

Short communication

# The feasibility of applying immature yard-waste compost to remove nitrate from agricultural drainage effluents: A preliminary assessment

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## Abstract

Nitrate is a major agricultural pollutant found in drainage waters. Immature yard-waste compost was selected as a filter media to study its feasibility for removing nitrate from drainage water. Different operation parameters were tested to examine the denitrification efficiency, including the amounts of compost packed in columns, the flow rate, and the compost storage periods. The experimental results suggested that hydraulic retention time was the major factor to determine the extent of nitrate removal, although the amount of compost packed could also contribute to the nitrate removal efficiency. The effluent nitrate concentration increased as the flow rate decreased, and the compost column reduced nitrate concentrations from 20 mg/L to less than 5 mg/L within 1.5 h. The solution pH increased at the onset of experiment because of denitrification, but stabilized at a pH of about 7.8, suggesting that the compost had a buffering capacity to maintain a suitable pH for denitrification. Storing compost under air-dried conditions may diminish the extent nitrate removed initially, but the effects were not apparent after longer applications. It appeared that immature yard-waste compost may be a suitable material to remove nitrate from tile drainage water because of its relatively large organic carbon content, high microbial activity, and buffering capacity.

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**Keywords:** Buffer capacity; Column studies; Compost bioreactor; Denitrification; Flow rate; Hydraulic retention time

## 1. Introduction

Agriculture is one of the major sources of water contamination in the Midwestern United States, and the application of nitrogen fertilizers has been implicated as the major component of this problem [1,2]. After agrichemicals are applied to a field, they can enter surface water directly through overland flow, or they can be transported by shallow groundwater that can discharge into surface water, and pose a threat to surface water quality [3–6]. To minimize the environmental impacts of subsurface drainage on water quality, substantial research has been done on designing in-line bioreactors to remove agricultural chemicals from tile-drainage effluent [2,7,8].

When designing bioreactors for nitrate removal, a supplemental carbon source is usually required for supporting denitrification processes. Several easily biodegradable carbona-

ceous materials, such as glucose, methanol, ethanol, propionate, or acetic acid, have been found to be useful carbon sources for denitrification in wastewater treatment plants [9–11]. These products, however, may not be suitable for field applications because of their high cost. Besides, because of their high solubility, they could be easily transported in the water. Other solid materials, such as tree bark [7], wood chips and corncobs [8], newspaper [12], and sawdust [13] have been proposed as the carbon sources in the denitrification bioreactors. However, these studies did not provide data on the rate of denitrification to suggest how long it would take to attain optimal conditions. In addition, some specific microorganisms were needed to inoculate into the mentioned media to initiate denitrification. Because these solid carbon materials were not as biodegradable as the more water-soluble carbon products, the application of these materials in a bioreactor may require a relatively long time for the biomass to accumulate to yield significant denitrification under field conditions. However, nitrate is highly water soluble and can be leached to the subsurface tile effluent after the first rainfall [6]; it might not be efficient to utilize these relatively inert

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biodegradable materials to denitrify surface runoff that occurs after a rainfall event. Therefore, an alternative solid organic material that could sustain abundant initial microbial activity could be a more desirable carbonaceous source for the denitrification purpose.

Compost is made by the microbial transformation of organic wastes and can sustain a large population of microorganisms. The high microbial activity in compost could readily utilize the carbon source for denitrification. Our previous study showed that immature yard-waste compost had larger carbon content when compared with mature compost, and immature compost could remove more herbicide from tile drainage water [14]. Besides, the immature compost would contain greater percentage of liable carbon source than the matured compost [15,16]. Therefore, it would be more efficacious to use the immature compost for denitrification. In this study, the potential for immature compost to denitrify water was studied, and the effects of flow rate and compost storage conditions on nitrate removal efficiency were investigated.

## 2. Materials and methods

### 2.1. Compost sample characterization

Six-month-old compost samples were collected and combined at the Urbana Landscape Recycling Center (ULRC) in Urbana, Illinois [14]. At the ULRC, the yard-waste pruning by-products were collected as initial composting materials every November, and no additional nitrogen sources were amended into the compost piles during the composting processes. As a consequence, it generally requires about two and a half years for the compost to mature for typical agricultural applications. About 10 kg of compost was collected from the composting site, and the collected 6-month-old compost sample was stored in plastic bags at  $20 \pm 2^\circ\text{C}$ . Except for studying the effect of compost storage on nitrate removal, the studies were conducted within two weeks after the compost was collected.

