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The Potential of Municipal Yard Waste to be Denitrification Bioreactor Fill

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Abstract

The use of denitrification bioreactors to mitigate nitrate in agricultural drainage has recently gained much interest in the US Midwest and in other agricultural regions around the world. However, because this is a new technology, there are still many questions regarding bioreactor design and construction including uncertainty about denitrification carbon source material. The physical, chemical and biological properties of the utilized carbon media effect overall bioreactor performance through factors such as hydraulic conductivity, porosity, carbon: nitrogen ratio, and microbially available carbon. In selecting a carbon source material, there is an important balance between the optimal media properties, practicality, and material cost. The use of free material may help minimize material cost, but may not provide other sufficient media properties. To investigate this, pilot scale bioreactors were used to compare nitrate removal efficiency and media longevity of hardwood chips (summer #1) with free, municipal chipped storm debris (summer #2). Bromide tracer tests allowed comparisons between reactor hydraulics and buried bags of carbon media allowed for pre- and post-operation observations of the media. Initial results were confounded by flooding and operational problems in summer #2, but generally indicated the storm debris provided nitrate removal but also degraded over the period.

Keywords

Denitrification bioreactor, agricultural drainage, woodchip, yard waste, nitrate

Disciplines

Agriculture | Bioresource and Agricultural Engineering

Comments

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The Potential of Municipal Yard Waste to be Denitrification Bioreactor Fill

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Abstract. *The use of denitrification bioreactors to mitigate nitrate in agricultural drainage has recently gained much interest in the US Midwest and in other agricultural regions around the world. However, because this is a new technology, there are still many questions regarding bioreactor design and construction including uncertainty about denitrification carbon source material. The physical, chemical and biological properties of the utilized carbon media effect overall bioreactor performance through factors such as hydraulic conductivity, porosity, carbon: nitrogen ratio, and microbially available carbon. In selecting a carbon source material, there is an important balance between the optimal media properties, practicality, and material cost. The use of free material may help minimize material cost, but may not provide other sufficient media* *properties. To investigate this, pilot scale bioreactors were used to compare nitrate removal efficiency and media longevity of hardwood chips (summer #1) with free, municipal chipped storm debris (summer #2). Bromide tracer tests allowed comparisons between reactor hydraulics and buried bags of carbon media allowed for pre- and post-operation observations of the media. Initial results were confounded by flooding and operational problems in summer #2, but generally indicated the storm debris provided nitrate removal but also degraded over the period.*

Keywords. *Denitrification bioreactor, agricultural drainage, woodchip, yard waste, nitrate*

Introduction

In the US Midwest, denitrification bioreactors for agricultural drainage have shown potential as a useful technology for reducing nitrate (NO_3^-) in surface waters (Woli et al., 2010). However, in order for these drainage bioreactors to provide maximum water quality benefit, they must be practical in a farm setting. One of the most important factors affecting their practicality is the carbon media selected as bioreactor fill. Though these systems have colloquially been termed “woodchip bioreactors”, material other than woodchips has been investigated as a bioreactor carbon source. Cardboard, corn stalks, shredded newspaper, walnut and almond shells, among many other materials, have been tried under a variety of research-scale conditions with varying NO_3^- removal results (Diaz et al., 2003; Greenan et al., 2006; Volokita et al., 1996). Investigations into specific woodchip species (Christianson et al., In preparation) and wood types (i.e. hardwood, etc.) (Cameron and Schipper, 2010) have also been done.

Not just any carbon material will be appropriate to support sustained, enhanced denitrification over the estimated several decade bioreactor life (Long et al., 2011; Moorman et al., 2010; Schipper et al., 2010). The physical, chemical and biological properties of the media effect overall bioreactor performance through factors such as hydraulic conductivity, porosity, carbon: nitrogen ratio (C:N), and microbially available carbon. In selecting a carbon source material, there is an important balance between the optimal media properties, practicality, and material cost.

In terms of practicality, one potentially readily available carbon source is municipal yard waste. Municipal yard waste/storm debris could be a very convenient fill material as it is often considered a waste and is usually free or very low cost. Concerns about the use of this material as bioreactor fill include inclusion of green foliage, compaction, longevity, plugging, and fines. It was hypothesized that the use of free yard waste material may help minimize material cost, but may not provide other sufficient media properties.

