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Nitrate Removal in Greenhouse Water Using Mushroom Compost within Artificially Constructed Wetlands

Research Article

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Abstract

Artificially constructed wetlands have been utilized for treatment of wastewater for decades. Originally designed for treating human wastewater, such wetlands have shown promise in other wastewater applications, including plant nursery and greenhouse (glasshouse) operations. Recently, these facilities have become more concerned about how to effectively minimize adverse environmental impacts associated with wastewater runoff from their operations. One solution is to utilize artificially constructed wetlands to reduce their impact. The authors investigated this problem by evaluating nitrate removal in water within three artificially constructed wetlands containing three treatments: 1) gravel alone; 2) gravel planted with vegetation; and 3) gravel mixed with spent mushroom compost and planted with vegetation. Nitrate removal differed among the three treatments, with mushroom compost-amended substrate showing greatest removal.

Keywords: Artificial wetlands; Mushroom compost; Nitrate removal; Nursery and Greenhouse Wastewater

Introduction

Use of artificial wetlands in plant nurseries

The original use of artificially constructed wetlands was to treat human and livestock wastewater in Germany [1], with three general types of wetlands: free water surface (FWS); horizontal subsurface flow (HSSF); and vertical flow (VF). In a wetland system, plants serve multiple roles, including insulation in colder months [1], nutrient uptake [3], and acting as a carbon source for microbes [3,5]. Although original constructed wetland systems focused on human and animal wastewater, the systems also show promise for mitigating nursery and greenhouse wastewater [2-5]. Large nurseries and greenhouse industries use as much as 19,000 L/ha water [6], which may contain various water-borne chemicals such as pesticides and fertilizers in the water runoff [6]. In a study to evaluate loss of applied herbicides in a nursery, Gilliam et al. [6] reported that even with a closely spaced pot arrangement (adjacent pots touching), 30% of the applied herbicides was lost due to runoff between pots. When pot spacing was increased to 30 cm, the amount of lost herbicide almost tripled, with 80% lost due to water runoff. Regulating agencies are beginning to address such chemical-runoff from nurseries. Several states in the USA and Australia have passed laws requiring nurseries to manage water runoff [3,7,8]. Consequently, many nurseries and greenhouse operations are exploring the option of recycling their wastewater [3,7] to reduce adverse threats to outside aquatic ecosystems [2]. However, several issues arise with wastewater reuse in green industries, including the possibility that recycling nursery wastewater can lead to a build-up of harmful contaminants [9-11]. However, multiple studies have demonstrated that artificially constructed wetlands can successfully serve as a sustainable management solution for nutrients and contaminants found in nursery wastewater [2-4,7,11-14].

Use of mushroom compost

Pennsylvania (PA) is the top producer of white button mushrooms in the USA, a crop valued at over $500,000,000 [15]. White button mushrooms are grown in controlled-environment houses on a managed substrate, termed "compost," which usually consists of horse manure, straw, and other agricultural plant wastes. Mushroom farms in (PA) produce more than 900,000 m3 of waste compost/year [15]. While considered an unwanted waste byproduct to the mushroom industry, spent mushroom compost can help remove unwanted chemicals from water, even including harmful acid-mine water drainage [16].

Fertilizer runoff is a major issue impacting waterways of the world. Elevated levels of nitrogen and phosphorus accelerate eutrophication in these waters leading to a suite of issues. One adverse outcome is the development of significant algal biomass, with the resulting die-off creating large anoxic areas, issues that have historically plagued important waterways like the Chesapeake Bay in the USA [17]. Expected increases in precipitation due to climate change in some areas are predicted to further contribute to nutrient pollution, making nutrient management even more crucial [18]. Algal blooms consisting of species that produce toxins can, and have, shut down drinking water supplies for communities. A prominent example is when the city of Toledo, OH, USA was forced to issue a "Do Not Drink" order due to detecting high levels of microcystins (a toxin produced by cyanobacteria) in the water during August 2014 [19]. Nitrates are typically more mobile in soil due to their negative charge and are one of the contributing nutrients in eutrophication [20], making nitrate the target for this research.

Objectives

We utilized laboratory-scale artificially constructed HSSF wetlands, consisting of a gravel substrate planted with water-tolerant vegetation augmented with mushroom compost, to evaluate the potential to sustainably reduce nitrates in nursery runoff. If successful, this research would also suggest a sustainable, recycled use for large volumes of used mushroom compost, which can be an economic and environmental challenge for USA mushroom farms.