The combined sample was screened through a 4 mm sieve, and subsamples were used for subsequent chemical characterization. The compost pH was measured with an electrode on a 1:2 compost:water (w/w) solution. The total water content was determined gravimetrically at  $80^\circ\text{C}$  for 24 h. The C:N:H ratio was determined using a CHN Analyzer (Exeter Analytical, Inc).

### 2.2. Batch extraction

A batch extraction study was conducted to examine whether the compost itself was a source of water-soluble nitrate, using the modified method developed by Roy et al. [17]. Different amounts of compost sample, in a range of 0.5–25 g, were added to 50-mL polyethylene centrifuge tubes followed by the addition of 25 mL of deionized (DI) water. The tubes were mixed in a rotating tumbler for 24 h at  $20 \pm 2^\circ\text{C}$ , and nitrate concentration was measured after filtration with a  $0.45\text{-}\mu\text{m}$  mixed cellulose ester filter using an ion chromatograph (Dionex model DX-120, USA).

Table 1  
Characteristics of the 6-month-old compost sample used in this study

Moisture content (%)	pH (1:1) <sup>a</sup>	C (%)	N (%)	H (%)	C/N
44.1	6.9	33.5	1.7	4.3	19.7

<sup>a</sup> Mass compost (g):volume of deionized water (mL).

### 2.3. Effect of compost mass on denitrification

Column experiments were conducted by packing compost into glass cylindrical columns, each with a 30 cm length and 2.5 cm diameter. The volume of each column was about  $150\text{ cm}^3$ . Different amounts of compost (30, 40, and 50 g) were packed into the column to examine the effects of compost mass on nitrate removal. The compost was poured into the columns in batches and packed with a glass rod.

A 20-mg/L nitrate solution (27.42 mg/L of  $\text{KNO}_3$ ) was continuously pumped from the bottom to top of each column at a flow rate of 1.2 mL/min by a peristaltic pump (Pharmacia Biotech, St. Louis). At pre-selected times, a 20 mL effluent sample was collected for nitrate analysis.

### 2.4. Effect of flow rate on nitrate removal

To study the effect of flow rate on nitrate removal, 40 g of compost was packed into a glass column. A 20 mg/L nitrate solution was pumped through the column at 0.6 mL/min, 1.2 mL/min, or 2.4 mL/min. The effluent pH was measured when the system was operated at a flow rate of 1.2 mL/min.

### 2.5. Effect of compost storage on nitrate removal

To examine the effect of compost storage on nitrate removal, a compost subsample was air-dried for two months, and then packed into a column to test its efficacy for denitrification. All of the column experiments were carried out at  $20 \pm 2^\circ\text{C}$ .

## 3. Results and discussion

### 3.1. Compost characterization and batch study

The 6-month-old compost ULRC sample had a moisture content of 44.1% and a pH of 6.9 (Table 1). The sample had a carbon content of about 33.5%, and a C/N ratio of 19.7, which was greater than the reported range of 13–16 for stabilized yard-waste compost [18].

In the batch extraction study, nitrate was not detected until more than 5 g compost was incubated with 25 mL DI water (Table 2). Based on the results, we calculated that each kilogram of compost contributed less than 0.6 mg nitrate, suggesting that 6-month-old compost sample from the ULRC site would not be a significant source of nitrate.

### 3.2. Effects of compost mass on denitrification

During the column experiments, some compost particles were carried to the top of the columns by the upstream flow, especially

Table 2  
Nitrate concentrations from the batch extraction study

Mass of compost (g)	Solid:liquid ratio (g/mL)	Nitrate concentration detected in solution (mg/L)	Mass of nitrate per mass of compost (mg/kg)
0.5	1:50	<0.15 <sup>a</sup>	<7.50
1	1:25	<0.15	<3.75
2.5	1:10	<0.16	<1.50
5	1:5	<0.17	<0.75
10	1:2.5	0.18	0.5
25	1:1	0.56	0.6

<sup>a</sup> Less than the detection limit of 0.15 mg/L.

when the columns were not fully packed. These floating particles would settle down at a latter time, but the compost settling time could not be controlled easily. Therefore, it is difficult to determine the actual compost-solution contact time (hydraulic retention time), and hence no statistical analysis was performed. For this reason, only one set of data per treatment is presented in this paper.