Methods

Three pilot-scale denitrification bioreactors of different shape as described in Christianson et al. (2011) were filled with chipped municipal yard waste for the second year of their operation (Figure 1a). See Christianson et al. (2011) for details on bioreactor construction, design and results with purchased woodchips from the first year of operation (Figure 1b). The yard waste for this investigation was obtained free of charge from the Parks & Recreation Department, Ames, Iowa on 18 November 2009. Porosity of the yard waste was measured using methods described in Christianson et al. (2010). Though the bioreactors were filled with the media in November 2009, bioreactor operation began approximately six months later in May 2010. These pilot bioreactors received drainage water at a controlled flow rate fed from an underground storage reservoir. During summer 2010, the flow rates were manipulated to obtain a range of bioreactor retention times (1.8 hrs to 13.8 hrs, based on average depths) and influent and effluent grab samples were collected for NO_3^- analysis. A graduated cylinder and stopwatch were used to measure the inflow and outflow rates. The outflow rate was used to calculate the retention time except during 4 May to 17 May and 16 June where only inflow readings were taken (inflow used to calculate retention on these dates).

Figure 1. Yard waste used in pilot bioreactor study (a) and woodchips used in previous pilot bioreactor study (b). Note difference in beakers used for size reference: 2000mL beaker for yard waste (a) and 3500 mL beaker shown by "standard" woodchips (b).

In addition to these general nitrate removal studies, tracer tests were done on 13 July 2010 to investigate hydraulics of the three bioreactors. A slug of 3 g to 5 g potassium bromide mixed with 0.5 L water was injected directly by the bioreactor inlet. Thirty-five effluent samples were collected over 12 hours from each bioreactor (at least 3 cumulative pore volumes). The bioreactors were operated at flow rates of 0.96 L/min to1.6 L/min with estimated retention times of 2.2 hrs to 3.8 hrs. Influent and effluent samples were analyzed for NO_3^--N and bromide using a colorimetric method with a Lachat Quick-Chem 8000 automated analyzer (Standard Methods, 1998).

During installation, media bags filled with yard waste were prepared using tile sock/drain sleeve and zip ties. The bags were weighed before installation in the bioreactors and also at the end of the summer of operation (i.e. pre- and post- operation). Six bags were placed in each reactor with three at the top and three at the bottom. The yard waste in its initial condition was also analyzed for organic carbon and nitrogen content (combustion analysis, ISU Soil and Plant Analysis Laboratory) for comparison with the woodchip material previously used.

Results

Water Quality Parameters

The municipal yard waste was a sufficient carbon source to support NO_3^- removal in the four months the pilot bioreactors were operated (Figure 2). However, site flooding in early June, early July, and early August 2010, complicated testing of the pilot bioreactors which were installed in the ground (i.e. no sampling during these periods). Dilution of both the influent and effluent was possible especially during early August (Figure 2) thus samples from 6 August to 21 August were removed from analysis. Additionally, in September 2010, the rectangle bioreactor became saturated with standing water potentially due to plugging so these sample events were excluded from analysis.

