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Compost liquor bioremediation using waste materials as biofiltration media

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Abstract

Compost liquor results from the percolation of precipitation through composting waste; the release of liquids from high moisture content feedstocks; and as a result of runoff from hard surfaces and machinery. This research aimed to establish the potential for waste materials to act as media for low-cost compost liquor biofilters. Six types of potential biofilter media were packed into experimental biofilters (1 m long x 0.11 m diameter) and irrigated with compost liquor (organic loading rate of 0.6 kg/m^3/d) for three months. The pH, BOD_5, NH_3/NH_4^+, and phytotoxicity of the effluent was monitored regularly. Natural, organic materials (oversize, compost and wood mulch) performed best, when compared to synthetic materials such as polystyrene packaging or inert materials such as broken brick. On average, the best media achieved 78% removal of both BOD_5 and ammoniacal nitrogen during the study period. Although significant improvements in liquor quality were achieved, the effluent remained heavily polluted.

Keywords: composting, compost liquor, biofiltration, bioremediation, treatment

1. Introduction

The mass of organic matter composted in the UK has increased every year since national monitoring began in 1994 (Slater et al., 2000). In 1999, 833,000 tonnes of organic matter were composted at 197 composting sites. This growth in composting has been driven by targets for phased reductions in the amount of biodegradable municipal waste being landfilled as set out in the EU Landfill Directive (1999/31/EC) (EC,1999) and in national targets such as the Waste Strategy 2000 (DETR, 2000). The majority of UK composting facilities process the organic waste using mechanically-turned open-air windrows. Open-air windrows are likely to generate contaminated liquor at certain times of the year. This liquor results from natural precipitation which falls onto the windrow and percolates through the waste, dissolving soluble substances in the process. Liquor will also be generated by high moisture content wastes (such as waste fruit and vegetables) as it decomposes (Environment Agency, 2001). Following periods of wet weather, the windrow may exceed its drainable limit leading to seepage from the base. If the windrow has been sited on an impermeable surface (such as concrete), this seepage will have to be collected and stored to avoid uncontrolled runoff and pollution of watercourses (The Composting Association, 2001). In addition to liquor derived from the windrow, polluted runoff from contaminated hard surfaces and machinery may also be collected and diverted to the liquor storage lagoon. In its draft Technical Guidance on Composting Operations, the Environment Agency of England and Wales advises that where possible, liquor should be recirculated on to dry windrows as a wetting agent (Environment Agency, 2001). This practice is not always acceptable to the composting site operator however. For instance at some sites, recirculation of liquor back to windrows has been found to generate odours and thus give rise to complaints from neighbours – a problem alluded to by Fischer (1996). Where re-circulation is not possible, other arrangements have to be made for the disposal of liquor such as tankerage to local sewage treatment works – an option that is highly costly. At some sites, especially where composting is carried out on a farm, it would appear sensible to apply the liquor to land in order to make use of its nutrient content. However, this practice is not always acceptable to the regulator because of concerns over phytotoxicity or potential water pollution.

Very few studies of compost liquor quality have been published to date. There appears to be no database in existence of the composition of liquors from composting facilities in the UK in stark contrast to that available for landfill leachates (DoE, 1995). Fischer (1996) published some data for sites in Germany where composting occurs under cover, but where maturation occurs outside. This work suggested liquor was highly variable in composition and very strong in nature (e.g. BOD_5 10000 – 50000 mg/l; NH_3/NH_4^+ 300 – 1200 mg/l). It is also known that the composition of compost liquor is likely to vary according to the duration of composting (Frederickson, 1997). Frederickson (1997) found that liquors leached from aerobically-digested green waste contained higher levels of BOD_5, ammoniacal nitrogen and electrical conductivity in the first six weeks of composting than in the second 6 weeks of the trial (Table 1). This study also detected significant phytotoxic effects on radish plants irrigated with untreated leachate from the first six weeks of the composting process. This finding raised concerns about the potential use of untreated compost liquor as an agricultural fertiliser.

The investigations described in this paper stemmed from discussions with a composting facility operator who was seeking to identify a low-cost, on-site compost liquor bioremediation process that may permit discharge of the treated effluent to a watercourse as an alternative to land application. The specific aim of the research was to establish whether low-cost materials, such as organic solids readily available at a green waste composting facility, have the potential to act as media for simple aerobic biofilters suitable for farm-level design, construction and operation.

