

Paired Woodchip Bioreactors and P-Filters for Combined Nutrient Removal from Agricultural Effluents

Christine Lepine¹, Laura Christianson², Philip Sibrell³, Chad Penn⁴, and Steven Summerfelt¹

¹ The Conservation Fund Freshwater Institute (Shepherdstown, WV); ² University of Illinois (Urbana-Champaign, IL);

³ USGS Leetown Science Center (Kearneysville, WV); ⁴ Oklahoma State University (Stillwater, OK)

Introduction

Nitrogen (N) and phosphorus (P) are both agriculturally-based non-point source pollutants causing increasing concerns at multiple scales. Significant negative water quality impacts have been documented from nutrient contamination often associated with fertilizer use and waste.



Photo Credit: Iowa Soybean Association

Fig. 1: Woodchip denitrification bioreactors are an increasingly common "in-field" N-mitigation technique.

Denitrification bioreactors (Fig. 1) use a carbon source (i.e., woodchips) in an artificially engineered anoxic environment to encourage naturally occurring bacteria to convert nitrate-nitrogen (NO₃-N) into atmospheric di-nitrogen gas.

Recent studies have also demonstrated P removal with phosphorus sorbing materials such as acid mine drainage residuals (AMDr) or steel slag (SS) in flow through settings. Dissolved reactive phosphorus (DRP) is chemically transformed by adsorption and/or precipitation, effectively reducing the amount of available P in solution.

Enhanced bioreactor design can potentially pair existing denitrification technology with experimental P-sorbing filters, capturing these concomitant nutrients in tandem.

Objective

Evaluate removal efficiency of two P removing media, acid mine drainage treatment residuals (AMDr) and steel slag (SS), when placed upstream or downstream of N removing woodchips to refine paired nutrient removal designs (Fig. 2).



Fig. 2: Flow configurations of N (woodchips-WC) & P (acid mine drainage-AMDr; steel slag-SS) removal pairings.

Materials and Methods

A bench-scale experiment (Fig. 3) consisting of upflow denitrification woodchip columns (n=10, 15.2 x 60.9 cm PVC) paired with P-filters (AMDr, n=6, 2.7 x 51.6 cm; SS, n=4, 2.7 x 78.1 cm) was constructed at The Conservation Fund's Freshwater Institute in May 2015.

N removal: woodchips, hardwood blend set to achieve a hydraulic retention time (HRT) of 6-9 h (fines <1 cm removed; Fig. 4).

P removal: p-filters placed either up or downstream of woodchips, bed depth scaled for ~ 7 min. HRT; all upflow.

- **AMDr (iron based):** treatment residuals of acid mine drainage (0.6-4.0 mm; Fig. 4).
- **SS (calcium based):** industrial waste from steel production (0.2-0.6 mm; Fig. 4).

Nutrient Source: Aquaculture production wastewater dosed with NaNO₃ and KH₂PO₄.

Three Phases: observed over 148 days.

- **Phase I*** fresh AMDr and SS.
- **Phases II & III*** rejuvenated AMDr (i.e., P was harvested using 0.5 M NaOH) and fresh SS.

* Woodchips remained in columns throughout all phases.



Fig. 3: Woodchip columns (white PVC) paired with P-sorbing filters (clear PVC).



Fig. 4: (from left, same scale) N removing woodchips and P removing AMDr and SS.

