Nitrogen Removal in a Vermifilter Treating Urban Domestic Wastewater

Understanding nitrogen removal processes throughout vermifiltration is a crucial step in creating an optimised treatment model that can help close both water and nutrient cycles via effluent reuse. Kayla Coppens[1], Serge Stoll[1], Linda Strande[2]

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Photo: To better understand the mechanisms effecting the nitrogen cycle throughout vermifiltration, the six lab-scale reactors seen in this photo have been installed at Eawag and tests are ongoing. Three of the six filters are currently receiving blackwater (flush water, urine, faeces and toilet paper) and the other three are receiving brown water (flush water, faeces and toilet paper).

Introduction

The United Nations's Sustainable Development Goal 6 (SDG 6) aims to assure the availability and sustainable management of water and sanitation for all. Global challenges inciting researchers and practitioners to search for more sustainable strategies for wastewater management include rapid densification of urban areas, aging of treatment infrastructures and the increasing occurrence and intensity of extreme weather events, such as floods and droughts due to climate change [1]. Additionally, increasing water demand and consumption have led to greater interest in the reuse of treated wastewater for both agricultural and domestic purposes.

Due to its low operational and investment costs and non-waste generation, vermifiltration has been gaining attention as a sustainable wastewater treatment solution. Vermifiltration is a nature-based, non-sewered sanitation technology, which uses earthworms and microorganisms to aerobically treat and stabilise wastewater [2]. One challenge facing vermifiltration is balancing its ability to remove nutrients that cause eutrophication in natural water bodies with the need to retain these nutrients for agriculture and food security. Considering that the effluent of vermifiltration is rich in nutrients, its reuse for irrigation and agricultural practices is an opportunity that needs further study.

To better understand the treatment of nitrogen and potential reuse of the effluent in vermifiltration for agricultural practices, we studied the pilot-scale vermifiltration installation at the building Soubeyran in Geneva, Switzerland. It has been in use since 2017 and treats an average of 6.87 ± 1.43 m^3 of wastewater from an apartment building with 100 residents per day [3]. This study is unique as it focuses on a full-scale setting. The presented results are, therefore, a crucial part in creating an optimised treatment model for vermifiltration as a global and circular sanitation solution.

Methods

The pilot-scale installation includes two separate vermifilters, one for greywater, which is pumped from the bottom of a degreaser, and another for blackwater from toilets. Each vermifilter is made up of three layers: 0.2 m of compost (top), 0.2 m of fine biochar (middle), and 0.5 m of coarse biochar (bottom). The water quality of the influent, the compost layer, and the effluent was characterised six times from November 2022 to August 2023 for both the grey and blackwater vermifilters (Table). Throughout the study time, operational parameters, such as the hydraulic loading rate and temperature, were also recorded.

	Greywater VF	Blackwater VF
Hydraulic Loading Rate (m^3/m^2/day)	0.071 ± 0.05	0.057 ± 0.01
Organic Loading Rate (g COD/m^2/day)	59.3 ± 29.1	148.5 ± 53.0
Nitrogen Loading Rate (g TN/m^2/day)	1.3 ± 0.5	18.6 ± 5.1
Influent pH	7.1 ± 0.6	9.0 ± 0.1
Influent DO (mg/L)	1.37 ± 0.58	1.08 ± 0.85
Influent Conductivity (us/cm)	648 ± 72	2660 ± 491
COD RR (%)	77.7 ± 23.7	83.8 ± 3.4
TSS RR (%)	93.9 ± 4.6	95.2 ± 3.4
TN RR (%)	38.7 ± 26.1	17.3 ± 9.1
NH4-N RR (%)	74.3 ± 50.1	50.0 ± 14.7

Table: Operational parameters, influent water quality and summarised removal rates (RR) for the Greywater and Blackwater vermifilters at Soubeyran.

Results

This study used the unique opportunity of having two full-scale vermifilters with the same design to better understand how operating parameters affect the fate of nitrogen throughout vermifiltration. Despite having a similar design, the two vermifilters treat two distinct waters: grey water, which has lower nitrogen loading, and blackwater, which has a higher nitrogen content due to the presence of urine. The Table summarises the distinct operating parameters observed, as well as the removal rates for the basic wastewater components of each vermifilter. The greywater vermifilter (GW.VF) observed higher nitrogen removal than did the blackwater vermifilter (BW.VF). Despite the lower removal rate, the amount of total nitrogen (TN) removed was higher in the BW.VF, with154.9 ± 97.1 g of TN removed daily, compared to only 1.4 ± 1.9 g of TN in the GW.VF. Similarly, removal rates of NH4-N were also higher in the GW.VF, though the total grams of NH4-N removed per day by the BW.VF was over 100-times larger. These results propose that the nitrogen loading rate impacts the removal of nitrogen throughout the vermifilter, where lower loading rates have higher removals.

By looking at the different forms of nitrogen present after different layers in the vermifilter, the predominant treatment mechanisms in each step can be hypothesised. The evolution of nitrogen throughout the two vermifilters varies, indicating that distinct mechanisms are likely occurring. Nitrate was absent in the effluent of the compost layer (top) of the BW.VF, though it makes up 46% of the nitrogen in the final effluent, insinuating that nitrification is occurring only in the biochar layer (bottom) of the BW.VF. As the majority (79.5 ± 15.3%) of the TN removed in the BW.VF is occurring in the compost layer, it can be assumed that the predominant mechanisms for nitrogen removal is volatilisation of NH3-N. In the GW.VF, the concentration of nitrogen actually increases throughout the compost layer, which is likely due to the leaching of nitrogen found in the compost and vermicasts. It can, therefore, be hypothesised that at higher nitrogen loading rates, more volatilisation of nitrogen in the form of ammonia occurs. If the goal is to reuse the effluent for agricultural purposes, the loss of nitrogen through volatilisation could possibly be lowered by decreasing the daily nitrogen loading rate.

Finally, the effects of temperature on the nitrogen fate throughout the vermifilters were observed by studying the system in both winter (average temperature 5.9 ± 4.13°C) and summer (average temperature 21.84 ± 5.22°C). As nitrifying bacteria, which stabilise nitrogen for agricultural reuse, are known to be negatively impacted at lower temperatures, it was hypothesised that nitrification would be less during the winter months. However, our findings did not confirm this hypothesis. For the BW.VF, the nitrification rate remained stable throughout the year. This may be due to the large temperature buffer capacity (temperature in BW.VF in winter is 13.45 ± 1.34°C) observed by the filter, which is likely because of the fact that the filter is located underground and straw is added to insulate the filter during colder seasons.

Conclusion

These findings are important to optimise either nitrogen reduction, if the effluent is destined to natural water bodies, or nitrogen retention and stabilisation via nitrification in the case that the effluent is to be used for agricultural purposes. The effects of temperature on vermifiltration were not as drastic as found in other studies, which implies that vermifiltration is a promising treatment technology even in cold climates. The nitrogen loading rate may impact the overall fate of nitrogen throughout vermifiltration and, therefore, should be investigated further. This will be done using lab-scale vermifilters with real wastewater simulating both blackwater (with urine) and urine separated water (brown-water) (Photo). Additionally, a study looking into other parameters which may impact effluent reuse in agriculture, such as pathogens, heavy metals, and micropollutants, is ongoing. •

References

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