In the column study, nitrate concentrations decreased from 20 mg/L to less than 0.4 mg/L immediately after the onset of the experiment at a flow rate of 1.2 mL/min, but nitrate increased to about 4.5 mg/L after 8 h (Fig. 1a). The compost sample could have provided a readily biodegradable carbon source for denitrification such that the nitrate concentration in the effluent decreased relatively rapidly at the beginning of the operation. After the readily biodegradable carbon source was consumed or leached from the column, the denitrification rate was limited by the available electron donors in the system, resulting in

the increase in nitrate concentration in the effluent. The slowly biodegradable organic substances could have then be used as electron donor sources providing for a relatively slow rate of denitrification, either through a hydrolysis process or fermentation by microorganisms [10], resulting in the steady effluent nitrate concentration.

Both the compost mass and hydraulic retention time affected the nitrate removal, although their effects could not be significantly separated in this study (Fig. 1). Between these two factors, the experimental results seem to suggest that the effect of hydraulic retention time should be the major consideration in designing the bioreactor for nitrate removal. When the column was packed with 30 g compost, the compost mass did not occupy the entire column (about 75% length of column). At the beginning of the experiment, however, some of the compost sample floated to the top of the column. Therefore, this treatment (packed with 30 g compost) yielded the longest hydraulic retention time at the beginning of the experiment, and hence, the smallest effluent nitrate concentration during the first 6 h was observed (Fig. 1b). After 48 h of incubation, the floating compost settled down at the bottom of the columns. Hence, the column packed with 40 g compost had the longest hydraulic retention time, and demonstrated the highest denitrification efficacy (Fig. 1a). When the column was packed with 50 g of compost, the smallest nitrate concentration was only observed from 12 to 48 h of operation, probably because more easily biodegradable carbon source was still available in the system during that period because of the larger compost mass. These results, therefore, suggest that compost could provide sufficient carbon source for denitrification, and packing the fixed-volume bioreactor with excessive mass might not be the optimal approach for nitrate removal.

### 3.3. Effects of flow rate on nitrate removal

The effluent nitrate concentrations decreased with decreasing flow rate (Fig. 2). When the column was packed with 40 g of compost, the 30 cm long column reduced nitrate to concentrations less than the U.S. EPA drinking water standard of 10 mg/L as N at the flow rate of 0.6 mL/min or 1.2 mL/min, but not at the flow rate of 2.4 mL/min. Based on the effluent nitrate concentrations at 72 h (assuming that the system had equilibrated), the total amount of nitrate being removed per day at the different flow rates were calculated and compared in Table 3. The maximum extent of nitrate removal was achieved at a flow rate of

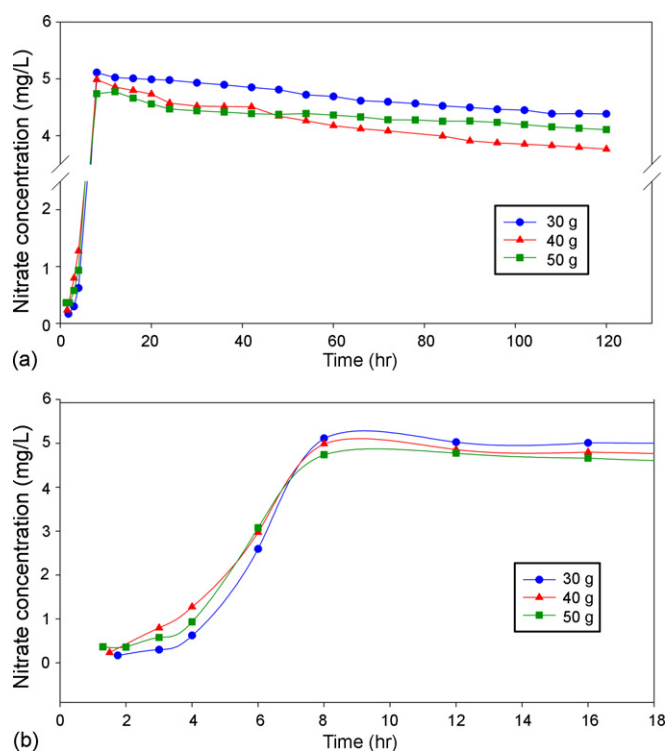


Fig. 1. Effect of compost mass in the fixed-volume column on nitrate removal. The initial nitrate concentration was 20 mg/L. (a) The operation time of 120 h and (b) the first 20 h.

