Reduction of Phosphorus in Dairy Effluent with a Constructed Wetland-Steel Slag Filter System

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ABSTRACT

Aquatic ecosystems can be disturbed by pollutant sources such as untreated urban and agricultural runoff. In Vermont, runoff from dairy farms containing phosphorus (P) can be transported to surface waters where increased biological productivity can result in blue-green algae proliferation and eutrophication. Excess algae and eutrophication can cause depleted oxygen levels, high turbidity, reduced aquatic species diversity, undesirable taste, and foul odor in municipal water supplies. This experiment evaluated the efficiency of a constructed wetland (CW) and steel slag filter (SSF) treatment system for removing P from dairy farm runoff. In the experiment, dairy runoff was passed through the small-scale system consisting of a CW followed by a SSF. The effluent from each unit was sampled and analyzed for pH and dissolved reactive P (DRP). Results showed that DRP levels were drastically reduced by both treatment units; however, the SSF showed higher DRP removal efficiencies (97 to 98%) than the CW (-32 to 89%). The high DRP treatment efficiency achieved by the SSF (97 to 98%) shows the potential of this technology for removing P from dairy farm runoff or concentrated effluents.

KEYWORDS: steel slag (filter), dissolved reactive phosphorus levels, phosphorus removal, constructed wetland, water treatment system.

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1. INTRODUCTION

In 1669, Hennig Brandt, an alchemist from Hamburg, Germany, discovered a white material that glowed in the dark and burned brilliantly after evaporating urine to distill salts [1]. Brandt had produced phosphorus (P) (Greek for “light-bearer”).

In Vermont, runoff and other effluents from dairy farm operations (barnyard runoff, feed bunk runoff, dairy parlor wastewater, etc.) contain large amounts of P. Although P is an essential element for plant and animal growth, P introduction to surface waters can increase the biological productivity leading to blue-green algae proliferation and eutrophication [2, 3]. Excess algae and eutrophication can cause low water oxygen levels, high turbidity, reduced aquatic species diversity, undesirable taste, and foul odor in municipal water supplies (e.g. Lake Champlain [3]).

Without access to a municipal collection and treatment system, the treatment of dairy farm runoff and effluents is challenging. Constructed wetlands (CW) are a relatively simple technology developed to treat wastewater generated in rural areas. Although CWs can effectively reduce many pollutants in wastewaters, the ability of these systems to effectively remove P is still debated.

In an effort to find better ways of reducing P from wastewaters and untreated runoff, much research has been carried out to find materials capable of P adsorption. One type of material with P adsorption properties is steel slag, a byproduct of the steel industry. The type of steel slag depends on the manufacturing process used in the steel mills (blast furnace, electric arc furnace (EAF), iron melter, etc.). Of these slag materials, EAF steel slag has shown the greatest P adsorption capacity.

2. MATERIALS AND METHODS

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Diagram 1. Experimental Setup.

The system had four components: the inlet tank containing 1:10 diluted dairy effluent, the CW, the SSF, and the wastewater effluent tank. The plumbing tubing was connected as seen in Diagram 1.“T” adapters were installed in the tubing after the inlet tank, CW, and SSF to create 3 sample ports. The CW bin was filled with 1.64 kg of drainage rocks and two species of wetland plants (*Acorus* alternifolius 'Wild Spike' and *Cyperus* americanus 'Calamus') were transplanted from pots in the UVM greenhouse into the gravel within the CW bin. The SS system filter bin was filled with 1.93 kg EAF steel slag. The pore volume of each bin was approximately 4.3 L.

A peristaltic pump was set on a simple plug in, ”click” timer to run for one hour each day, passing an average of 2 L/day of the dairy effluent through the treatment system. Therefore, the average retention time of the water in each component (CW, SS) was two days and the total system retention time was 4.3 days.