2. Methods

2.1 Biofilter media

Six potential biofilter media were tested in this research. They were:

- Polystyrene packaging
- Soil
- Broken brick
- Compost
- Oversize
- Wood mulch

The criteria for media selection were that they should represent readily available (where possible waste) materials; be of no/low cost; and should present a range of physical and chemical characteristics. The broken brick material was acquired from Hanson Brick, Stewartby, Bedfordshire. Broken brick fragments are normally pulverized and recycled back into the system to make new bricks. The material used in these experiments was oversize fragments from pulverization known as “grog oversize” with a typical particle size of 3-4 mm. The soil used in these experiments was a freely draining sandy loam from Cranfield University farm estate at Silsoe, Bedfordshire. The expanded polystyrene media was acquired from All Purpose Packaging Ltd, Hertfordshire and is used as a loose-fill protective agent in packaging (known as "packing peanuts") . The remaining three media selected were all organic materials readily available at green waste composting facilities, and in this case sourced from Organics Recycling Ltd., Crowland, Lincolnshire. Two of these, oversize and finished compost, are the outputs of the screening of mature composted material. The fine material passing through a 10 mm screen is the finished compost. The material with a particle size of >10 mm is referred to as oversize. The oversize is normally recycled back into new windrows. The third of these organic media, wood mulch, was also acquired from Organics Recycling Ltd. where it is used as a bulking agent in the formation of windrows.

2.2 Biofilter set up

The media to be tested were held in plastic pipes of 110 mm diameter and 1 m length, supported within a steel-framed stand. The bottom of each biofilter pipe rested inside a plastic funnel filled with gravel, in order to support the filter media. The funnel was connected to a 4 litre collection vessel by means of rubber tubing. Natural ventilation was encouraged by drilling holes drilled in the upper and lower sections of the plastic pipes. The plastic pipes were filled with the media to be tested to a depth of 1 m. In filling the filters, the various media were gently agitated to avoid bridging and the formation of large voids, and also to avoid unnecessary compaction. A total of 24 biofilters were established, representing four replicates of each of the six media to be tested. The biofilters were situated in the open air at Cranfield University's Silsoe campus in Bedfordshire, UK. A diagram of the biofilter arrangement is shown in Figure 1.

2.3 Source of compost liquor and its use in the experiments

Compost liquor from the Organic Recycling Ltd. site in Crowland, Lincolnshire was used in this study. The majority of the incoming waste at this site comprises fruit, vegetables and food processing waste. This is mixed with various bulking agents such as shredded paper and straw to create structure and absorb excess liquor in the windrows. A summary of key water quality characteristics of the liquor used can be seen in Table 2. The compost liquor was transported by lorry to Silsoe and stored in galvanised tanks.

An organic loading rate of 0.6 kg BOD_5/m^3 of biofilter volume/d was used in these experiments which is at the lower end of the range typically categorised as “high rate” aerobic biofiltration (Askew, 1969; IWEM, 1988; Gray, 1989). High organic loading rates lead to high oxygen demands and large accumulations of biofilm. With media not specially designed to permit good ventilation, drainage and permit room for slime accumulation, it was considered sensible to adopt a relatively conservative organic loading rate. The volume of liquor required to achieve the required organic loading (285 ml) was applied daily to each of the biofilters.

2.4 Analysis of liquor

The untreated compost liquor (influent) and treated compost liquor (effluent) were tested for the chemical parameters, pH, BOD_5 and ammoniacal nitrogen and a biological test was made to identify the suitability of the media in treating phytotoxicity effects on plants, using a simple cress bioassay. BOD_5 was determined using an Orion 862 dissolved oxygen probe (Thermo Electron, Boston, USA) according to standard methods (HMSO, 1988). Ammoniacal nitrogen was measured using the automated phenate method (APHA, 1998) using a Burkard Series 2000 segmented flow analyser

(Burkard Scientific, Uxbridge, UK). pH was measured with an Jenway 3020 pH probe (Jenway, Dunmow, UK). The cress seed germination assay technique described by Zucconi et al. (1985) was employed.

