing vegetated SUDS devices such as swales. It provides pollutant remediation and could therefore be used in other SUDS devices, such as brown roofs (similar to green roofs, but utilising locally sourced waste material) and porous paving relying for its structural integrity on plastic crates. Using compost for this purpose provides sustainable credentials and a market for a material which was once considered a wasted waste. However, these preliminary experiments have shown that composts have potential but need to be followed up by field trials in order to ascertain whether their abilities shown under laboratory conditions can be applied at the larger scale in the field.

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