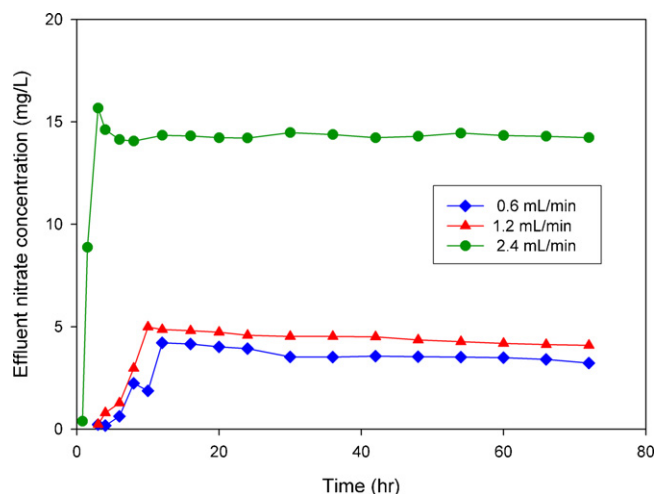
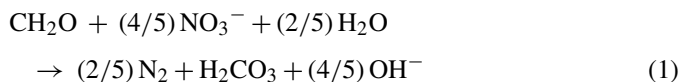


Fig. 2. Effect of flow rate on nitrate removal in a column packed with 40 g compost. The initial nitrate concentration was 20 mg/L.

1.2 mL/min. At flow rate of 2.4 mL/min, there might not have been sufficient hydraulic retention time for microorganisms to accumulate in the column for denitrification, resulting in the relatively less nitrate remove when compared with a flow rate of 1.2 mL/min. The least amount of nitrate was removed at a flow rate of 0.6 mL/min, because the smallest amount of nitrate flowed through the column at that flow rate.

### 3.4. The pH change during the denitrification processes

When organic carbon serves as electron donor for denitrification, the chemical reaction can be expressed as [19]:



According to Eq. (1), carbonate alkalinity increases when nitrate is reduced, and thus, denitrification tends to increase solution pH.

The relationship between nitrate removal and pH at a flow rate of 1.2 mL/min is shown in Fig. 3. During the first 2 h of operation, microorganisms could have utilized the relatively biodegradable carbon sources for denitrification, resulting in the increase of solution pH. After the initial readily biodegradable organic substances were consumed, the denitrification processes may have slowed down until more degradable carbon sources were

Table 3  
Effect of flow rate on daily nitrate removal

Flow rate (mL/min)	Effluent nitrate concentration at equilibrium <sup>a</sup> (mg/L)	Daily nitrate removal <sup>b</sup> (mg/d)
0.6	3.22	14.49
1.2	4.18	27.32
2.4	14.23	19.94

<sup>a</sup> The system was assumed to reach equilibrium at 72 h, and the data were used to calculate the daily nitrate removal.

<sup>b</sup> The daily nitrate removal was calculated by multiplying flow rate with the difference between influent and effluent nitrate concentration.

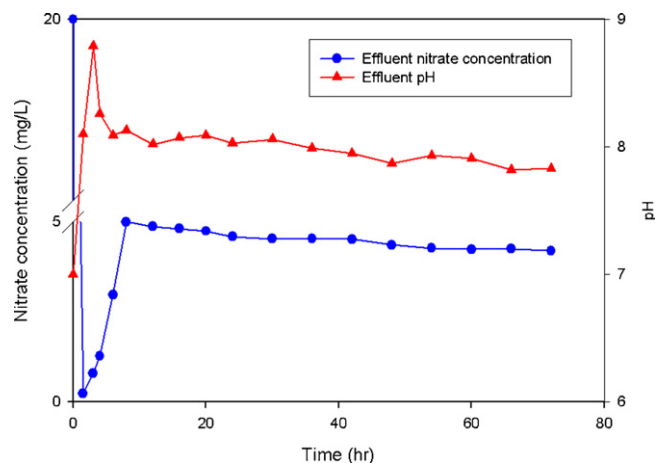


Fig. 3. Column effluent nitrate content and pH at flow rate of 1.2 mL/min.