3. Results

Summary statistics for the ammoniacal nitrogen removal capability of the different biofilter media are presented in Table 3. The oversize media demonstrated the best performance over the 3 month study period achieving a mean percentage removal of 78% and a mean post filter ammoniacal nitrogen concentration of 172 mg/l. There was considerable variation around this mean value over the experimental period (Figure 2). Wood mulch, the next best media, performed similarly to oversize and the polystyrene media produced the worst quality effluent.

A similar range of values for percentage removal were attained for BOD_5, with compost performing best (78%) and polystyrene again the least effective (34%) (Table 4). The variation in filter effluent quality over the study period for the two best media (compost and oversize) and the worst (polystyrene) is shown in Figure 3 (data for the other media omitted for clarity).

The effect of biofiltration on the phytotoxicity of the compost liquor was investigated using a cress seed germination bioassay. The untreated compost liquor was found to be sufficiently phytotoxic to completely inhibit cress seed germination (Figure 4). Biofiltration had a limited bioremediation effect, with the oversize media again showing the best performance giving a mean post filter germination index of 12% (Table 5). Biofiltration through the polystyrene media, which again performed least well, made virtually no impact on the phytotoxicity of the compost liquor (Table 5).

The compost liquor used in this study had an acidic pH in the range pH 4.6-5.8. The impact of passage through the different filter media on pH is indicated by the mean post filter pH values given in Table 6 and by the curves shown in Figure 5. In general, biofiltration led to an increase in pH with compost and wood mulch media facilitating the greatest increase in pH and polystyrene media the least.

4. Discussion

4.1 General trends in effluent quality

Biofiltration led to significant improvements in effluent quality as measured using BOD_5, ammoniacal nitrogen and cress seed germination index as quality indicators. The degree of improvement was affected by the biofiltration media utilised. The best media were able to achieve on average a 78% removal of both BOD_5 and ammoniacal nitrogen during the study period. This figure compares favourably with work done on high rate sewage biofiltration using bespoke plastic media (Flocor) in the 1960s with filter depths of 1.8-5.5 m. Askew (1969) presented curves for the performance of Flocor in terms of percentage BOD_5 removed versus BOD_5 load (kg/m^3/d) for high rate biofilters. Askew's curves suggest that about 80-85% BOD_5 removal could be expected at a BOD_5 loading rate of 0.6 kg/m^3/d.

It is assumed that microbial oxidation processes were principally responsible for the removal of readily biodegradable organic substances and ammoniacal nitrogen from the liquor. It is reasonable to expect this as the organic loading rate of 0.6 kg/m^3/d is at the lower end of the range typically described as high rate aerobic biofiltration. Although significant percentage reductions in the concentration of BOD_5 and ammoniacal nitrogen were achieved in the experimental filters, the actual post-filter effluent remained very heavily polluted. The biofiltration process may therefore be considered to have been a partial or roughing treatment step. The poor performance of the experimental biofilter media with respect to reduction in phytotoxicity highlights the extent to which only partial treatment was achieved. The best biofilters were only able to register a mean percentage cress seed germination index of 12% which is considerably less than the threshold value of 60% below which a substance may be considered to be phytotoxic (Zucconi et al. 1985). The factors responsible for this phytotoxic effect were not investigated but ammonia toxicity may be one explanation. The cress seed germination bioassay is quite a sensitive test and tells us little about possible negative impacts of land spreading of partially treated compost liquor to an established crop of grass. The findings therefore highlight a cause for concern associated with the land recycling route and indicate the need for caution and further investigations.

The pH of the raw compost liquor was between 4.6 – 5.8. This acidic pH was assumed to be the result of the formation of fermentation products in the wet conditions found in some parts of the compost windrows. Biofiltration led to an increase in pH (Figure 5). It was also noted that the media that generally performed least well at BOD_5 and ammoniacal nitrogen removal had the smallest impact on pH whereas the more effective biofilters led to a greater increase in pH. It is likely organic acids were responsible for the low pH of the untreated compost liquor. Oxidation of these organic acids in the biofilters will lead to an increase in pH – a process analogous to the control on acidity imposed by methanogens in the anaerobic digestion process (Marchaim, 1992). Consequently, those biofilters promoting the greatest oxidation of organic acids will have the greatest impact on BOD_5 with the knock on effect of having the greatest impact on pH.

