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BIOREMEDIATION OF LEACHATE FROM A GREEN WASTE COMPOSTING FACILITY USING WASTE-DERIVED FILTER MEDIA

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ABSTRACT

The evaluation of two waste-derived materials used to treat compost leachate by biofiltration is described in this paper. Nine biofilters were constructed using 240 litre, high density polyethylene containers. Three containers were filled without compaction with 200 litres of each of three types of filter media. Waste-derived filter media (compost and oversize) were compared to a mineral control (granite chips). The filters were fed with compost leachate from a typical green waste composting facility at hydraulic loading rates ranging from 0.05 m^3/m^3/day to 0.5 m^3/m^3/day over a period of twelve months. The oversize medium emerged as the most effective demonstrating characteristics of consistency of effluent quality and resilience to stress. The oversize medium produced an effluent of <10 mg/l ammoniacal nitrogen on >95% of sampling occasions. The organic component of compost leachate was dominated by compounds that proved to be recalcitrant to biodegradation. The solids content of the treated effluent remained too high to be acceptable for direct discharge to a watercourse without further treatment and if discharge to a watercourse is to be considered, a polishing stage (e.g. reed bed) able to remove solids and dampen occasional peaks of ammoniacal nitrogen should be employed.

Key words – biofiltration, compost, leachate, treatment, wastewater, windrow

INTRODUCTION

Whilst composting technology has successfully facilitated the diversion of millions of tonnes of organic waste from landfill in the UK, and can produce a very high quality end-product, it is associated with some potential environmental hazards, one of which is the production of compost leachate. The majority of UK composting facilities process the organic waste using mechanically-turned open-air windrows (Slater *et al.* 2005). A leachate may be formed at certain times of the year when, following periods of wet weather, the windrow can exceed its drainable limit leading to seepage from the base. Leachate can also be generated by high moisture content wastes (such as fruit and vegetables) as it decomposes (Environment Agency, 2001). If the windrow has been sited on an impermeable surface, this seepage has to be collected and stored to avoid uncontrolled runoff and pollution of watercourses (The Composting Association, 2001). In addition to leachate derived from the windrow, polluted runoff from contaminated hard surfaces and machinery is also likely to be produced.

There exists only a small body of published literature that makes reference to compost leachate quality (Savage and Tyrrel, 2005). The available evidence suggests that compost leachate is variable in terms of its chemistry and that this variability is influenced by factors such as: the nature of the feedstock; the maturity of the compost giving rise to the leachate; the composting technology employed; the degree of cover; and, the weather. A recent study of leachate from a green waste composting facility concluded that the concentrations of readily biodegradable organic compounds and nutrients were of a similar order to those found in untreated urban wastewater (Tyrrel *et al*. 2005). In its draft Technical Guidance on Composting Operations, the Environment Agency of England and Wales advises that where possible, compost leachate should be recirculated on to dry windrows as a wetting agent (Environment Agency 2001). In some situations re-circulation is not possible and other arrangements have to be made for the disposal of leachate such as tankerage to local sewage treatment works – an option that is highly costly. On-site treatment may be an alternative to paying high tankerage costs, although there have to date been few published studies on compost leachate treatment. Liu and Lo (2001) describe the use of bench-scale columns packed with zeolite to remove ammonia from leachate derived from composted vegetable waste. The ability of waste-derived filter media to bioremediate compost leachate was investigated in a short-term laboratory-scale study by Savage and Tyrrel (2005) using an approach previously adopted for nitrogen removal from landfill leachate in Finland (Jokela *et al.*, 2002). Savage and Tyrrel (2005) screened a number of waste-derived materials and found that mature compost and the woody waste produced in the final screening of compost (known as oversize) performed best in reducing the oxygen demand; ammonia concentration and toxicity of a high-strength leachate derived from a vegetable waste composting facility. These organic materials have the advantage of being readily-available at a composting facility and therefore offer the possibility of being used in the design of a low-cost biofilter for compost leachate bioremediation. The aim of the research described in this paper was to characterise the performance of two waste-derived media in pilot-scale biofilters used to treat leachate from a green waste composting facility. The performance of the waste-derived media was compared to that of a conventional rock filter medium.