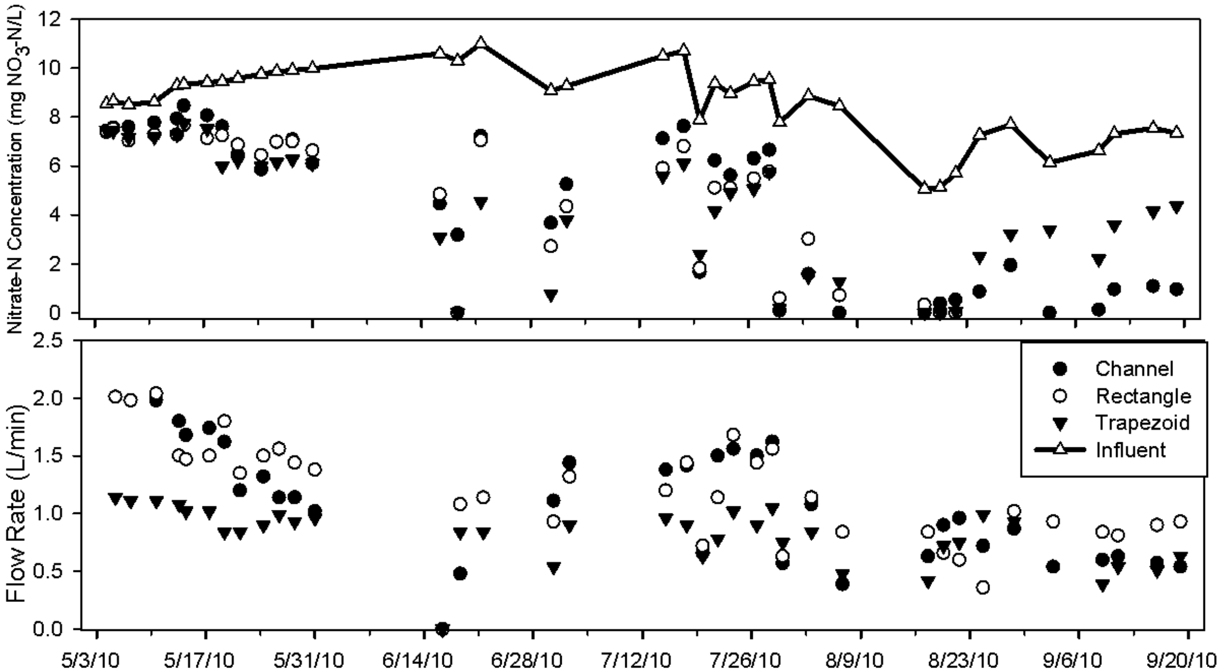

Figure 2. Influent and effluent NO_3^--N concentrations (a) and associated flow rates (b) for three pilot scale bioreactors filled with municipal yard waste operated during summer 2010.

With flooded/diluted samples removed from analysis, NO_3^--N mass removal correlated with retention time (Figure 3). This correlation was also documented, albeit more clearly, with results from the first summer of operation where woodchip material was used (Christianson et al., 2011). Sustainability of the material and longer term NO_3^--N removal (i.e. greater than five months) were not evaluated.

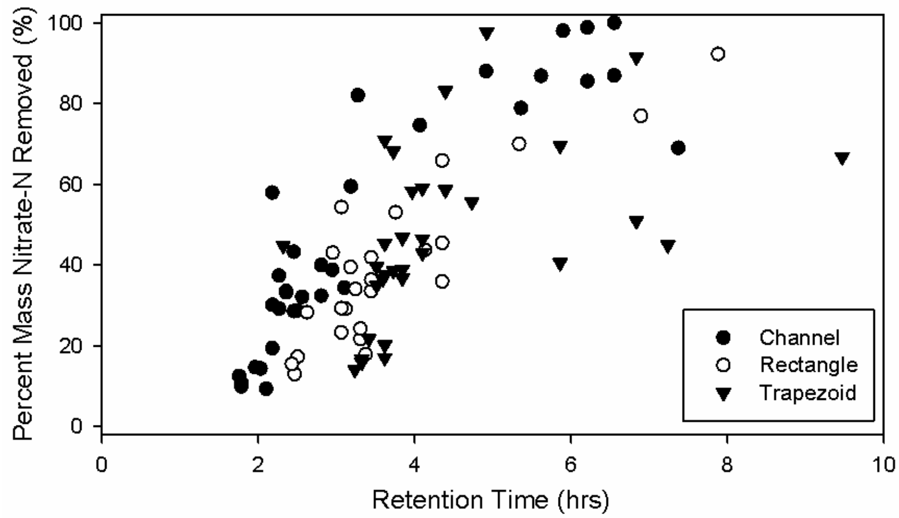

Figure 3. Retention time correlation with mass NO_3^--N removal for three pilot-scale bioreactors.

Bromide tracer recoveries for the three bioreactors were all near 80% with a minimum cumulative pore volume of approximately 3 for the tests (Table 1). Tracer residence times were 29.5%, -1.2%, and -2.6% different than the theoretical retention times for the channel, rectangle, and trapezoidal designs, respectively (Table 1). The Morrill Dispersion Index (MDI) ranged from 4.1 to 5.2 (Table 1) with an MDI of 1 associated with ideal plug flow (Metcalf and Eddy, 2003). The channel bioreactor had the most dispersion as evidenced by its wider tracer curve and corresponding higher MDI (Figure 4).

