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Short Communication

Effect of media type and particle size on dissolved organic carbon release from woody filtration media

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ABSTRACT

Sequential batch leaching tests were used to evaluate the mass of DOC released from composted garden organics (yard waste), pine and hardwood under pseudo-equilibrium conditions. All media showed an initial rapid decline in DOC values followed by a slower rate during later time periods. Greater than 50% of the DOC leached occurred within the initial time period (<24 h). The mass of DOC leached varied significantly between the materials and to a lesser degree between different particle size ranges. The pine had the lowest leached DOC fraction (2.8–4.8 mg/g), while the hardwood (21–27 mg/g) and compost (13.6–32.7 mg/g) were significantly greater. The type and processing of the woody material incorporated into these systems can have a significant impact on the treated stormwater.

1. Introduction

Water Sensitive Urban Design (WSUD) is an emerging approach to tackle environmental issues associated with water planning. It has grown out of recognition of the linkages in the water cycle (a complex interaction of rain fall, evapotranspiration, over land flow and ground water flow) between urban development, stormwater treatment technologies and the quality of down stream ecosystems. Treatment of stormwater by vegetated and unvegetated filtration has shown considerable promise as a technology (Hunt et al., 2006; Davis, 2007; Seelsaen et al, 2006). However, it should be recognised that the biogeochemical conditions existing within the filtration media will vary widely depending on the type and physical properties of the materials incorporated in the media, the dimensions of the treatment system and the imposed hydraulic regime. To improve the performance in these systems; woody materials can be integrated into stormwater treatment systems either through application as a mulch or mixed throughout the filtration material. These woody materials can efficiently remove dissolved metals and hydrocarbons from aqueous systems through sorption (Ray et al 2006; Bailey et al 1999; Boving and Zhang, 2004; Seelsaen et al, 2007; Jang et al 2005; Sud et al, 2008).

One consequence of using woody filtration media for water treatment is that it can be an additional source of dissolved organic carbon (DOC), nitrogen and phosphorous to the infiltrated water (Dietz and Clausen, 2006). In some treatment systems this may be intended since the leached DOC may be necessary to drive microbial processes underpinning nitrogen or metals removal (Gibert et al, 2005; Tsui et al, 2007). In these cases predicting the quality and quantity of leached DOC is important. However, dissolved organic carbon can contribute significantly to the mobility of metals (Benedetti et al, 1995), nutrients and contaminants in soils. In these cases the leached constituents may threaten surface and ground water quality. Therefore the DOC leaching behaviour is an important criterion for safe application of these materials as filtration amendment in stormwater treatment systems. There are many factors that can affect the amount of DOC leached from woody material. Such factors include wood species, wood processing (e.g. composting), particle size, contact time between the extract media and the leached material, as well as the properties of the infiltrated water such as pH, ionic strength and composition. The nature of the particles will impact their hydraulic properties since wood has different diffusion co-efficient for longitudinal and transverse travel, therefore the orientation of the cut for a particular fragment may influence the rate by a factor of 100 (Mackay and Gschwend, 2000). In addition the properties of composted woody materials can vary widely (Bary et al, 2005; Benito et al, 2003; Zmora-Nahum et al 2007). Münch et al. (2005) examined two soils and found the DOC release kinetics in one soil was first-order with respect to time and was independent of time in the other soil. They attributed these differences in part to different rates of diffusion in the soils and suggested that the DOC release was governed by two DOC fractions which involved the mobilisation of a ready soluble DOC and a desorption process. Cao et al. (1999) found an equation with three additive terms for degradation, desorption/diffusion,

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and convection represented DOC release from an upland soil and included four pools of DOC in their model. Microbial activity or the physical disturbance during experimental work (wetting/drying, repacking, sieving, grinding) may lead to an extra pool of readily mobilised DOC in soils (Haynes; 2005; Wehrer and Totsche, 2005). Given the complexity of DOC release kinetics from these types of materials, whether these DOC pools and the models used to describe DOC release from soils are applicable to woody filtration materials is not yet resolved.