METHODOLOGY

Nine biofilters were constructed using 240 litre, high density polyethylene containers typically used for domestic waste collection (height 1060 mm, depth 730 mm, width 585 mm). The biofilters were approximately twenty times larger in volume than those used in the work by Savage and Tyrrel (2005). A media support structure was made using a plastic grid covered in a nylon mesh. This was inserted into the container with a 100 mm space to allow drainage from an outlet at the base. A PVC vent pipe was installed to permit free air-flow to the base of the filter and aeration of the media .

The containers were filled without compaction with 200 litres of one of three types of filter media:

- Compost – sourced from SITA UK's Lount composting facility in Leicestershire, England. The compost is made from garden waste using the open windrow method. The mature windrow compost is screened through a 10 mm trommel screen to remove large particles.
- Oversize – also sourced from SITA's Lount composting facility. Oversize is the coarse fraction retained on the 10 mm trommel screen and is largely composed of wood fragments that are too large to be degraded during the composting process.
- Granite chips – sourced from a local roadstone supplier. The roadstone was passed through a 12 mm sieve in order to remove small stones, and then washed with water to remove fines. 99% of the stones used in the biofilter were in the size range 12 mm to 37 mm. Chipped granite is a traditional medium used in the construction of biofilters for the treatment of urban wastewater and as such was included for comparison with the organic filter media.

The biofilters were supplied with leachate stored in a 1 m^3 elevated header tank. Initially, 10 litre doses of liquor were applied manually to the top of each filter once or twice per day depending upon the desired application rate (Table 2). From 10 February 2004, controlled doses of leachate were applied every weekday to the surface of the filter media via a multi-dripper distribution system plumbed into the container lids. Each 10 litre dose applied to the dripper system took approximately 1.5 hrs to be dispensed onto the filter surface. On a 24h hour cycle, periods of leachate application were therefore much shorter than periods of drainage and drying, a regime designed to encourage predominantly unsaturated, aerobic conditions. The treated effluent draining from the biofilters was collected in a 1 m^3 ground level collection tank. A system of pipes and valves was used to connect the tanks and biofilters. Provision was made in the system design for the header tanks to be filled from a single feed pipe connected to a leachate delivery vehicle. Following construction, the experimental biofilter facility was tested using clean water for three weeks.

The compost leachate used in the trial was delivered by tanker from Sita's Lount composting facility. In all, four 25 m^3 batches of leachate were treated during the 12 month experimental period. The first batch received was more dilute than expected but subsequent batches were more concentrated (Table 1). The performance of the three sets of biofilter media were compared between December 2003 and September 2004 during which time three batches of leachate were treated. The biofilters filled with oversize were operated for a further fourteen weeks during which time the fourth batch of leachate was treated. The purpose of this supplementary experiment was to extend the range of application rates applied to the oversize biofilters and to assess the effect on treatment performance (Table 2). Table 2 summarises the leachate application regime.

Samples of leachate were taken for analysis throughout the monitoring period at approximately weekly intervals. Samples were taken from each of the nine biofilters on 45 sampling occasions for comparative analysis. Samples were taken on a further 16 occasions for the supplementary experiment. A 60 ml sample of untreated leachate was taken from the individual dose applied to each filter. A 60 ml sample of treated effluent was collected, at least 2 hrs after the dose was applied, from the bottom of each filter.

The untreated compost leachate and treated effluent samples were filtered through a 0.45 μm filter prior to analysis. The mass of oven dried residue on the filter membrane was used as a measure of suspended solids. The filtered samples were tested for ammoniacal nitrogen, total oxides of nitrogen, pH, electrical conductivity, chemical oxygen demand (COD), phosphate and potassium. Ammoniacal nitrogen, total oxides of nitrogen and phosphorus were measured colorimetrically using a Burkard Series 2000 segmented flow analyser (Burkard Scientific, Uxbridge, UK) using the automated phenate method, the automated hydrazine method and the automated ascorbic acid reduction method respectively (APHA, 1998). pH and electrical conductivity were measured with an Jenway 4330 probe (Jenway, Dunmow, UK). COD was measured on a HACH spectrophotometer (HACH company, Loveland, Colorado, USA) using the closed reflux method (APHA, 1998). Potassium was measured by flame photometry (Corning 400, Halstead, Essex). Samples of leachate were also taken on 25 February, 7 April, 17 June and 9 Dec 2004 for 5 day biochemical oxygen demand (BOD_5) analysis (i.e. one sample from each batch). BOD_5 was determined on unfiltered samples using an Orion 862 dissolved oxygen probe (Thermo Electron, Boston, USA) according to standard methods (HMSO, 1988). Statistical analysis (ANOVA) of the chemical data was performed using STATISTICA 7.0 (StatSoft inc. Tulsa, USA).

