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Department of Food, Agricultural and Biological Engineering

Ditch-style Filters for Mitigating Dissolved Phosphorus Losses

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INTRODUCTION

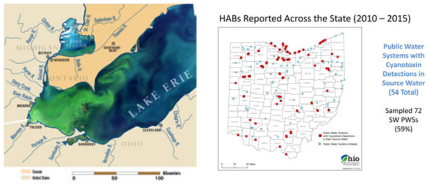
Eutrophication of water bodies due to excessive nutrient enrichment is a major concern at local, regional and national levels. The transport of excess nitrogen and phosphorus species from a variety of sources to the receiving water bodies promotes growth of harmful algal blooms (HABs), some of which may release toxic substances making the water unsuitable for use. For example, it has been established that spring dissolved reactive Phosphorus (DRP) loads drive the extent of HABs in the Western Lake Erie Basin (Wilson et al. 2019). The Maumee River, a major tributary to the Western Lake Erie, has over 70% of its catchment under agricultural land use. It is estimated that about 88% of P loads come from non-point (agricultural) sources in the Maumee River (Ohio Environmental Protection Agency, 2016, 2018).

Many practices intended for mitigating P losses are intended to reduce particulate P transport and are usually not effective in controlling DRP transport (Penn and Bowen, 2018). Phosphorus removal structures or P-filters are primarily intended to trap and filter the “legacy” DRP in runoff and drainage water. A trench filter or ditch-style filter P removal structure is designed such that a layer of P sorption material (PSM) is placed at the bottom of a ditch with some freeboard to allow for excess water conveyance. Trench filters or ditch style filters are desirable due to a narrower footprint, and the dual utility in terms of P removal as well as a water conveyance. Although, the ditch-style P filter shows promise, limited work has been done to evaluate the design and performance of such systems.

AIM

The objectives of this study were to (1) evaluate performance of a ditch P removal structure for treating subsurface drainage water; (2) compare field performance to expected performance based on laboratory flow-through experiments; and (3) assess the design considerations and economics of P removal.

Issue of concern



Examples of issues associated with excess nutrient runoff causing HABs in receiving water bodies.
Left: Extensive HAB caused in Western Lake Erie in 2011
Right: Water bodies reporting HABs issues across the state of Ohio

METHODS

Study site

Study site was a privately-owned farm field located in Northwest Ohio near Fort Recovery in Mercer County. A trench P filter was installed at the outlet of a 4.5 ha farm field and received subsurface (tile) drainage discharge at the inlet. The dominant soil is somewhat poorly drained Blount silt loam (Fine, illitic, mesic Aeric Epiaqualfs). During the study period, the field was planted with soybean in May 2016, followed by a post-harvest fall tillage operation, and then planted with Alfalfa and Oats in April 2017 and remained in Alfalfa until Spring 2019. The soil test P concentrations (Mehlich 3P) in 2017 ranged from 430 μg g-1 near surface (0-5 cm) to 340 μg g^{-1} at 15-30 cm depth.

Data collection and laboratory analysis

The outlet of the trench filter was a 30 cm diameter PVC pipe fitted with a compound weir insert (Thel-Mar, LLC; Brevard, NC), Isco 4230 Bubbler Flow Meter (Teledyne Isco, Lincoln, Nebraska) and an area velocity sensor (Isco 2150, Teledyne Isco; Lincoln, NE) for discharge measurement. The discharge at each outlet was measured continuously at 10 min intervals using the compound weir and the area velocity sensor. All water samples were handled according to USEPA method 353.3 for N analysis and USEPA method 365.1 for P analysis (USEPA 1983).

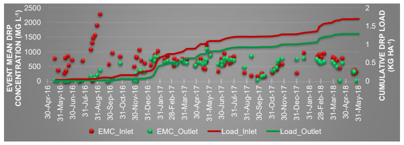
Slag samples were collected at three different times, viz. slag material that was used for designing the P-filter, material that was used for actual installation of P-filter, and representative samples of material collected from the P-filter at the end of the study period. Flow-through experiments in laboratory involved subjecting these samples to 1 mg L^{-1} inflow DRP concentration at two different retention times (a) 17s and (b) 10 min.

Photo/Table description

Layout and photo of installed ditch-style P-filter

RESULTS

DRP concentrations and loads



The mean DRP concentrations at the inlet were 697 ppb (σ = 354 ppb), and those at the outlet were 472 ppb (σ = 275 ppb) suggesting a 32% reduction in concentration (paired t-test, α = 0.05). However, the difference in concentration was the greatest (up to 100%) during the initial period, suggesting greater DRP removal in the beginning, and gradual decrease in the removal efficiency of the P-filter.