The main goal of this paper is to evaluate the mass of dissolved organic carbon (DOC) released under pseudo-equilibrium conditions from materials commonly used in filtration systems. The tested materials are composted garden organics (yard waste), pine and hardwood. A secondary goal was to identify the significance of particle size on the mass and rate of DOC release. It is expected this study will help to fill a research gap and provide guidance to water treatment engineers wanting to use woody materials as a filtration amendment in unvegetated stormwater treatment devices, particularly in environments which are sensitive to infiltrated water quality or contaminant mobilisation. Within vegetated treatment systems (e.g. bio-retention) there are likely to be additional carbon sources (e.g. soil, plant roots) and more complex hydraulic flow regimes which need also be considered.

2. Experiment methodology

2.1. Materials

Pine, hardwood and compost (yard waste) were selected for testing due to their common use as woody filtration materials. The received pine (Superior Pine Chip, Soilco Pty Ltd.) and hardwood (Hardwood chips, Soilco Pty Ltd.) material were furthered sorted to remove bark fragments. The compost (Composted Leaf mulch, Australian Native Landscapes) was compliant with the Australian Standard for composts, soil conditioners and mulches (AS4454, 2003) and consisted of a screened composted mulch (nominally 10–35 mm) sourced from garden organics. Garden organics include putrescible garden organics (grass clippings); non-woody garden organics; woody garden organics; trees and limbs; stumps and root balls. All woody filtration materials were then dried at 45 °C for 48 h and then ground using a hammer mill until the required particle size range was obtained. The 4.75 mm material passed through a 6.5 mm mesh sieve but was retained over a 4.75 mm mesh sieve. The 1.18 mm material passed through a 2.36 mm sieve but was retained over a 1.18 mm mesh sieve. The 0.60 mm material passed through a 1.18 mm sieve but was retained over a 0.60 mm mesh sieve. All these materials were subsequently dried at 45 °C for 48 h prior to use.

2.2. Analytical methods

Leachate samples were measured for electrical conductivity (EC) and pH (TPS WP-81). A 20 ml collected sample was filtered with a 0.45 μm cellulose membrane filter, then 4 ml from this was scanned for absorbance using UV–visible spectrophotometer (Shimadzu UV-1700), and the remainder was preserved by acidifying the samples to pH <2 using 1 N HCL (APHA/AWWA/WEF, 1998). Dissolved Organic Carbon (DOC) was determined in duplicate with a Phoenix 8000 TOC analyser. Total carbon and nitrogen for all solid materials were determined in duplicate using a Truspec Carbon Nitrogen determinator. Ash content was measured using the method for Total Volatile Solids (APHA 1998) at 550 °C. All plasticware and glassware in contact with samples was acid washed for 24 h with 0.1 M HNO_3 and rinsed with Milli-Q water, unless otherwise noted.

2.3. Leaching test

The leaching potential of the woody materials was determined using a sequential batch leaching procedure. The leaching test was performed at a ratio of liquid to solid sample (L/S) 10:1 L/kg. A 150 g oven dried (100 °C) sample of each particle size fraction were added to a 2 L polyethylene reaction vessel with distilled water (pH 4.8) and shaken on an orbital shaker at 200 rpm for 24 h. Due to the low bulk density the woody materials had a volume of 0.4–0.6 L which when combined with the liquid occupied 80% of the reaction vessel volume. In addition all vessels were removed from the mixer and manually inverted twice every 24 h period. At the end of this period the leachate was then decanted from the batch reaction vessel by filtration through a 150 μm sieve with the volume of leachate, pH and EC measured immediately. This sequential batch leaching procedure was repeated every 24 h until the DOC of the leachate water was below 20 mg/L. This required between 6 (pine) and 18 (compost) sequential batch extractions due to the different leaching characteristics of the materials.

3. Results and discussion

3.1. Leachate pH and EC

The pH of a leaching test is considered the most significant factor affecting the amounts of leached elements from solid media. Leached DOC concentrations increase with leachate pH until a plateau at pH 12–13. This is a general property of soils, sediments and waste materials (Comans, 2001). This reflects the increased solubility in that pH range. In this study, a de-ionized water with a pH 4.8 of selected was as being representative of the lower end of Australian data for runoff from rooftops (Engineers Australia, 2006).