RESULTS

Ammoniacal nitrogen (NH_3-N/NH_4-N)

All three media were able to reduce NH_3-N/NH_4-N concentrations in the leachate, although to differing degrees. On a percentage removal basis, the oversize medium clearly outperformed the other two test media and maintained a consistent performance during the treatment of the three batches of leachate (Table 3). The compost medium appears to have failed during the treatment of batch 3. The pattern of NH_3-N/NH_4-N fluctuation can be seen in time-series plots (Figure 1). The two organic filter media both produced NH_3-N/NH_4-N in the first few weeks of the trial presumably due to the leaching of residual NH_3-N/NH_4-N formed during the mineralization of proteins in the garden waste feedstock. The oversize medium removed more NH_3-N/NH_4-N more consistently than the other two media. The percentage of samples showing a statistically significant treatment effect ($p < 0.05$) was 89% for oversize, 70% for granite and 51% for compost. On 70% of sampling days, the mean NH_3-N/NH_4-N concentration in the treated liquor from the oversize medium was <5 mg/l and on 95% of sampling days the mean NH_3-N/NH_4-N concentration in the treated liquor was <10 mg/l. These concentrations are in the range that may be considered for direct discharge to a watercourse. Treatment efficiency became more variable when new batches of leachate were received, although the oversize medium showed the greatest resilience to these perturbances.

Total oxides of nitrogen (NO_2-N/NO_3-N)

Untreated compost leachate generally has a very low concentration of NO_2-N/NO_3-N (<0.5 mg/l) because of the anaerobic nature of the storage lagoons. Biofiltration of compost leachate through the three biofilter media led to different patterns of NO_2-N/NO_3-N production (Figure 2). NO_2-N/NO_3-N concentrations in the effluent from the compost biofilters remained < 5mg/l throughout the trial. By comparison, the effluent from both the granite and oversize filters exceeded 5mg/l from April 2004 onwards, and reached peak concentrations in excess of 20 mg/l.

Chemical oxygen demand (COD) and biochemical oxygen demand (BOD_5)

During the start-up phase when the biofilters were receiving only tap water, the two organic media (compost and oversize) produced an effluent with a considerable COD. In contrast, the granite showed no such impact on the COD of the tap water (Figure 3). During the treatment of the first batch of leachate (until 25th February 2004), the compost media continued to produce an effluent with a COD that was higher than the untreated leachate. The differential between influent and effluent COD was less marked during the treatment of subsequent batches. The granite medium appeared to have no effect on the COD during the course of the experiments. The oversize medium behaved similarly to the granite medium during the treatment of batch 1 but demonstrated an ability to reduce consistently a small proportion of the COD during the treatment of subsequent batches. A limited survey of the biochemical oxygen demand of the leachate was conducted to complement the more frequent COD analysis. The BOD_5 of the untreated leachate was much lower than the COD, although the COD:BOD_5 ratio varied from batch to batch (Table 4).

DISCUSSION

This experiment has provided an insight into the dynamics of the nitrogenous and carbonaceous compounds that are likely to be of concern with regards to protection of the water environment from discharges of compost leachate. It has shown that the mineral and organic biofilter media under investigation have exhibited quite distinct responses to the application of compost leachate. The oversize medium emerged as the most effective of the media under trial and clearly outperformed the "control" mineral medium. An investigation of the fate of the nitrogen applied to the filters was beyond the scope of this experiment. Nevertheless, a simple assessment of the masses of NH_3-N/NH_4-N removed and NO_2-N/NO_3-N produced provides an insight into the processes at work in the different filters (Table 5). The three filters performed quite differently with respect to the dynamics of inorganic nitrogen. The behaviour of the granite medium appears to be different from that of the two organic media. 80% of the NH_3-N/NH_4-N removed from the leachate by the granite biofilter was accounted for as NO_2-N/NO_3-N in the treated effluent. This behaviour is indicative of the presence of an active community of ammonia oxidising bacteria. By contrast, the compost biofilter produced virtually no NO_2-N/NO_3-N and only 28% of the NH_3-N/NH_4-N removed by the oversize media was detectable as NO_2-N/NO_3-N in the treated effluent, despite demonstrating the greatest daily mass removal of NH_3-N/NH_4-N. The superior NH_3-N/NH_4-N removal performance of the oversize medium is likely to be due to the role of adsorption processes such as cation exchange. Previous research on soil-based wastewater treatment systems has suggested a linkage between cation exchange (as a short-term store of NH_4^+ ions), nitrification and denitrification (Kruzic and Schroeder, 1990) . There is evidence from related studies that the residual materials resulting from the aerobic biodegradation of plant matter have a high adsorptive capacity. Smet et al., (2000) in their investigations of the removal of ammonia from waste gases using compost biofilters found high ammonia removal efficiencies from day one of their trials which suggested that no microbiological start-up period was needed. Subsequent analysis of the biofilter medium found a significant store of adsorbed NH_4^+ ions in the compost. In a study of the properties of decaying plant stems and leaves in a wetland treatment system, Eriksson and Andersson (1999) found the cation exchange capacity (CEC) of the macrophyte litter to be in the range 40 to 140 meq (100 g dry wt. litter)$^{-1}$, which is higher than values of CEC recorded in most soils. Therefore it is plausible that the oversize medium performed best by combining chemical and biological processes more effectively than the other media.