Materials

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Influent Wastewater: Mixed barnyard runoff and dairy effluent obtained from the University of Vermont, Paul Miller Dairy Farm, diluted 1:10 in tap water

Filter System Materials:

- Plastic Bin Containers
- Vinyl Tubing (Clear),
- Masterflex Peristeltic Pump connected to standard 'plug-in' click timer
- Gravel Rocks (diameter: 20-50 mm)
- EAF Steel Slag (diameter: 5-10 mm)
- Tube Clamps
- 2 *Cyperus alternifolius* ('Wild Spike')
- 1 *Acorus americanus* ('Calamus')

Sampling Materials:

- Syringe Filters: WHATMAN (0.45 µm NYL w/GMF)
- Lock Tip Syringes: WHATMAN, 5ll plastic
- 50ml plastic sample storage tubes

Methods

About 50 mL sample was collected from each of the three sample ports (inlet water, CW outlet and SSF outlet) immediately prior to the pump ‘on’ cycle. The pH of each sample was immediately measured using a laboratory pH meter (Fisher Scientific, Accumet AP71). The samples were then filtered into sterilized 50mL tubes using syringes and 0.45 µm syringe filters to separate the dissolved reactive phosphorus (DRP) from the total P present within the samples. The 50 mL tubes were stored in the refrigerator at 4°C before DRP analysis. DRP analysis was performed within 24 hours of sampling.

DRP concentrations were determined by my mentor Eamon Twohig using the molybdate - reactive P method [5].

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3. RESULTS

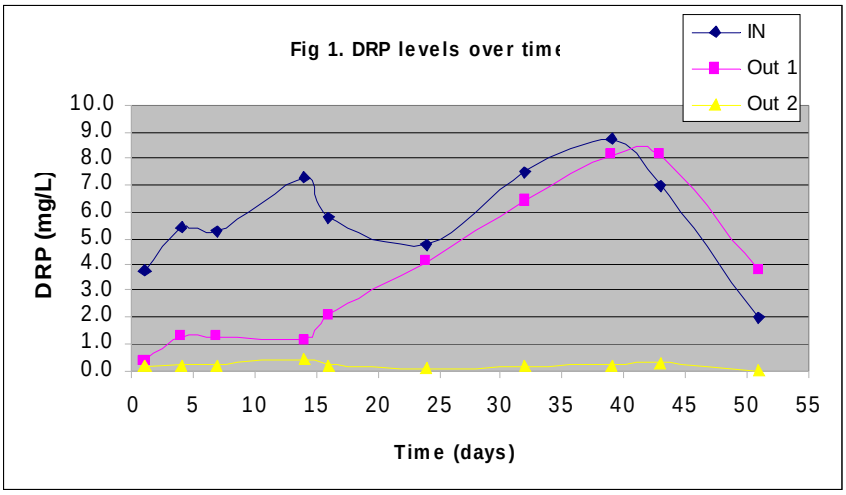
Fig 1. DRP levels over time
IN
Out 1
Out 2
DRP (mg/L)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
5
10
15
20
25
30
35
40
45
50
55
Time (days)