4.2 Performance of different biofilter media

A simple assessment of the performance of the different biofilter media can be made by ranking them according to their ability to improve the quality of the compost liquor with respect to the key quality indicators of BOD_5, ammoniacal nitrogen and cress seed germination index (Table 7). This simple ranking system shows that the oversize media had the best overall ranking with compost and wood mulch tied for second. The polystyrene media consistently performed least well.

It was beyond the scope of this research to try to investigate how the different physical and chemical properties of the different biofilter media tested affected the treatment of the compost liquor. In theory, the key properties are likely to be specific surface area; void size and connectivity; media durability and strength; adsorption capacity; and absorption capacity. The relative importance of some of these properties was evident in the behaviour of some of the media. For example, the small pore sizes afforded by the soil-filled biofilter led to a rapid reduction in permeability, probably associated with the accumulation of biofilm. This in turn probably led to zones of saturation, a reduction in the ventilation efficiency and the development of anoxic conditions. Conversely, the large and connected voids of the polystyrene media coupled with a low absorptive capacity appeared to shorten its hydraulic retention time in comparison to that of the other filters. The other observation that can be made is that the three best media were all natural, organic materials sourced from and readily available at an operational composting facility.

4.3 Implications of the findings for compost liquor bioremediation and management

In the case of strong compost liquors such as the one used in this experiment, a low-cost biofilter is not going to be able to produce a treated effluent that is capable of meeting the quality requirements for discharge directly to a watercourse. Aerobic biofiltration has traditionally been used as a pre-treatment to be followed by discharge to sewer or some further on-site treatment process. In the case of on-farm composting facilities, there is a role for pre-treatment prior to land disposal.

The poor performance of the treated liquor in the cress seed germination bioassay is a cause for concern if biofiltration is intended to be a precursor to land application. Further research would be needed in the development of operational biofilters to ensure that this phytotoxicity can be brought under control. Such investigations could also usefully assess the extent to which established crops are damaged by irrigation or by the accumulation of phytotoxins following prolonged periods of application.

The fact that the best performing filter media in these experiments are all readily available at most green waste composting facilities is promising, as this would help to reduce purchase and transport costs. The other bonus is that if the filter media needed to be replaced, the used materials could be simply recycled back into the composting process.

5. Conclusions

Of the potential biofilter media tested in this research, the natural, organic materials (oversize, compost and wood mulch) performed best. In terms of the mean percentage reduction in BOD_5 over the study period, these media were able to achieve a level of performance that is slightly below that of bespoke biofilter media designed for high rate applications. Although the biofilters made a significant impact on compost liquor quality, the filtrate remained highly polluted and would require further treatment if it were to be discharged to a watercourse. Furthermore, the filtrate inhibited cress seed germination and could be considered to be phytotoxic. This has implications for the sustainable irrigation of this effluent to agricultural land.

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Table 1 Composition of leachates from composted green wastes (adapted from Frederickson, 1997)

Parameter	Mean concentration weeks 0-6	Mean concentration weeks 6-12
BOD_5 (mg/l)	4214	1068
Ammoniacal-N (mg/l)	147	51
Electrical conductivity (µS/cm)	7130	5623
pH	5.7	6.8

Table 2 Some characteristics of the compost liquor used in the study

Parameter	Value	(± standard error)
BOD_5 mg/l	48720	4034
NH_3/NH_4^+ mg/l	705	23
Suspended solids mg/l	2275	184
pH	5.36	0.16

Table 3 Summary statistics for the performance of different filter media with respect to the bioremediation of ammoniacal nitrogen associated with compost liquor

Media	Mean percentage removal during study period (%)	Mean post-filter quality achieved during study period (mg/l)	Best post-filter quality achieved during study period (mg/l)	Worst post-filter quality achieved during study period (mg/l)
Oversize	78	172	11	424
Wood mulch	75	201	100	394
Compost	55	352	4	566
Soil	38	489	<1	816
Broken brick	35	515	207	944
Polystyrene	31	540	341	725

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Table 4 Summary statistics for the performance of different filter media with respect to the bioremediation of 5 day biochemical oxygen demand associated with compost liquor