Although on average the oversize media demonstrated remarkably consistent NH_3-N/NH_4-N removal during the treatment of the 4 batches (range 81-84%), there were short periods of instability. The biofilters tended to become destabilised following a batch changeover at which point the effluent quality might be variable for a period of days or even weeks. This effect is particularly noticeable following the batch changeovers at the beginning of March 2004 and at the end of June 2004 (Figure 1). In late August 2004 there was also a period of instability during the treatment of batch 3. The influent NH_3-N/NH_4-N concentration of batch 3 was higher and samples exhibited more variability than that found in previous batches. Although the hydraulic loading rate was steadily increased during these experiments from 0.05 m^3/m^3/day to 0.5 m^3/m^3/day, there was no clear relationship between hydraulic loading rate and treated effluent quality. The treatment period in October and November 2004 is interesting in that the hydraulic loading rate was increased from 0.125 to 0.25 and then to 0.5 m^3/m^3/day. During this period, the effluent quality from the oversize filters was consistently <5 mg/l NH_3-N/NH_4-N – although it did not get as low as in earlier stable periods (e.g. during May and early June) when concentration was <2 mg/l NH_3-N/NH_4-N for several weeks.

A robust or stable system should demonstrate both resistance and resilience in terms of its ability to maintain treatment function in response to perturbation. Resistance is the capacity of the system to withstand disturbance and resilience is the ability to recover after disturbance (Griffiths *et al*., 2001; Griffiths *et al* 2005; Tilman *et al*, 2006). Plotting the ammoniacal nitrogen treatment efficiency against time for the period just prior to, and including the whole of, the second more concentrated batch (Feb 4th to 16th June 2004 - Figure 4), we see that the oversize material filters exhibits a typically "resilient" response – i.e. efficiency initially dips, and then recovers after a time to near 100% efficiency, the compost filter dips then recovers to a lower level of efficiency, and the granite gradually improves. Development of these types of responses as quantified metrics will further inform future design and operation of waste treatment plant.

The removal of oxidisable organic compounds from compost leachate was limited in comparison to the removal of nitrogen. During the start-up phase when the biofilters were receiving only tap water, the organic media produced an effluent with a considerable COD (Figure 3). It is likely that the leaching of humic acids and other relatively recalcitrant organics resulting from the composting process was the cause of this phenomenon. The compost medium continued to add COD to the effluent during the treatment of batches 1 and 2, before finally producing a net COD removal of 5% during the treatment of batch 3. The granite medium had a negligible effect on COD removal, recording a maximum COD removal of 7% during the treatment of batch 2. The oversize medium had no effect on the COD during the treatment of batch 1 but was able to remove 24%, 16% and 9% of the influent COD during the treatment of batches 2,3, and 4 respectively. It is apparent from the results of these experiments that the majority of the COD in compost liquor is not readily biodegradable. It is known that the BOD:COD ratio of leachate derived from stabilised landfilled wastes typically exceeds 10 as a result of the high proportion of recalcitrant humic-like substances relative to readily biodegradable substances such as volatile fatty acids (Kurniawan *et al.*, 2006). It is likely that physico-chemical treatments would be needed if significant COD removals were required prior to discharge of treated compost leachate to the environment (Kurniawan *et al.*, 2006) although such additional treatment may not be environmentally justified due to the relatively benign nature of these humic substances (Archibald *et al.*, 1998).