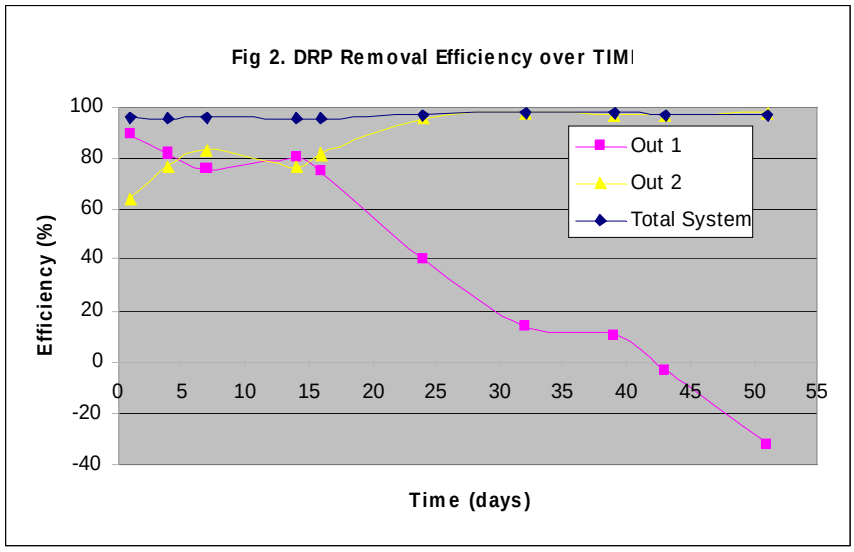
Fig 2. DRP Removal Efficiency over TIME
Out 1
Out 2
Total System
Efficiency (%)
100
80
60
40
20
0
-20
-40
0
5
10
15
20
25
30
35
40
45
50
55
Time (days)

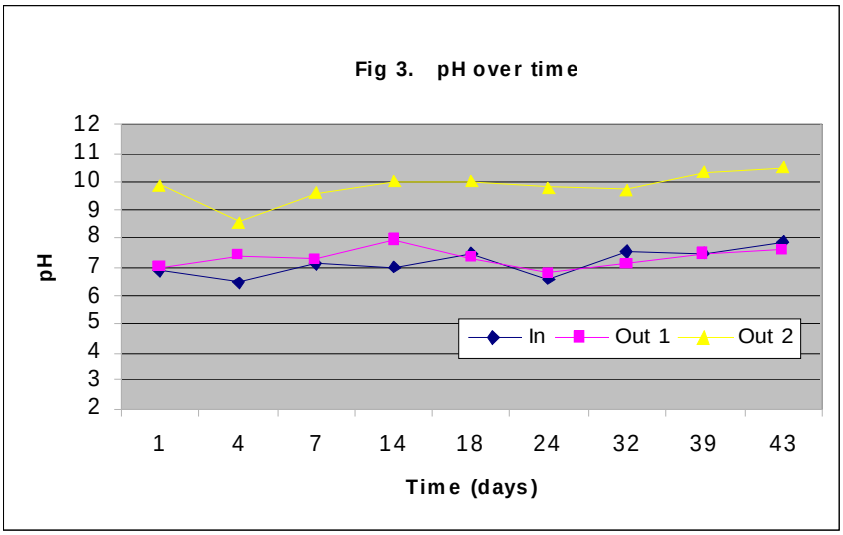
Fig 3. pH over time
pH
12
11
10
9
8
7
6
5
4
3
2
In
Out 1
Out 2
1
4
7
14
18
24
32
39
43
Time (days)

DRP concentrations of the inlet water (1:10 diluted dairy effluent) fed to the treatment system averaged 5.73 mg/L but ranged from approximately 2 to 9 mg/L over the 51 days of the experiment (Figure 1). DRP levels averaged 3.69 mg/L in the CW outlet and 0.20 mg/L in the SSF outlet. The DRP removal efficiencies averaged 43% for the CW and 87% for the SSF (Figure 2). The total treatment system achieved an average DRP removal efficiency of 96%. The pH of the inlet water averaged 7.2, (range 6.5-7.9; Figure 3). The average pH at the CW outlet was 7.4 (range 6.8- 7.9). The average pH at the SSF outlet was 9.8 (range 8.6-10.5).

4. DISCUSSION

On average the DRP levels were reduced significantly by both the CW and the SSF system components but the SSF system showed much higher DRP removal efficiencies than the CW system (Figure 2). The CW P treatment efficiency decreased over a 51-day span of the experiment from removing 89% to adding 33%. This represents an average performance deterioration of 1.2/day. The SSF DRP removal efficiency, on the other hand, improved from 64% to 98% and was > 95% for the last 30 days of the experiment.

