In situ treatment of phosphorus in agricultural runoff with a novel green engineered removal structure

UNIVERSITY of WISCONSIN
UWMILWAUKEE

Kiana Modaresahmadi, Kevin Hicks, Louis Chapman, Marcia Silva*
Water Technology Accelerator, Global Water Center
*Corresponding author: msilva@uwm.edu

ABSTRACT

Phosphorus (P) pollution has become a challenging global issue in recent decades, imposing negative effects on aquatic environments. While P is an essential element for life on earth, large amounts of P runoff from agricultural sites cause a huge dilemma in lakes and rivers. These high levels of P being pumped into the bodies of water often induces eutrophication as a result. While advances in water retention in urban areas using green infrastructure and land tillage have improved, the aspects nutrient capture and recycling have not advanced at the same rate. We report a pilot runoff treatment system using a functionalized natural porous material with metal oxides to capture P that can be regenerated and has a high capacity. This material can be recycled, and resultant P effluent can be recovered as a slow release fertilizer. In order to evaluate the performance of this engineered natural porous material, the quality of treated and untreated runoff was examined. The results revealed that the efficiency removal reached a peak of 55 % for soluble reactive phosphorus (SRP) and 97% total phosphorus (TP), while also aiding in the removal of other nutrient (reaching a peak of 60% for ammonia) and solids (peak of 37% for total dissolved solids (TDS) and 54% for total suspended solids (TSS)). While the results showed that the pilot plant has great potential for in situ removal of P, it was challenged by design parameters that will be improved moving forward.

INTRODUCTION

Phosphorus (P) is an essential nutrient with a limited resource, which cannot be replaced by any other element.[1] The main source of P pollution in inland and coastal water is farming operations require nutrient fertilizers to maintain consistent production levels [2] [3]. It is estimated that about 80% of mined P ends up in fertilizers and manure in agricultural fields which cause an excessive amount of P in soil. In the long-term, soil gets accumulated by excess amount of P and then being seeped into waterbodies and cause eutrophication [2] [4]. Around 36% of the lakes are eutrophics, and total economic cost of eutrophication mitigation in the U.S. is estimated around $2.2 billion. [5] There are different methods like biological and precipitation, and various adsorbents that have been studied to remove P from water, but the unsteady condition and large amount of disposal impact their efficiency. New technique needs to be designed to provide an efficient and cost-effective way to remove nutrient from water body. A team at UWM WaTA Technology Accelerator developed and deployed a novel green engineered removal structure to treat agricultural runoff from subsurface drainage system in a farm.

The objectives of this study are to:
(1) Fabrication of engineered filter material to adsorb phosphorus from runoff in lab scale.
(2) Scaling up the fabrication from lab scale to pilot scale.
(3) Deployment of engineered filter material to Port Washington and verify its performance for one month.
(4) Protect environment and save the non- renewable P resource.
(5) Helping agricultural industry to not loss its profit.

METHODOLOGY

Several tests were performed to evaluate the structure, morphology, and quality of engineered filter material including SEM, FTIR and adsorption capacity. After that, engineered removal structure with a designed collection network system (box and cage design were by Kieser & Associates, LLC under the GLPF grant and associated) and rain gage was deployed, installed, and operated in Port Washington, WI in late October 2019 for seven weeks. In the first two weeks two samples were collected by thirty minutes intervals and then it increased to six samples in last two weeks. To evaluate the efficiency of engineered removal structure, all collected samples were transferred to the UWM lab for further experiments to characterize the agricultural runoff before and after treatment. These experiments was including: (a) soluble reactive phosphorous (SRP) with standard method number of USEPA 365.3 to determine the average load of phosphorus in runoff, (b) total phosphorus (TP) was performed following method USEPA 363.3, (c) ammonia was determined based on the Presley (Modified Strickland and Parsons method (USEPA 350.1) , (d) pH performed by pH meter (handheld Oakton PCTS 50 pH meter), (e) conductivity by conductivity meter (handheld Oakton PCTS 50), (f) turbidity by turbidity meter (LaMotte 2020we turbidity meter), (g) dissolved oxygen with Oakton Instruments Portable Meter, (h)Oxidation-Reduction Potential by Oakton ORP Tester BNC handheld, (i)Total dissolved solids (TDS) and (j) total suspended solids (TSS) by following methods USEPA160.1 and USEPA 160.2, respectively. Moreover, batch experiment was performed to measure the changes in adsorption capacity after deployment to the farm. from top, middle and bottom of the filter bags and was added to three different concentrations (50 mg/l) P solution for 24 hours at 180 rpm in room temperature.