Mean suspended solids concentrations in the untreated leachate varied from batch to batch in the range 86-192 mg/l (Table 1). The oversize medium had the greatest effect on suspended solids concentrations of the media tested (46% of samples showed a significant treatment effect ($p<0.05$)) although the mean quality was still relatively high at 82 mg/l (data not shown). If treated leachate were to be discharged to surface waters then some form of clarification system would be needed, although this would be unnecessary if the leachate were to be reclaimed through land application.

CONCLUSIONS

The waste-derived oversize medium clearly out-performed the other media tested (compost and oversize). At hydraulic loading rates up to 0.25 $m^3/m^3/d$ the oversize medium was able to produce an effluent of <10 mg/l of ammoniacal nitrogen on >95 of sampling occasions over the twelve month experimental period. Biofiltration using oversize material may provide a low cost option for leachate treatment at composting facilities if there is a subsequent polishing stage (e.g. constructed wetland) to reduce solids and dampen occasional peaks of ammoniacal nitrogen.

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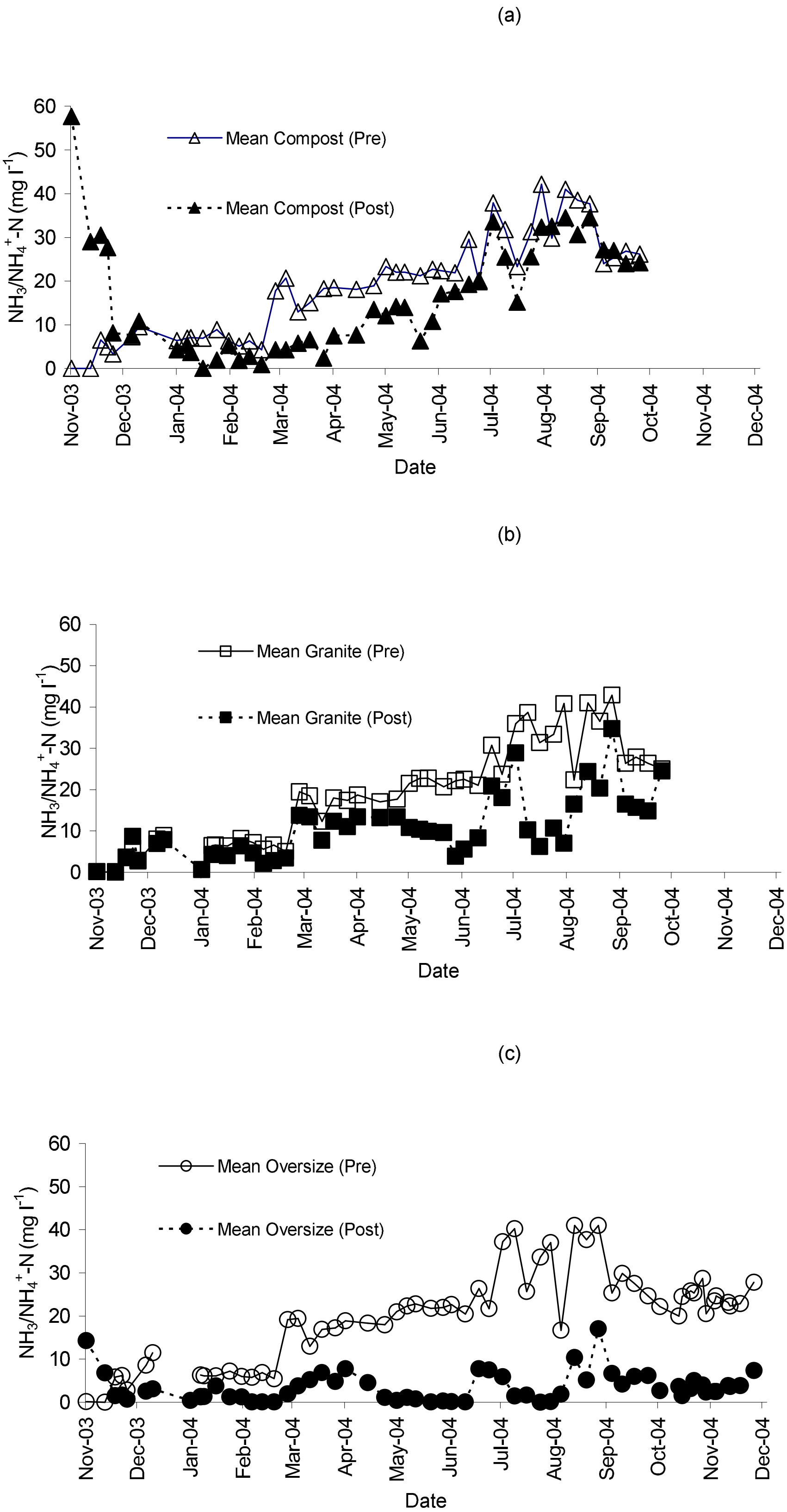