produced in solution through fermentation or by the hydrolysis of organic matter. The effluent nitrate became relatively constant after 8 h of operation, and the pH remained about 7.8 (Fig. 3). The stable pH suggested that the compost sample buffered the pH to maintain the optimal pH for denitrification at the range of 7–9 [10], despite the expectation that the pH should continue to increase during denitrification, as suggested by Eq. (1).

### 3.5. Effect of compost storage on nitrate removal

Compost might not be used for field application immediately after it is collected from the composting site. Because the storage of compost under different conditions could affect microbial activity, the impact of compost storage time on nitrate removal was studied (Fig. 4). Compared with the compost sample used immediately after collection, the air-dried compost that had been stored for two months removed significantly less nitrate during the first 60 h, ranging from 32% less nitrate removal after 12 h to a 5% less after 60 h. The less nitrate removal during the first 60 h might have resulted from the difference in microbial activ-

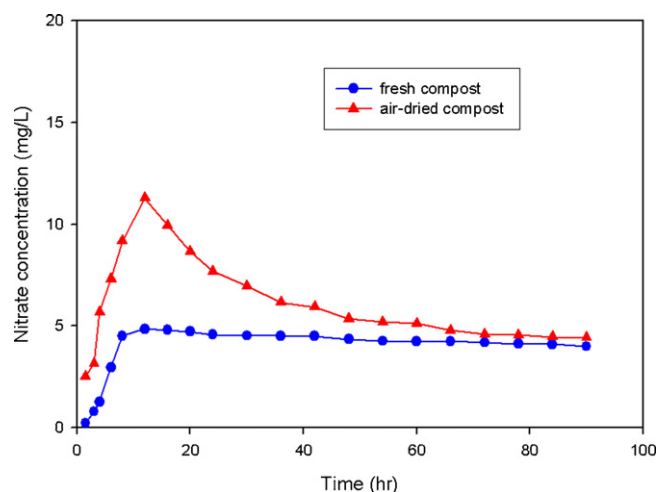


Fig. 4. The effect of compost storage on nitrate removal. The initial nitrate concentration was 20 mg/L.

ity as well as the availability of readily biodegradable carbon source for denitrification. After 60 h of incubation, however, the microorganisms stored under air-dried conditions seemed to be able to accumulate sufficient biomass to yield comparable bioactivity for denitrification, and hence, demonstrated similar (less than 5% difference) nitrate removal when compared with the fresh compost sample.

### 3.6. Future study

The overall results indicated that the compost sample selected in this study could be a viable medium for use in a bioreactor for denitrification because the immature compost had a relative large carbon content, high initial bioactivity, and buffering capacity. It should be acknowledged, however, that compost itself could contribute dissolved organic carbon and amber color to the receiving water body [20]. It should also be evaluated how often the compost in the bioreactor should be replaced in order to sustain significant nitrate removal. Therefore, additional research is needed in order to apply a compost bioreactor in the field.

## 4. Conclusions

A 6-month-old compost sample collected from the Urbana Landscape Recycling Center site demonstrated a significant potential as a bioreactor medium to remove nitrate from solution. The extent of nitrate removal depended primarily on the hydraulic retention time, but not necessary on the compost mass in the columns. Denitrification took place at the onset of operation, and the column-compost system yielded a stable pH during denitrification. In addition to providing the initial microbial activity, the compost sample also served as the carbon source for denitrification in this study. In general, providing easily biodegradable carbon source would favor denitrification. However, when designing a fixed-volume denitrification bioreactor, it is also important to consider selecting a proper hydraulic retention time. Compost is a porous material and excessive packing in a bioreactor could reduce the hydraulic retention time. How long compost is stored until used could influence microbial activity, and thus, influence the extent of nitrate removal. A compost bioreactor could be used to remove nitrate from drainage water, although more research is still needed.