Construction of artificial wetlands

Treatments

In this study, artificial wetland treatments were generally as described by Gruyer et al. [5]: 1) gravel only control (G); 2) gravel planted with vegetation (P); and 3) a 60/40 v/v mixture of mushroom compost and gravel planted with vegetation (C). Each treatment was constructed in triplicate. Substrate for all three treatments was local limestone crushed to ~12-mm diameter gravel. Mushroom compost was obtained from The Pennsylvania State University Mushroom Research Center (University Park, PA). Vegetation consisted of native perennial wetland pickerelweed (*Pontederia cordata* L.) and native perennial wetland soft stem bulrush (*Schoenoplectus tabernaemontani* (Gmel) Palla.). Both plant species are tolerant to excessive water and are used locally in wetland reconstruction.

Wetland construction

Nine artificial wetland cells (three for each treatment) were constructed within a university greenhouse (40˚ 42' 44"N, 77˚ 56' 04"W). Each wetland was constructed with lumber to create an interior dimension of ~1.1 m long x 0.3 m wide x 0.4 m high (Figure 1). Waterproof polyvinylchloride (PVC) "pond-liner" was installed to contain treatment substrate and water, while water-resistant "marine plywood" was attached to the base of each wetland for additional support. One end of each wetland was elevated to produce in a 5% slope towards a water collection system at the lower end of each cell. To sample water for nitrate analysis, water collectors were installed in holes in the bottom of the pond liner within each cell. A 2-cm dia. rigid PVC pipe with drilled holes was used as a collection unit in each cell, with a "T-junction" in the middle (Figure 1). For maintenance, a PVC "union" was installed. A standpipe was used to establish water level and a PVC ball-valve installed for drainage. To facilitate sample collection, a PVC section was predrilled with a series of holes along its length and inserted vertically in the wetland. When required, a pipette was lowered into the pipe and a sample retrieved, or a probe could be inserted. A threaded cap was installed for cleaning the collection system, which consisted of a PVC pipe drilled with holes to allow for complete water exchange within each wetland. A male threaded adapter and cap were placed at the top to seal the port until needed.

Initially, the wetlands were operated under constant-flow conditions for approximately 5 months (August 2015 to January 2016), after which operation was altered to a batch-feed method. During start-up, it was determined that a consistent 7-day hydraulic residence time was not achievable with the system due to the low flow required and limitations of available equipment. Tap water was utilized as the influent source during this semi-continuous flow startup period, and again approximately 6 months into the batch-feed operations (August 2015 to June 2016). Simulated wastewater composition was finalized by the beginning of 2017, leading to the wetlands operating under steady-state conditions for approximately 1 year before experiment initiation. Simulated nursery wastewater was created by adding 85 g water-soluble fertilizer in 340 L water. The greenhouse containing the wetlands had heating capabilities, and temperature was monitored to prevent damage from freezing. Otherwise, temperature was not strictly controlled to allow the wetlands to go through seasonal variation. Greenhouse temperatures ranged between extremes of 10 and 45 °C, with typical temperatures in the 15 to 25 ˚C range.

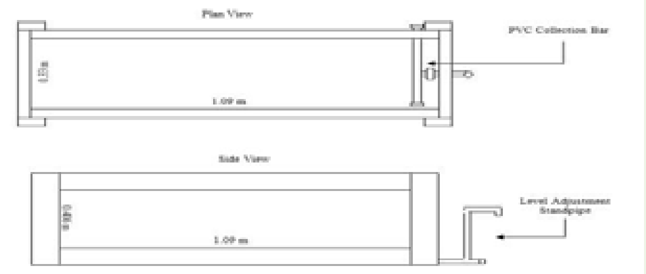

Figure 1: Wetland frames were constructed of lumber and based with marine plywood. The interior of the wetland was created by draping a flexible PVC liner inside the wooden frame. PVC pipe was utilized to make the collection system. A true union was utilized to connect the collection bar to the standpipe, to allow for maintenance as needed.

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Water chemistry measurements

The starting nitrate concentration was determined via a Vernier LabQuest (Beaverton, OR), and starting pH, temperature, oxidation/reduction potential, and conductivity were measured using a Sension meter with a MM150 probe (Hach, Loveland, CO). This same equipment was used for subsequent analyses. The wetlands were operated in the previously described batch method for the duration of these experiments with refills occurring once a week for a total of 3 weeks (labeled Week 1, Week 2, and Week 3 in Figure 2) in early 2018.