Figure 1 Mean NH_3-N/NH_4-N concentrations pre and post biofilter for compost (a), granite (b) and oversize (c) media

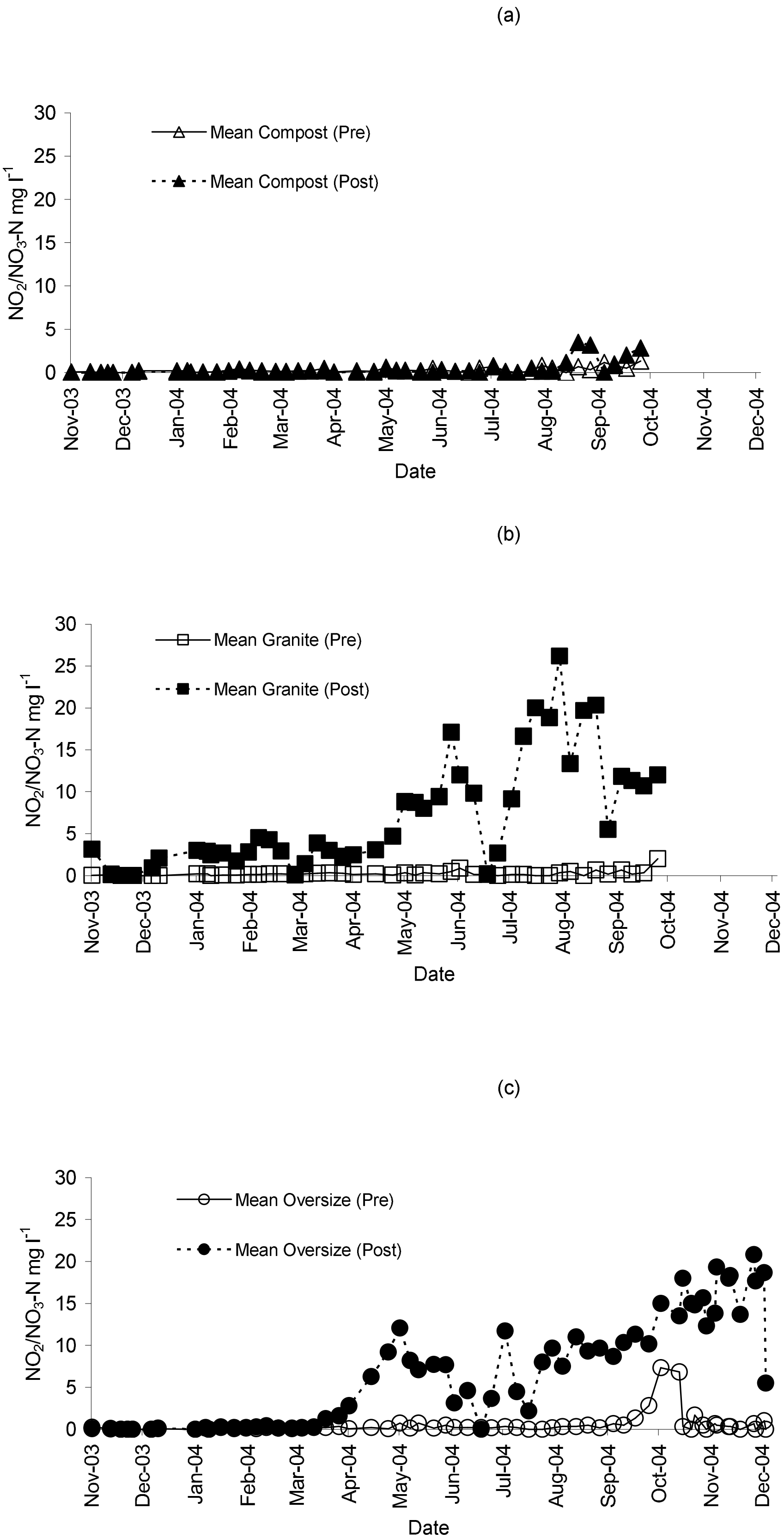

Figure 2 Mean NO_2-N/NO_3-N concentrations pre and post biofilter for compost (a), granite (b) and oversize (c) media