Media	Mean percentage removal during study period (%)	Mean post-filter quality achieved during study period (mg/l)	Best post-filter quality achieved during study period (mg/l)	Worst post-filter quality achieved during study period (mg/l)
Compost	78	9740	2965	18324
Oversize	74	10806	5743	12420
Broken brick	74	11652	2790	31525
Wood mulch	70	12214	4807	34213
Soil	44	24651	17005	37168
Polystyrene	34	27234	14625	33195

Table 5 Summary statistics for the performance of different filter media with respect to the bioremediation of phytotoxicity associated with compost liquor

Media	Mean post-filter percentage germination index during study period (%)	Best post-filter percentage germination index achieved during study period (%)	Worst post-filter percentage germination index achieved during study period (%)
Oversize	12	43	4
Wood mulch	9	18	0
Soil	8	76	0
Compost	7	23	0
Broken brick	1	9	0
Polystyrene	0	5	0

Table 6 Impact of different filter media on pH of compost liquor compared to mean untreated liquor

Media	Mean post-filter pH during study period
Compost	8.22
Wood mulch	8.21
Oversize	8.01
Broken brick	7.63
Soil	6.96
Polystyrene	6.59
Untreated	5.36

Table 7 Rankings of biofilter media according to their ability to improve compost liquor quality according to specific characteristics and overall (where 1 is best and 6 is worst)

Media	Ammoniacal nitrogen	BOD_5	Phytotoxicity	Overall rank
Oversize	1	2	1	1
Compost	3	1	4	2=
Wood Mulch	2	4	2	2=
Soil	4	5	3	4
Broken brick	5	3	5	5
Polystyrene	6	6	6	6

Figure 1 Diagram of the arrangement of the principal components of the experimental biofilters

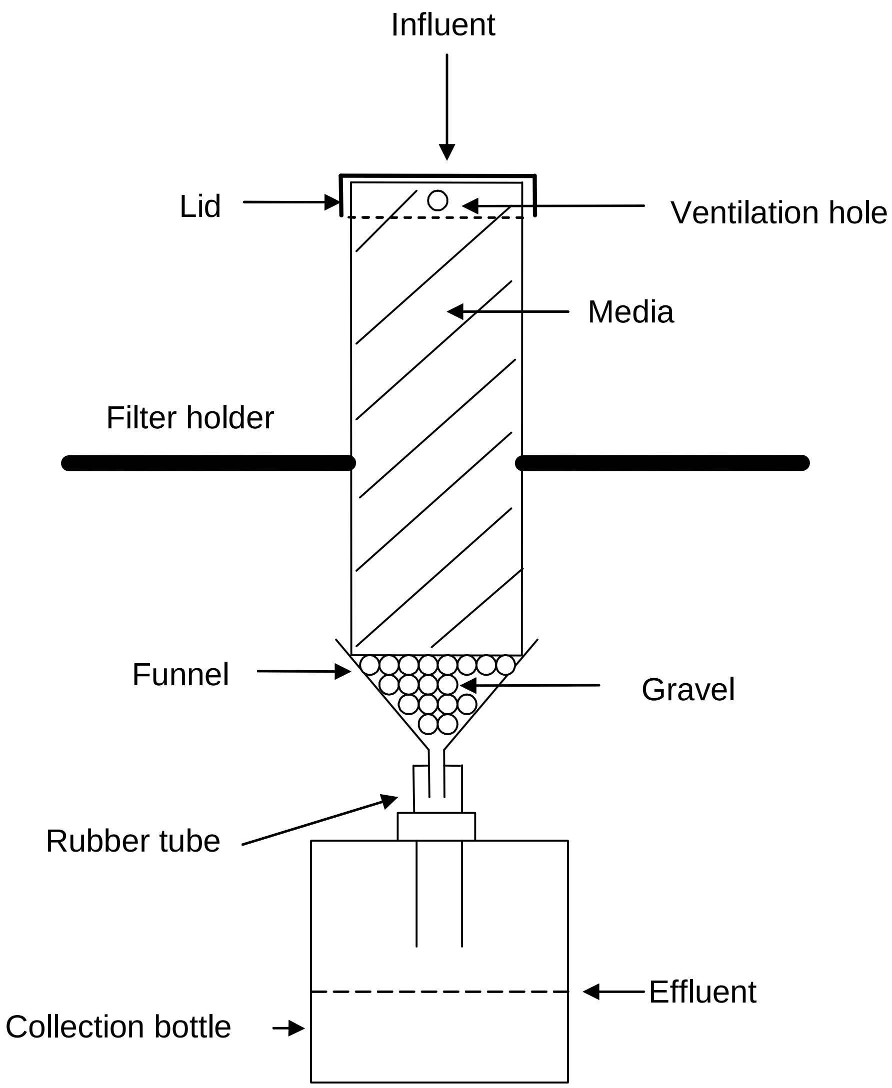


Figure 2 Changes in the ammoniacal nitrogen concentration of the untreated influent and of the biofilter effluent during the study period (selected media shown only for clarity)