RESULTS AND DISCUSSION

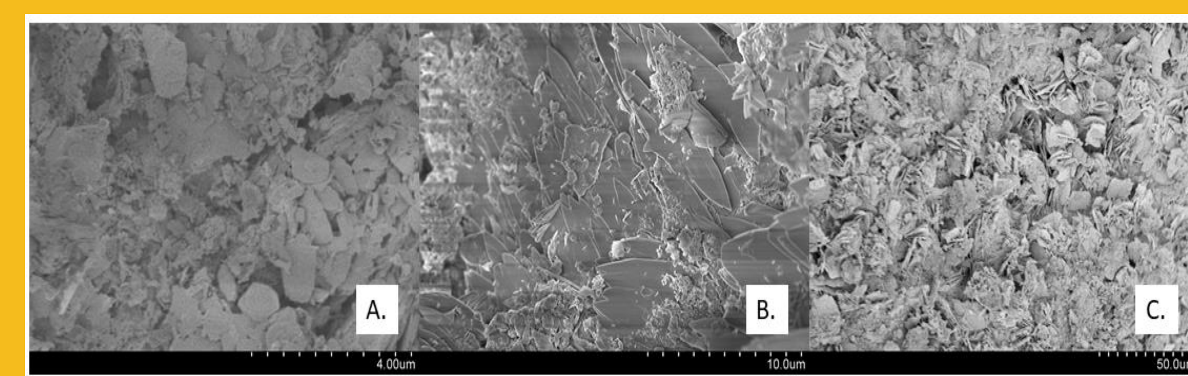

Figure 1: Surface morphology of the engineered filter material in pilot scale using SEM of (A) at 400 ×, (B) 1000 × magnifications, and (C) 5000 × magnifications.

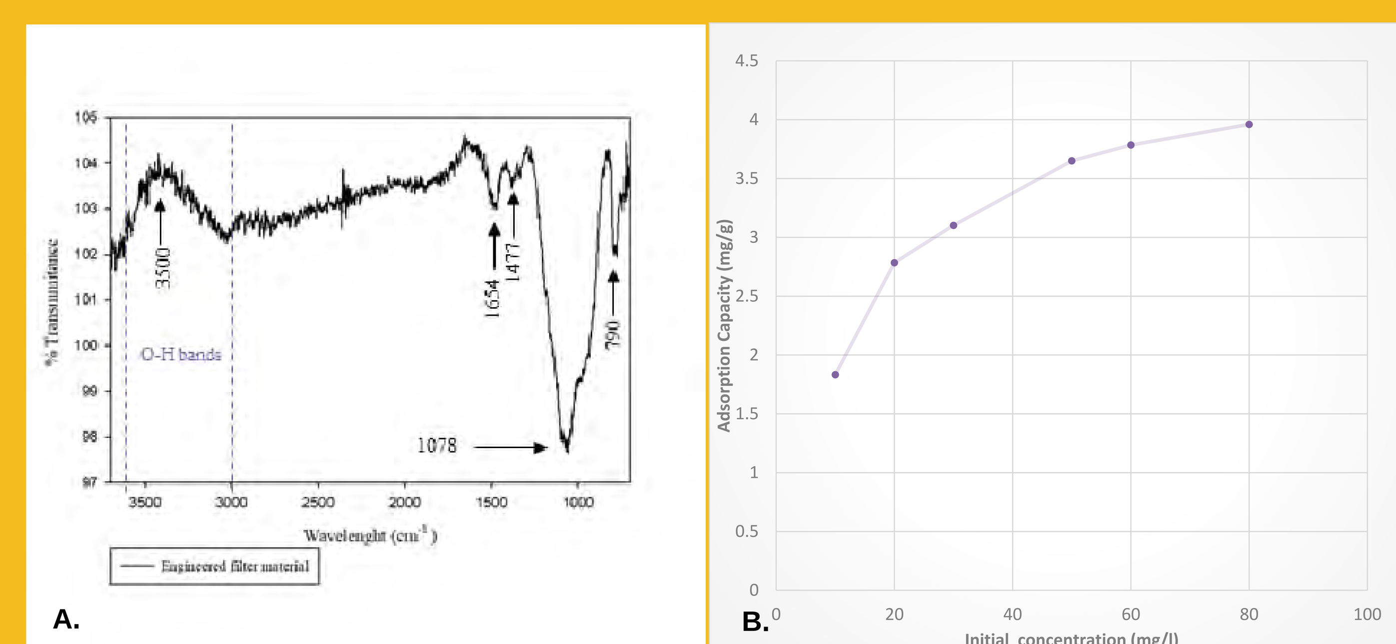

Figure 2: A. FTIR spectra of engineered filter material between 700 $cm^{-1}$and 3700 cm^{-1}. B. Adsorption Capacity of engineered filter material

Table 1: Inflow agricultural runoff before treatment.