Results

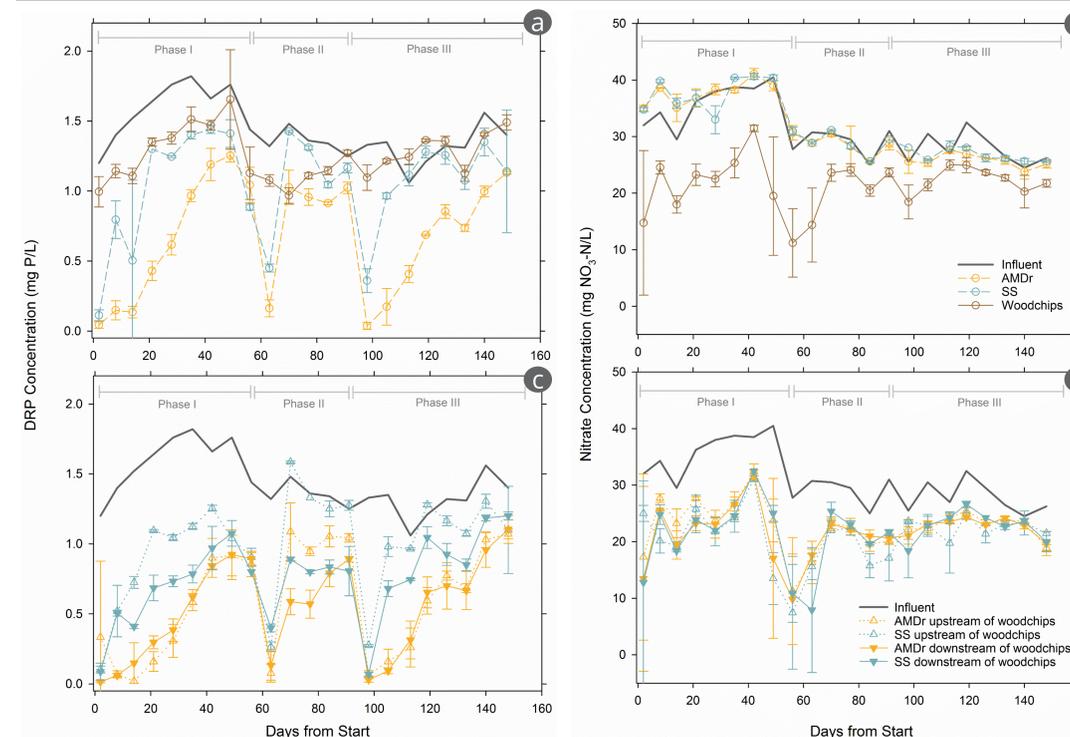


Fig. 5: DRP and NO₃-N influent/effluent concentrations for individual (a & b, respectively) and denitrification/P-sorbing paired (c & d, respectively) columns over three phases.

Results

Sampling points between and after denitrification and P-sorbing columns allowed for analysis of individual media (Fig. 5, a & b) or paired nutrient-removal column's (Fig. 5, c & d) concentrations of DRP and NO₃-N, seen across three phases.

Overall AMDr outperformed the SS in DRP removal; precipitate buildup caused poor conductivity in SS. Reduced DRP concentrations occurred downstream of woodchips (Fig. 5, c), particularly in SS. Placement of P-sorbing media had no notable effect on nitrate removal (Fig. 5, d).

Differences in removal efficiencies (Table 1) between Phase I & Phase III were observed. AMDr saw reduced P-sorbing capacity with each rejuvenation, though fresh SS also saw an unexplained P-sorbing reduction. Nitrate removal efficiency decreased over time (lower seasonal temperatures, data not shown) with removal rates ranging 1.23-52.43 g N m⁻³ d⁻¹ (average 23.53 g N m⁻³ d⁻¹, n=105).

Table 1: Average discrete removal efficiencies (%) of NO₃-N & DRP from single or paired nutrient removal.

Removal Efficiency (%)	DRP		Nitrate	
	Phase I	Phase III	Phase I	Phase III
AMDr only	61 ± 2	53 ± 3	-6 ± 2	7 ± 2
SS only	38 ± 12	18 ± 10	-6 ± 2	3 ± 1
Woodchip only	18 ± 7	2 ± 3	40 ± 13	20 ± 5
AMDr upstream	71 ± 14	57 ± 4	33 ± 16	17 ± 2
SS upstream	47 ± 4	22 ± 7	41 ± 11	18 ± 6
AMDr downstream	72 ± 4	58 ± 4	40 ± 18	18 ± 3
SS downstream	59 ± 3	36 ± 2	39 ± 18	18 ± 6

Phase I (56 d, sample events = 9); Phase III (54 d, sample events = 8).
AMDr (n=3); SS (n=2); Woodchips (n=5).

Conclusions

- Placement of P-filters, either upstream or downstream, had no notable effect on nitrate removal within woodchip columns.
- *In-situ* rejuvenation (P-harvesting) of P-sorbing AMDr did not affect nitrate removal capabilities of the woodchips. The ability to harvest P from AMDr gives it an advantage over other P-sorbing materials.
- Acid mine drainage residuals (AMDr) had greater P-removal efficiency than steel slag (SS), but volume-based removal rates still need to be calculated.
- Optimal conditions for maximum P-removal may differ between P-sorbing materials. Current SS fraction size may be too small to allow for optimal conductivity.
- Future research includes prolonging hydraulic retention times to increase nitrate removal.