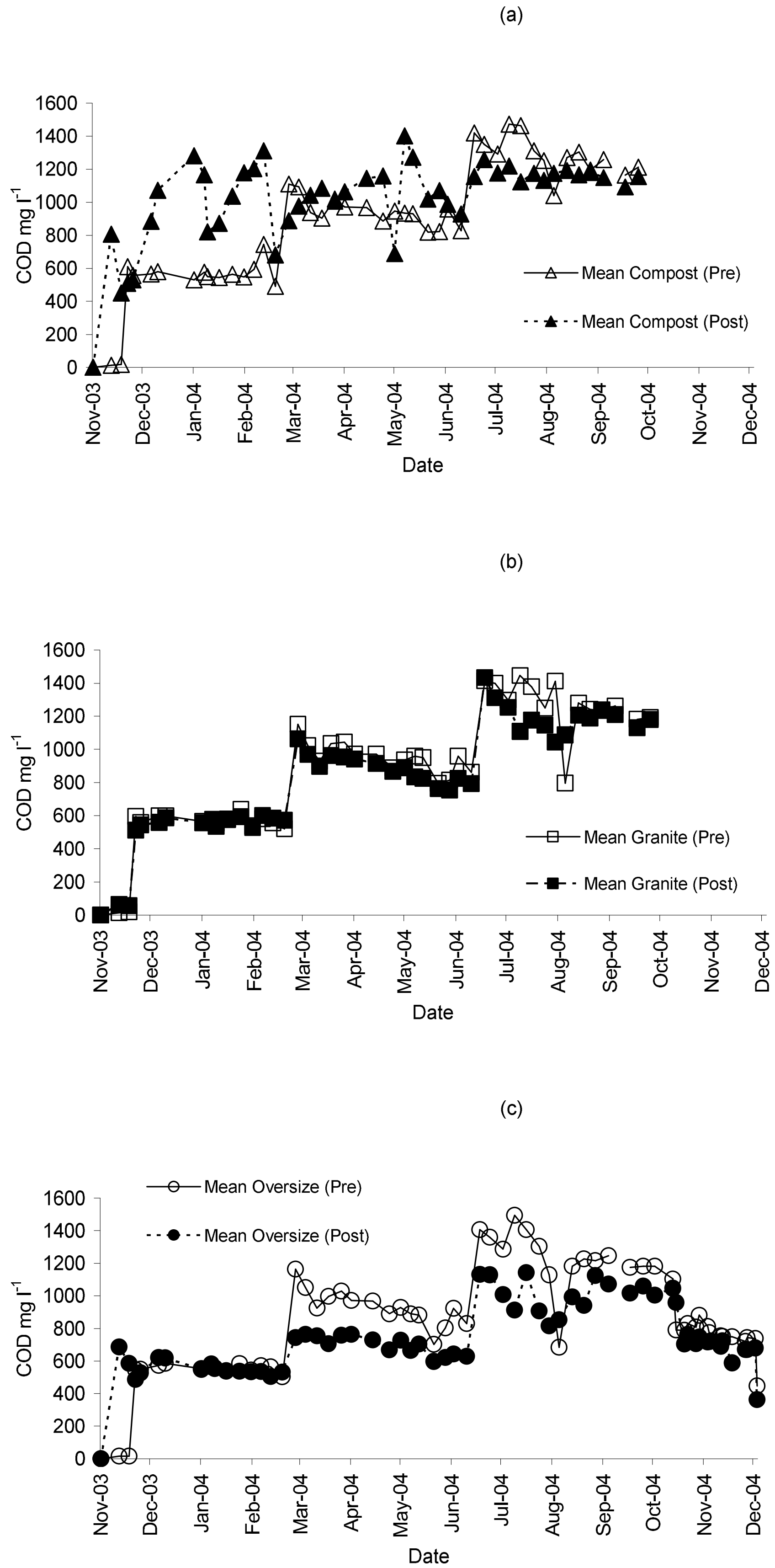

Figure 3 Mean COD concentrations pre and post biofilter for compost (a), granite (b) and oversize (c) media