Table 1. Tracer test parameters for three pilot-scale bioreactors.

	Channel	Rectangle	Trapezoidal Cross Section
Flow rate (L/min)	1.59	1.38	0.96
% Tracer Recovered	79.5%	80.8%	76.9%
Total Pore Volumes	5.13	3.17	2.97
Retention time based on flow rate (hr)	2.2	3.6	3.8
Tracer Residence Time (hr)	3.2	3.6	3.7
MDI	5.2	4.1	4.3

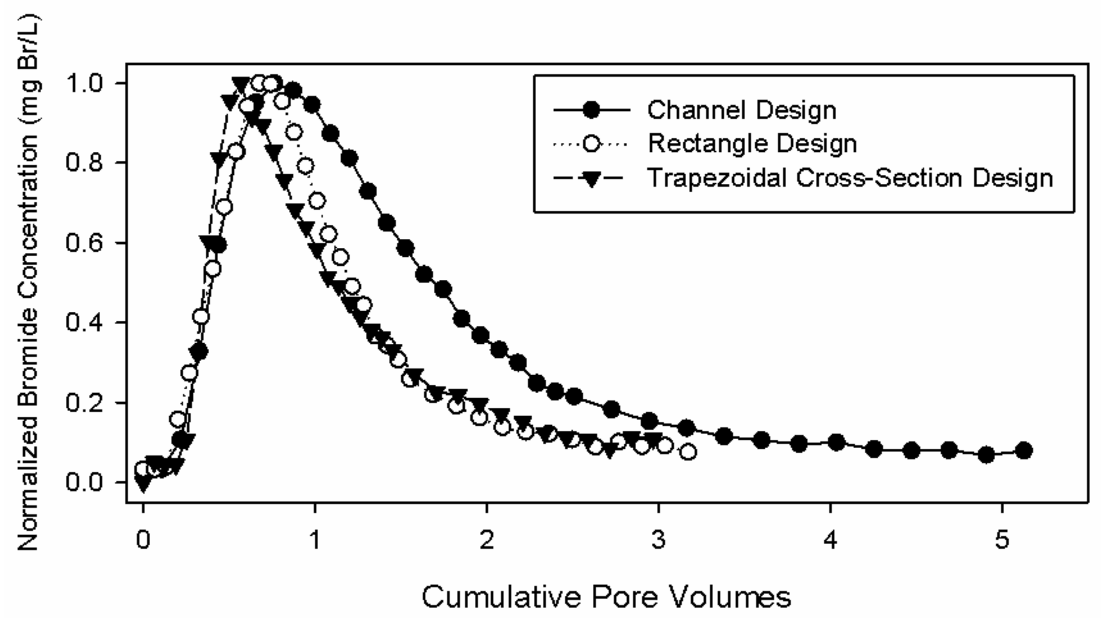

Figure 4. Normalized bromide tracer concentrations for three pilot bioreactors with yard waste as fill material.

Carbon Media Parameters

The porosity of the yard waste ranged from 62% to 69% (mean: 66% ±3.9%) at packing densities of 199 kg/m^3 to 178 kg/m^3, respectively. This porosity was similar to, but slightly lower than the 66% to 78% reported for woodchips at packing densities between 190 and 250 kg/m^3 (Christianson et al., 2010). Though no particle size analysis was done on the yard waste, visual observation showed this media generally had smaller particle sizes than for the woodchips (see Figure 1).