Tests	Actual Concentration of inflow Total P (mg/L)	Actual Concentration of inflow SRP (mg/L)	pH inflow	Dissolved Oxygen inflow (mg/L)	Conductivity inflow (µs/cm)	Turbidity inflow (NTU)	Temperture inflow (°C)	TDS inflow (mg/L)	TSS inflow (mg/L)
Maximum	1.409	0.06	8.24	9.14	1812	5.42	12	1136	32
Minmum	0.026	0.005	7.72	2.05	1016	-38	6	634	-24
Range	1.384	0.055	0.52	7.09	796	43.42	6	502	56
Standard deviation	0.402	0.011	0.097	1.744	208.935	16.462	1.456	154.215	11.516

Table 2: Outflow Agricultural Runoff after treatment.

Tests	Actual Concentration outflow (Total P (mg/L))	Actual Concentration of outflow SRP (mg/L)	pH outflow	Dissolved Oxygen outflow (mg/L)	Conductivity outflow (µs/cm)	Turbidity outflow (NTU)	Temperature outflow (°C)	TDS outflow (mg/L)	TSS outflow (mg/L)
Maximum	2	0.039	8.32	11.46	1193	644	12	1150	56
Minmum	0.032	0.004	7.9	3.23	1038	-38	6	670	-10
Range	1.968	0.035	0.42	8.23	155	682	6	480	66
Standard deviation	0.666	0.007	0.096	1.98	37.35	166.557	1.456	149.619	14.423

Table 3: Comparison between adsorption capacity of engineered filter material before and after deployment to the farm.

Filter bag number	Sample ID	Adsorption Capacity (After deployment) mg/g	Adsorption Capacity (Before deployment) mg/g
First close to inflow pipe	Top	3.2	3.3
	Middle	2.9	
	Bottom	3.8	
Second close to inflow pipe	Top	5.3	3.3
	Middle	3.9	
	Bottom	5.1	
Third close to inflow pipe	Top	2.8	1.9
	Middle	2.7	
	Bottom	2.7	

Results: (Cont.)

Preliminary results:

- Average equilibrium adsorption capacity of filter material ranged from 3.5 to 4 mg/g.
- Engineered removal structure removed a peak of 55 % (0.060 mg/l SRP load decreased to 0.027 mg/l) in runoff and 97% of TP (1.409 mg/l decreased to 0.045 mg/l).
- Engineered filter material adsorption for other nutrient like ammonia was a peak of 60% (0.136 mg/l decreased to 0.054 mg/l) and solids peak of 37% (1136 mg/l decreased to 712 mg/l) for TDS and 54% (26 to 12 mg/l) for TSS.
- Results indicates inconsistency in performance of engineered removal structure in second and fifth week of sampling.
- Adsorption capacity of the used filter material showed that the filters were not saturated, and in fact, maintained high adsorption capacity.
- SEM figures shows an orderly and even Si–O structure with few impurities was for porous adsorbent and well dispersed white materials were possessed because of metal oxide were produced after fabrication and calcination.
- The characteristic of band range between 2900 and 3750 cm^{-1} is related to interlayer adsorbed water (moisture/OH group). A peak around 3500 cm^{-1} is specifically attributed to moisture/OH group in the adsorbent, and another peak at band rang ~1078 cm^{-1} is corresponding to SiO_2 stretching. The ~796 band is assigned to the stretching vibration modes of SiO_2 and AlO_2 .

CONCLUSION

- This engineered filter material is more accessible and cheaper to produce and higher adsorption efficiency percentage.
- More importantly phosphorous can be desorbed from the filtration materials so that the nutrient can be collected and returned to the farmers.
- Additionally, the filter adsorption's capacity will then be restored so that it can be reinstalled at the site of runoff, creating a sustainable method of phosphorous removal and recovery allowing farmers to effectively reduce water pollution without experiencing considerable loss of profit.
- Result showed that the pilot plant has great potential for in situ removal of P, however design parameters will be improved for future study.

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