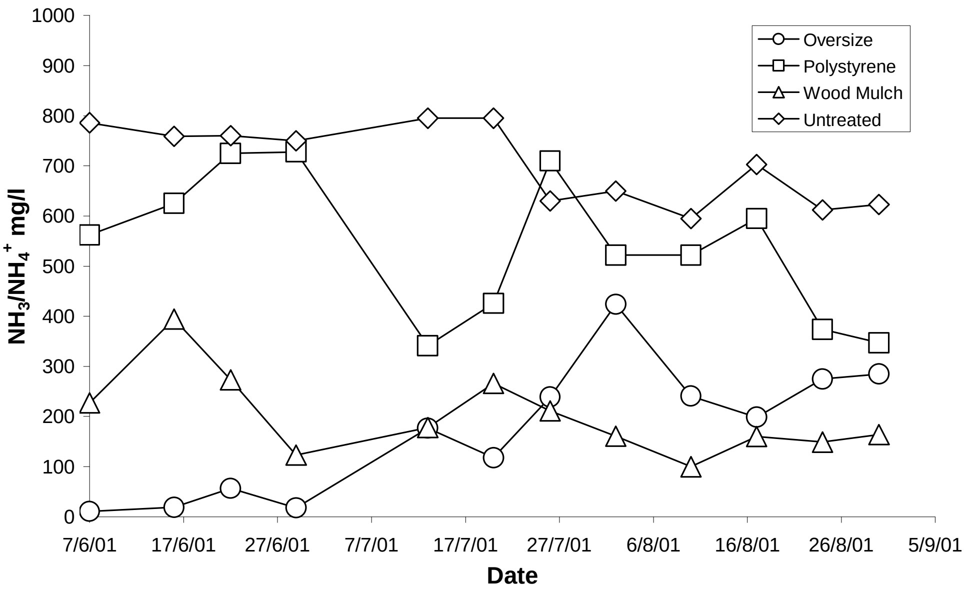


Figure 3 Changes in the 5 day biochemical oxygen demand of the untreated influent and of the biofilter effluent during the study period (selected media shown only for clarity)

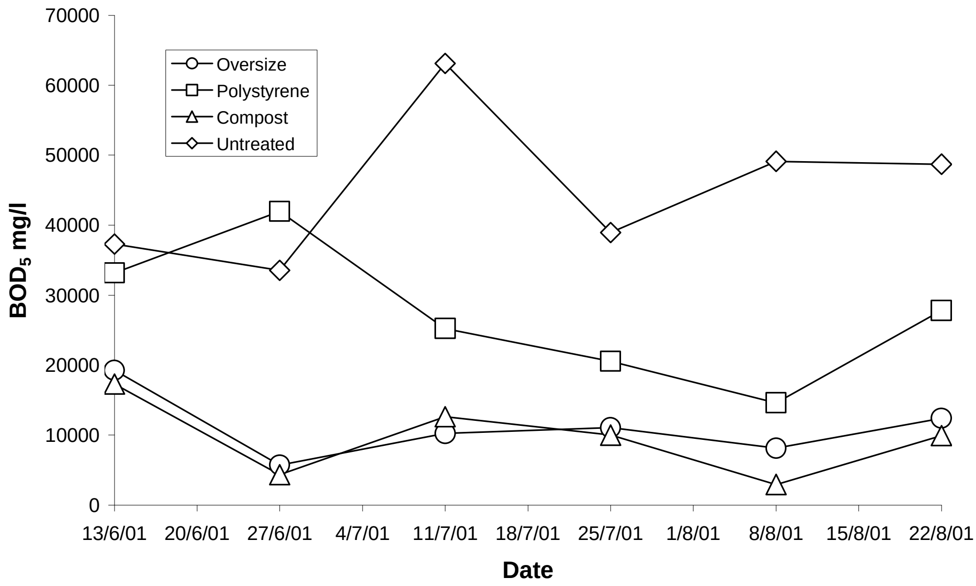


Figure 4 Changes in the value of the germination index for the untreated influent and of the biofilter effluent during the study period (selected media shown only for clarity)