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## References

- [1] U.S. Geological Survey, Data on natural organic substances in dissolved, colloidal, suspended-silt, and clay- and bed-sediment phases in the Mississippi River and some of its tributaries, 1991–1992, Water Resources investigations Rep. 94-4191, U.S. Geological Survey, Denver, CO, 1995.
- [2] D.D. Dinnes, D.L. Karlen, D.B. Jaynes, T.C. Kaspar, J.L. Hatfield, T.S. Colvin, C.A. Cambardella, Nitrogen management strategies to reduce nitrate leaching in tile-drained Midwestern soils, *Agron. J.* 94 (2002) 153–171.
- [3] D.D. Buhler, G.W. Randall, W.C. Koskinen, D.L. Wyse, Atrazine and alachlor losses from subsurface tile drainage of a clay loam soil, *J. Environ. Qual.* 22 (1993) 272–275.
- [4] K. Jayachandran, T.R. Steinheimer, L. Somasundaram, T.B. Moorman, R.S. Kanwar, R.S. Coats Jr., Occurrence of atrazine and degraders as contaminants of subsurface drainage and shallow groundwater, *J. Environ. Qual.* 23 (1994) 311–319.
- [5] G.W. Randall, D.R. Huggins, M.P. Russelle, D.J. Fuchs, W.W. Nelson, J.L. Anderson, Nitrate losses through subsurface tile drainage in conservation reserve program, alfalfa, and row crop system, *J. Environ. Qual.* 26 (1997) 1240–1247.
- [6] E.J. Kladvik, J. Grochulska, R.F. Turco, G.E. van Scoyoc, J.D. Eigel, Pesticide and nitrate transport into subsurface tile drains of different spacing, *J. Environ. Qual.* 28 (1999) 997–1004.
- [7] D.W. Blowes, W.D. Robertson, C.J. Ptacek, C. Merkle, Removal of agricultural nitrate from tile-drainage effluent water using in-line bioreactors, *J. Contam. Hydrol.* 15 (1994) 207–221.
- [8] A. Doheny, Amelioration of the nitrate and atrazine using inline biofilters, MS, Thesis, University of Illinois at Urbana-Champaign, 2000.
- [9] U.S. EPA, An Analysis of Composting as an Environmental Remediation Technology, U.S. Environmental Protection Agency, Washington, EPA/530-R-98-008, 1998.
- [10] B.E. Rittmann, P.L. McCarty, *Environmental Biotechnology: Principles and Applications*, McGraw-Hill Publication, Boston, 2001.
- [11] S.E. Oh, M.S. Bum, Y.B. Yoo, A. Zubair, I.S. Kim, Nitrate removal by simultaneous sulfur utilizing autotrophic and heterotrophic denitrification under different organics and alkalinity conditions: batch experiments, *Water Sci. Technol.* 47 (2002) 237–244.
- [12] M. Volokita, S. Belkin, A. Abeliovich, M. Soares, Biological denitrification of drinking water using newspaper, *Water Res.* 30 (1996) 965–971.
- [13] W.D. Robertson, J.A. Cherry, *In situ* denitrification of septic-system nitrate using reactive porous media barriers: Field trials, *Ground Water* 33 (1995) 99–111.
- [14] L. Tsui, W.R. Roy, Effect of compost age and composition on the atrazine removal from solution, *J. Hazard. Mater.* B139 (2007) 79–85.
- [15] R.T. Haug, *The Practical Handbook of Compost Engineering*, CRS Press, 1993.
- [16] Y. Eklind, Carbon and nitrogen turnover during composting, and quality of the compost product, Doctoral Thesis, Swedish University of Agricultural Sciences.
- [17] W.R. Roy, I.G. Krapac, S.F.J. Chou, R.A. Griffin, Batch-type procedures for estimating soil adsorption of chemicals. Technical Resource Document, U.S. EPA/530-SW-87-006-F, U.S. Environmental Protection Agency, 1992.
- [18] L. Wu, Q. Ma, Relationship between compost stability and extractable organic carbon, *J. Environ. Qual.* 31 (2002) 323–328.
- [19] M. Henze, P. Harremoës, J.C. Jansen, E. Arvin, *Wastewater Treatment: Biological and Chemical Processes*, Springer-Verlag, Berlin, 1995.
- [20] L. Tsui, W.R. Roy, M.A. Cole, Removal of dissolved textile dyes from wastewater by a compost sorbent, *Color Tech.* 119 (2003) 14–18.