The different P removal efficiency of the CW and SSF systems can be explained by the fact that the CW system filtered out P-containing solids and organic materials so that P removal is limited to filtration by the substrate (gravel and plant roots); on the other hand the SSF additionally retained P by chemical adsorption to the slag particles.

Even though the P removal efficiency of the CW system deteriorated over time, the total system efficiency was maintained at a consistently high level by the SSF. The total system P removal efficiency averaged 96% (range 95% to 98%).

The average influent pH (7.2) increased slightly after the CW treatment (average 7.4) but significantly (average 9.8) after SSF treatment. The DRP removal efficiency seemed to be strongly correlated with the effluent pH of the various processes P removal increasing with pH in the pH range from 7.2 to 9.8. Because the acceptable pH for wastewater effluent is typically pH 6.5 to 8.5 [4], the effluent from an SSF unit would require pH adjustments prior to discharge.

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The following factors that may have affected the results of these experiments:

- The plants obtained from the UVM greenhouse did not appear to be in the best condition. They were used because they were the only ones available at the time. When plants in constructed wetlands undergo senescence they release P taken during its growth[5].
- The laboratory experiments were highly controlled compared to what may be experienced under field conditions.

On the other hand, the dairy effluent used for the experiment was produced from an actual dairy farm operation and had varying P concentrations which could have had a negative impact on the CW treatment performance [6]. The SSF treatment efficiency appeared unaffected by this varying P concentration, further demonstrating the versatility and robustness of this system in treating dairy farm effluent.

The results of this experiment are significant because they provide an alternative method of removing P from wastewater without using chemical treatment. This method of treatment differs from others because it utilizes an industrial waste from steel factories to treat wastewater.

5. CONCLUSION

Very high DRP removal efficiency was achieved by a combined CW/SSF treatment process because of the steel slag material used in the SSF, demonstrating its potential for removing P. from dairy wastewaters.

6. ABBREVIATIONS AND ACRONYMS

CW: Constructed wetlands

DRP: Dissolved reactive phosphorus

EAF: Electric arc furnace

GMF: Glass microfiber filter

L: Liter

NYL: Nylon

P: Phosphorus

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SS: Steel slag

SSF: Steel slag filter

UVM: University of Vermont

7. ACKNOWLEDGMENTS

Credits

-Twohig , Eamon. Research Technician."Phosphorus and Steel Slag." Personal interview. 2009. University of Vermont. Project Mentor.

-Drizo , Aleksandra. Ph.D. "Phosphorus and Steel Slag." Personal interview. 2009. University of Vermont. Project Mentor.

-"The Constructed Wetland-Steel Slag Filter System" Diagram made by Michelle Yang

Author

This fall, I am going to be a junior at South Burlington High School in South Burlington, Vermont. Since moving from Texas to the extremely environmental state of Vermont, I have been continuously exposed to new ideas of helping and preserving our nature. This year, rather than just following the trend of ideas, I tried to be a trendsetter myself. I worked with the University of Vermont Department of Plant and Soil Science on my project and participated at the Vermont State Science and Math Fair 2009 (which was my first science fair). My project received Silver Medal Award from the Vermont Principal's Association, Recognition from the Sigma Xi Scientific Research Society, and 1st Place Award Winner from the Green Mountain Water Environment Association. I was also chosen to represent my state for I-SWEEEP 2009 (International Sustainability World Energy, Engineering, & Environmental Project Olympiad) that took place in Houston, Texas and received a Bronze Medal Award.

Apart from my project, I am dedicated to academics and music. In school, I have accelerated two math levels apart the rest of my class and plan to take Calculus BC this fall. I also participate in several school clubs, which include Math League and Green Team (which is our school environmental group). As a violinist, I have been a long time participant in the Vermont Youth Orchestras. From studying the violin since elementary school, I've learned to appreciate music in the non-mainstream genres. I hope

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the school I will go to in the future will enable me to continue both my passion for music and interest in water treatment sciences.

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