With a carbon to nitrogen ratio (C:N) of 77±5, the yard waste had a C:N lower than the purchased woodchips used in the first year of the study (woodchip C:N 251±37). This low C:N of the yard waste was due to its relatively higher nitrogen content (Figure 5). Such low C:N bioreactor media is not recommended as this material may ultimately leach nitrogen (Christianson et al., In preparation)

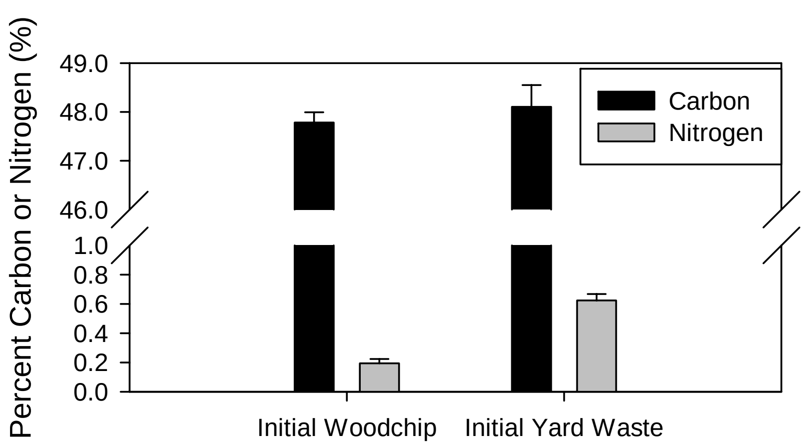

Figure 5. Yard waste and woodchip percent carbon and nitrogen.

Media bags placed in the reactors during both years of operation showed the yard waste lost weight more consistently than the woodchips (Figure 6). The first summer of operation with woodchips showed weight loss in the top section of the reactors. This top section would normally have been unsaturated, and thus, the weight loss was attributed to aerobic degradation which was also noted by Moorman et al. (2010). In the second year of bioreactor operation when yard waste was used, all the bags lost weight regardless of placement within the reactor. The bags near the top of the Trapezoidal Cross-Section and Channel reactors lost significantly more mass than the bags at the bottom of these reactors (based on one standard deviation) consistent with this aerobic degradation concept. The weight loss documented in all the yard waste bags indicates potential for shortened life of reactors filled with yard waste. Note, this result may have been complicated by the lag time between installation of the yard waste in Fall 2009 and operation in Summer 2010. Moreover, any conclusions about weight loss were complicated by the flooding conditions experienced by the yard waste.

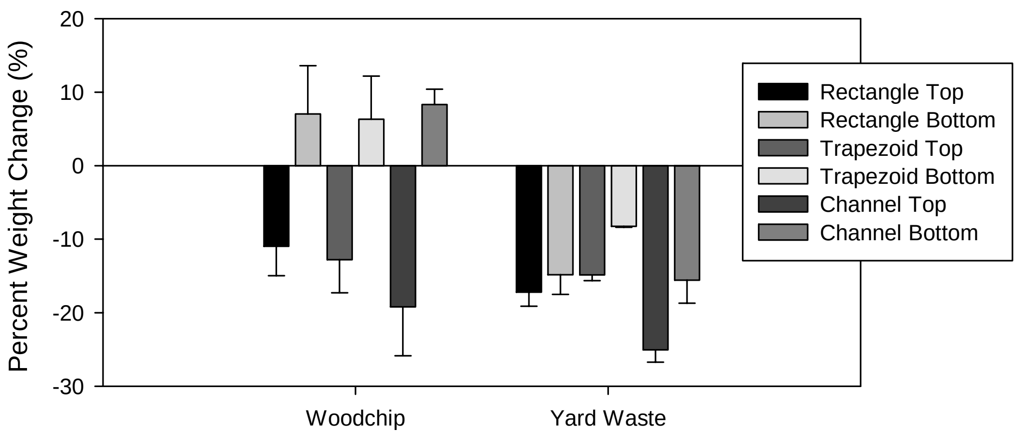

Figure 6. Weight change in buried media bags containing woodchips (Year 1) or yard waste (Year 2) after one summer of pilot bioreactor operation.

Conclusions

Though these results were complicated by non-ideal field conditions, yard waste as bioreactor fill may not be ideal. This yard waste supported NO_3^- removal, but given its weight loss, sustainability of this NO_3^- removal may be questionable. Importantly, for purposes of design standards, fill materials must be consistent with properties that can be anticipated. Non-uniformity of yard waste between suppliers and even within a given supplier over a year (storm debris depending) means this material would be potentially be too heterogeneous to accurately design a denitrification bioreactor for agricultural drainage.

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