The cumulative loads of DRP during the study period were 1.7 kg ha^{-1} (mean = 19.5 g ha^{-1}, σ = 28 g ha^{-1}) at the inlet, and 1.3 kg ha^{-1} (mean = 14.8 g ha^{-1}, σ = 24 g ha^{-1}) at the outlet. Over the 87 events, the P filter removed a total of 1.85 kg out of 7.6 kg of DRP observed at the inlet, suggesting a load reduction of 24%.

Discrete and Cumulative P removal

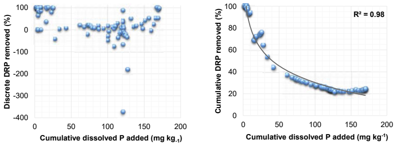
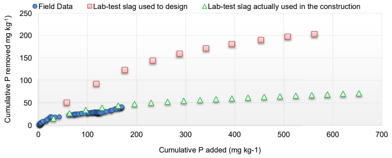


Figure shows the in-field performance of the slag filter for DRP and TP removal using discrete and cumulative P removal flow-through curves. The discrete removal of DRP ranged from -374 to 100% and TP ranged from -290 to 100%. The DRP as well as TP removal was 100% or close to 100% during the initial few events, and up to a cumulative P addition of 25 mg kg^{-1} of slag. Beyond the 25 mg kg^{-1} slag threshold, the discrete P removal rates fell drastically. Some events were associated with negative rates, suggesting greater loads of P in outflow than contributed by inflow.

Even during the later part of the monitoring period, the discrete removal was observed to be up to 100% for some events. This variation in removal rates possibly suggests that the steel slag was still effective in removing the DRP and TP during the events with longer retention time and allowing for matrix flow than preferential flow. The drop in removal efficiency was more rapid for DRP than for TP. The greater removal rates for TP may be attributed to the sediment retention by the slag filter, discussed in detail in subsequent section.

The slag filter was designed to ensure a DRP removal of up to 200 mg kg^{-1} of slag for a cumulative inflow loading of 600 mg kg^{-1} slag (Figure 4). Based on the removal rate curves developed in the laboratory, the expected DRP removal rates for a cumulative loading of 170 mg kg^{-1} slag is 70% or 120 mg kg^{-1} slag. However, the field measured data suggested that the actual removal rate for DRP was only 24% or 41 mg kg^{-1} slag. Laboratory analysis further confirmed that the PSM used for construction had much lower removal capacity than the material used for designing the structure (Figure 4).

Performance of P sorption material in lab vs in field



	Inflow	Outflow	% Reduction
Discharge (m^3)	113 ± 15	102 ± 15	9.7%
DRP Concentration (μg L^{-1})	697 ± 39	472 ± 31	32.3%
DRP Load (g ha^{-1})	19.5 ± 3	14.8 ± 2.5	24.1%

CONCLUSIONS

P-removal structures are effective in removing P at field scales. The P removal structure in this study helped remove 24% of DRP from drainage water. However, several factors play a role in the efficacy and feasibility of P-filters.

Ditch filters may provide advantage over other designs: Trench filters or ditch style filters are desirable for treating surface and subsurface drainage waters from agricultural landscapes due to a narrower footprint, compared to their counterparts. Furthermore, they provide dual utility in terms of P removal as well as a water conveyance. However, in cases where an existing ditch is used for P-removal, the loss of conveyance capacity due to filling of PSM may need to be considered. Compared to structures that may require placing PSMs in a tank, the ditch-style filters tend to be cheaper since the need for a tank and its installation are eliminated. Thus, the ditch-style filters have some obvious advantages over other P-removal structures for edge-of-field applications.

PSM selection and treatment is key: Selection of a suitable PSM, treatment, and mixing media are crucial to the success of P removal structures. This includes selection of the right type of material as well as material size. For example, in the current study, the presence of fine particles aggravated the clogging issue. Furthermore, the suitability of PSM for the composition of water being treated may be important. For example, water with high concentrations of biocarbonate????

Design considerations: Ditch filters need check dams at short length intervals that would slow down the water, increase the retention time, and more importantly, increase the depth of water, thereby utilizing greater slag matrix. This will especially benefit during high-flow events. However, the check dams should have a slow-release aperture at the bottom that would avoid ponding behind the dam during low or no-flow conditions.

Importance of bank stabilization: As demonstrated in the current study, it is very important to control the influx of sediment, especially from bank erosion. The sediment contributes to clogging as well as reduction of treatment capacity of the P filter. Additionally, if the sediment source is high in P concentration, it further reduces the treatment capacity.

Cover/protect from contamination like sediment and poultry dust: Even if measures like bank stabilization helped minimize the risk of sediment influx, other P-rich sources/contaminants in the surroundings may negatively affect the efficacy and longevity of the structure. Therefore, protecting such contamination by providing cover or other stacked practices measures may be crucial.

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