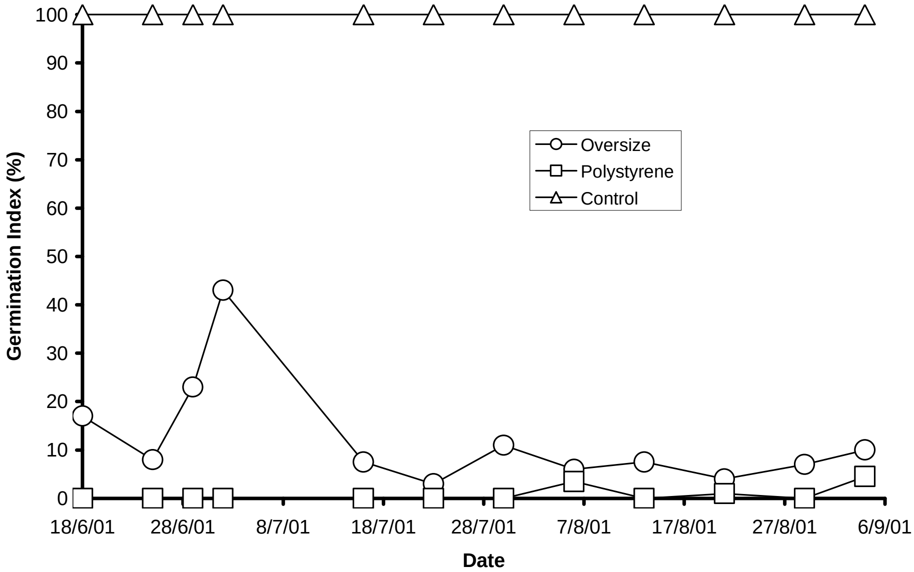
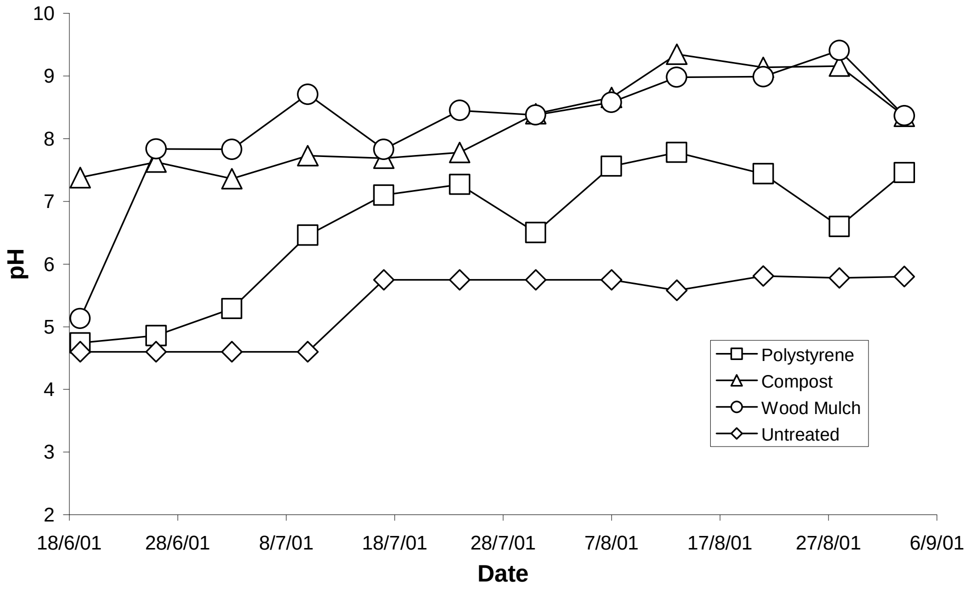


Figure 5 Changes in the pH the untreated influent and of the biofilter effluent during the study period (selected media shown only for clarity)



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