On day 7 of each week, water samples were collected during the draining process after 30 sec and analyzed for nitrate concentrations as well as pH, temperature, oxidation/reduction potential (ORP), and conductivity. Additionally, pH, temperature, ORP, and conductivity were measured on days 3 and 5 of each run using the previously mentioned PVC sampling port. These data were collected to help further elucidate any factors impacting nitrate removal. Five replicates of each analyte (nitrate, pH, temperature, ORP, and conductivity) were measured in each wetland cell.

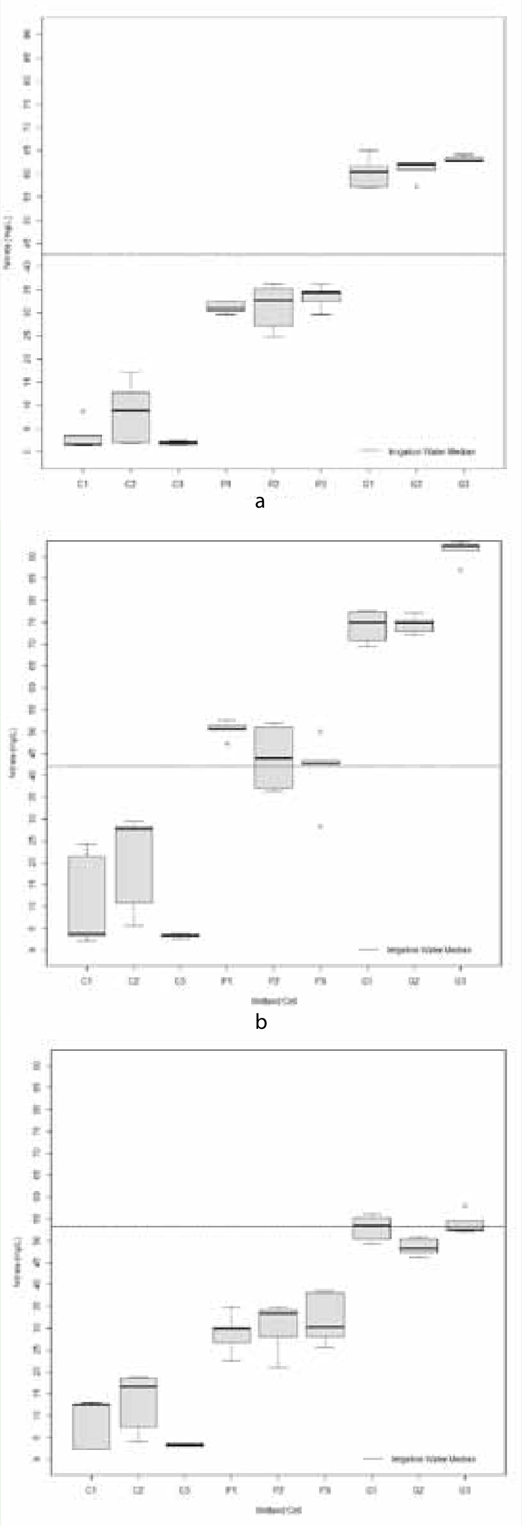
Data Analysis

All data analyses were performed using RStudio (Boston, MA). Since data were non-parametric, median and median absolute deviations were used to describe the data center and variance. Data are presented for each week by both individual wetland cell (n = 5, Figure 2a,b,c) and combined by treatment (n = 15, Table 1). Median nitrate concentration for each wetland were compared to median nitrate concentration of the starting simulated nursery wastewater to determine percent reduction (Table 1). Data were combined by treatment (n = 15 each) and compared with a non-parametric Lincon test (R Package WRS2) post-hoc test was used to determine if the treatments were statistically different from one another in nitrate concentration.

Results and Discussion

The median nitrate concentration for the simulated nursery wastewater influent was 42.6 mg/L (n = 5), 42 mg/L (n = 1), and 53.3 mg/L (n = 5) for Weeks 1, 2, and 3, respectively. A clear, and statistically significant ($p < 0.0001$ for all relationships) distinction in effluent nitrate concentration was observed between the 3 substrates (Figure 2). The compost-amended wetlands had consistently lower nitrate concentrations in the effluent compared to either the planted or gravel wetlands. The percent nitrate reduction was more than 90% for compost in all 3 replicates, which was double the greatest reduction in the other substrates (Table 1). Although the duration of active sampling in this study was relatively short, the 1-year acclimation period on synthetic nursery wastewater enabled the systems to become established prior to data collection, thereby allowing relatively consistent treatment efficiency.