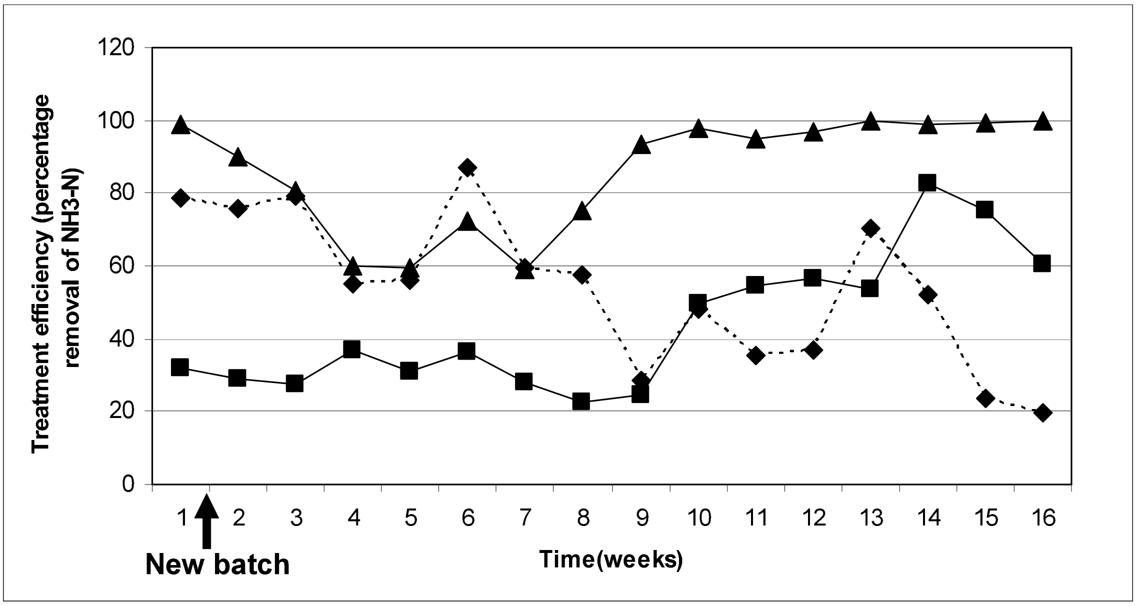

Figure 4 Change in ammonium treatment efficiency (percentage removal of NH_3-N) as a result of change between leachate batches 1 and 2. Triangles represents oversize, diamonds compost, and squares granite filter materials.

Table 1 Selected chemical properties of Lount compost leachate (mean ± S.E.)

	Batch 1	Batch 2	Batch 3	Batch 4
Suspended solids (mg/l)	86 ± 6	101 ± 5	180 ± 9	192 ± 12
NH_3-N/NH_4-N (mg/l)	6.49 ± 0.21	18.67 ± 0.37	32.07 ± 0.72	24.11 ± 0.80
NO_2-N/NO_3-N (mg/l)	0.09 ± 0.01	0.25 ± 0.02	0.36 ± 0.04	1.26 ± 0.37
EC mS/cm	2.86 ± 0.01	3.74 ± 0.03	5.05 ± 0.05	4.11 ± 0.09
pH	8.62 ± 0.02	8.74 ± 0.02	8.79 ± 0.02	8.59 ± 0.02
COD mg/l	530 ± 15	938 ± 14	1152 ± 36	804 ± 23
BOD_5 (ATU) mg/l	20	93	261	nd
P mg/l	nd	nd	1.5	2.4 ± 0.1
K mg/l	nd	nd	988	886 ± 26

nd – no data

Table 2 Volumes of leachate applied to the filters and equivalent volumetric and surface loading rates

Date	Volume (m^3) applied per filter per day	Volumetric loading rate m^3/m^3/day*	Surface loading m^3/m^2/day
08/12/03 – 15/01/04	0.01	0.05	0.023
16/01/04 – 31/05/04	0.02	0.10	0.047
01/06/04 – 01/10/04	0.025	0.125	0.058
01/10/04 – 18/10/04#	0.025	0.125	0.058
19/10/04 – 15/11/04#	0.05	0.25	0.116
16/11/04 – 09/12/04#	0.1	0.5	0.223

oversize filters only

* assumes effective volume of filter is 0.2 m^3