The pH and EC in the leached effluent was found to change with time during the leaching process. The trends for the EC during the leaching tests were very similar for all filtration media. There was an exponential decline. The compost showed the greatest amount of electrically conductive leached ions followed by hardwood and pine. There was over an order of magnitude difference between the compost and the pine. The impact on leachate quality due to different particle sizes was small compared with the influence of different woody materials.

The trends for the pH of the leached water varied significantly between the filtration media. The pine decreased slightly from the influent pH of 4.8. This may reflect the relatively small contribution of acidity to the leachate from leached DOC. In contrast the hardwood contributed significant acidity by depressing the leachate pH by about 1.8 U. In contrast the compost initially raised the pH by 1.2 U which gradually declined during the leaching period. This may reflect the consumption of the pH buffering capacity of the compost which could be generated from plant material in the compost or liming of the compost during compost manufacture. Other studies have found an increase in soil solution pH after an addition of plant matter to acid soils. The mechanisms attributed to pH increases include ligand exchange, nitrogen mineralisation, and decomposition of base cation-containing organic compounds (Sakala et al, 2004; Wong et al, 1998).

3.2. Rate of DOC leaching

The rate and overall amount of DOC leaching from woody materials for given influent water are affected by factors such as the particle size and the type of wood. The data for all filtration media show an initial rapid decline in DOC values during the early time period followed by a slower rate during later time periods (Figs. 1–3). This general trend of staged release has been previously ex-

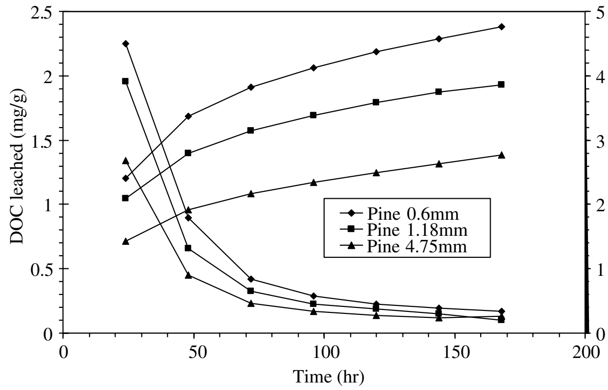

Fig. 1. Variations of DOC in leachate effluent from different particle size of pine.

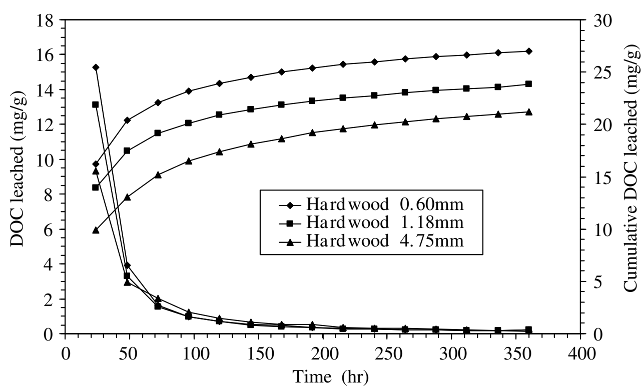

Fig. 2. Variations of DOC in leachate effluent from different particle size of hardwood.

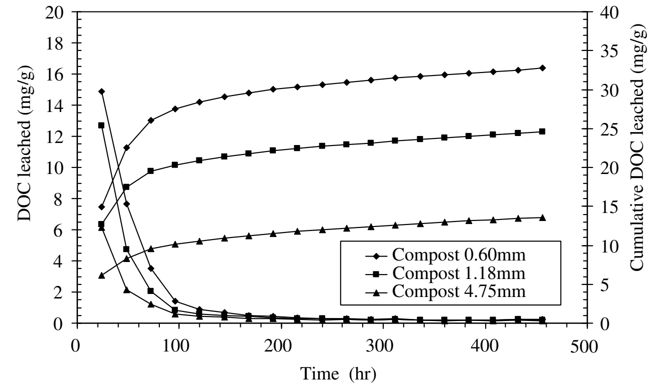

Fig. 3. Variations of DOC in leachate effluent from different particle size of compost.

plained in terms of various fractions of dissolved organic carbon, some of which can be readily mobilised (Münch et al, 2005) and other fractions released at later time periods (Wehrer and Totsche, 2005). Limitations on DOC mass transfer could arise depending on the extent to which the infiltrated water is in equilibrium with the woody material.