The median nitrate concentration for the gravel substrate wetlands exceeded, or was slightly less than, the median of the simulated wastewater. Similar results between the gravel and simulated wastewater were expected; however, the approximately 20 mg/L increase was not expected. One possible explanation is that



a

b

c

Figure 2: Box-and-whisker plots of effluent nitrate concentration for each wetland cell in weeks 1 (a), 2 (b), and 3 (c) following a 1-year acclimation period. Cells are grouped by treatment (C = compost amended, P = planted gravel, and G = gravel). Irrigation water median represents the median nitrate concentration in the influent simulated wastewater. N = 5 for all weeks except 2. (o) = no error bar.

Table 1: Median effluent water chemistry parameters combined by treatment over the course of the experiment after a 1-year acclimation period (± median absolute deviation, n = 15).

Treatment[1]	pH	Elec. Cond. (µS/cm)	ORP (mV)	Nitrate (mg/L)	Nitrate Reduction (%)
Week 1					
Plant	6.87 ± 0.06	546 ± 5.93	251 ± 14.8	32.4 ± 3.26	23.9 ± 7.66
Gravel	7.22 ± 0.10	506 ± 28.2	218 ± 13.3	62.4 ± 1.63	-46.5 ± 3.83
Compost	6.96 ± 0.06	554 ± 25.2	230 ± 8.90	2.10 ± 1.04	95.1 ± 5.43
Week 2					
Plant	6.91 ± 0.07	420 ± 10.4	295 ± 47.4	47.2 ± 6.38	-12.4 ± 15.2
Gravel	7.24 ± 0.13	396 ± 8.90	305 ± 22.2	77.1 ± 7.41	-83.6 ± 17.6
Compost	7.18 ± 0.13	416 ± 11.9	308 ± 16.3	3.80 ± 2.67	91.0 ± 6.35
Week 3					
Plant	6.94 ± 0.09	492 ± 25.2	243 ± 34.1	30.1 ± 5.93	43.5 ± 11.1
Gravel	7.27 ± 0.18	462 ± 17.8	230 ± 21.1	52.1 ± 3.56	2.25 ± 6.68
Compost	7.14 ± 0.10	468 ± 14.8	240 ± 43.0	4.00 ± 3.56	92.5 ± 5.00

[1] Five replicate samples from each wetland cell were combined by treatment (n=15).

ammonia present in the water underwent nitrification. As nitrifying bacteria are autotrophic and can fix their own carbon, they would not be limited in the gravel substrate wetlands, and in fact, might be selected for. There is ample evidence of these types of organisms surviving in oligotrophic environments. For example, Regan et al. [21] demonstrated the presence of survival of nitrifying organisms in a pilot drinking water system. Also, the limestone gravel could lead to an elevated level of dissolved CO_2, further selecting for nitrifiers.

The compost-amended wetlands were the most efficient in nitrate removal, likely due to an increase in available carbon supplied by the used compost that could be utilized for the denitrification of nitrate to nitrogen gas. The planted gravel wetlands were only moderately successful in nitrate removal. The addition of carbon, from both the plants and compost, provides nutrition for the microbes consuming the nitrate [13], a concept supported by the pH data. A lower pH was observed in both the planted and compost-amended substrates compared to the gravel wetlands. Although denitrification itself produces alkalinity, the lower pH observed may have been due to the production/presence of excess organic acids released from the plants and organic matter in the compost.

Most denitrifying organisms are anaerobic [20]. However, among all 3 replicates, the median ORP was similar for all three substrate types. Typically, a lower ORP would be observed in more anaerobic environments, which was expected within the compost-substrate. Nevertheless, there were indicators that the composted wetlands were anaerobic, primarily from the odor of reduced sulfur compounds in the water effluent. In addition, a possible reason for this disconnect in the ORP data was that placing the ORP probe in the sample port may have disturbed any subtle ORP gradient.

Conclusion

Our findings demonstrate that wetlands amended with used mushroom compost removed more nitrate than the 2 other treatments. Due to the small size of the dataset, the statistical analyses should be considering preliminary at this stage. However, these results serve as a basis to justify conducting future, larger studies with more robust datasets and statistical analyses to evaluate the role that used mushroom compost can play in reducing water contaminants within artificial wetlands. Considering that the efficacy of mushroom compost exceeded non-amended, but otherwise planted wetlands, mushroom compost-amended wetlands could be a key management practice to reduce nutrient pollution in such systems. In addition, the largest surpluses of mushroom compost in the USA are often found near areas with the most nutrient pollutant issues, further supporting the use of compost in artificial wetlands.

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