The data for the filtration media in all cases show that the smaller particle sizes have a more rapid rate of DOC release than the larger particle sizes. This may be expected since a larger particle has a smaller surface area to volume ratio which would lead to a lower mass of leached of DOC under mass transfer limited conditions. About 50% of the cumulative leached DOC was found to occur with the first 24 h.

The variations in DOC leached from the different particle size ranges were relatively small for the pine and hardwood compared with compost. All particle sizes for the pine and hardwood were ground from homogenous woodchips and therefore may only be expected to vary due to particle size rather than from compositional differences. However, the compost particles were ground from the supplied compost which was far more heterogeneous and the various particle sizes may have differed in composition as well as particle size. This was evident in the variation in C:N ratios between the smaller and large particle sizes (see later section).

3.3. Mass of DOC leached

Cumulative DOC leached from the compost, pine and hardwood for different particle sizes are shown in Table 1 and Figs. 1–3. In general the largest particle size has the lowest cumulative leached DOC for all the materials. The results show that compost leached higher amounts of DOC leached than pine and hardwood.

It has been stated that the main components in a wood cell are cellulose, hemicellulose and lignin (Vesterinen, 2003). These often form 99% of the wood with the ash containing the minerals and usually being less than 1% of the weight. This is consistent with the ash content measured for pine and hardwood (<1%, Table 1). The compost had much higher ash content (4–17%). The larger particle size (4.75 mm) had a lower ash value (4.7%) reflecting the greater wood content which was also reflected in the higher C:N ratio. These values are consistent with those reported for stem wood for soft and hardwoods (Vesterinen, 2003). The smaller compost particles had a higher ash content (11–17%) and lower C:N ratio which reflects the higher mineral content (e.g. Si, Ca) often found in leaves (Vesterinen, 2003).

The mass of DOC leached as a fraction of the total organic carbon (Table 1) from pine (0.6–1.1) is lower than the hardwood (4.3–5.5) by a factor of about 5. A similar trend is found when the organic carbon leached as a fraction of dry matter is measured.

Table 1
Fraction organic carbon leached from biofiltration media

Woody material	Particle size (mm)	Ash (%)	C/N ratio	DOC leached (g)	TOC (g)	Cumulative organic carbon leached (%TOC)	Cumulative organic carbon leached (mg/g DM[a])
Pine	0.60	0.2	416	0.71	63.5	1.1	4.8
	1.18	0.3	428	0.58	72.0	0.8	3.9
	4.75	0.4	590	0.42	70.7	0.6	2.8
Hardwood	0.60	0.2	374	4.05	73.1	5.5	27.0
	1.18	0.2	364	3.57	73.7	4.9	23.8
	4.75	0.6	288	3.18	73.8	4.3	21.2
Compost	0.60	17.0	37	4.91	60.2	8.2	32.7
	1.18	10.9	41	3.69	57.3	6.4	24.6
	4.75	4.7	128	2.04	63.3	3.2	13.6

[a] DM, dry matter.

The mass of DOC leached from the leafier (smaller) fractions of the compost is slightly greater the larger more woody fraction (4.5 mm). This is consistent with data reported by Godley et al. (2005). The values in this study for the pine and hardwood and the coarsest fraction of the compost (0.6–5.5%TOC) are similar to that reported by Godley et al. (2005) for twigs (~5% TOC) while the finer fractions compost (6.4–8.2%TOC) reflect the greater contribution of green grass (~9%TOC) The compost has a slightly greater value than the extractable DOC for hardwood is much greater than the pine.

4. Conclusion

Woody materials can be incorporated into stormwater treatment systems to improve treatment performance. This study has shown that the type of the woody material can significantly impact the amount of DOC leached while the particle size has less influence under the test conditions. Pine would appear to be a good choice for stormwater filtration if its metal removal performance was adequate and the goal was to minimise DOC leaching impacts. These results are cumulative values which reflect pseudo-equilibrium DOC values in the absence of biodegradation and would be applicable for many non-vegetated systems.

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