The Effect of Vermifiltration of Dairy Lagoon Water on Emissions and Microbial Communities

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Sustainable Conservation

BIOFILTRO
Innovation and Efficiency for Water

Background

Vermifiltration: a wastewater management system that uses earthworms to enhance removal of solids and contaminants from wastewater

The problem

- Dairy wastewater is traditionally stored in anaerobic lagoons, which primarily emit ammonia (NH_3), hydrogen sulfide (H_2S), carbon dioxide (CO_2), and methane (CH_4) as shown in Fig. 2 (Zhang, 2001). NH_3 and H_2S are odorous compounds, whereas CO_2 and CH_4 are greenhouse gases (GHGs). CH_4 has a global warming potential (GWP) of 28 (Stocker et al., 2013).
- Lagoon water is land-applied at agronomical rates to cropland adjacent to the dairy.
- California dairies are growing, but the cropland available to apply wastewater is not.
- Overapplication of lagoon water leads to nitrate (NO_3^-) leaching into the groundwater, preventing NO_3^- from continuing through the nitrogen cycle to denitrification (Fig. 1).

The solution?

- The new vermifiltration system claims to remove nitrogen from lagoon water, thus allowing dairy farmers to apply more lagoon water to cropland without exceeding agronomical rates for nitrogen (Fig. 2).
- In soil, earthworms have been shown to increase denitrification (Drake and Horn, 2007); however, the earthworm gut favors incomplete denitrification, preferentially producing N_2O as opposed to N_2 (Horn et al., 2006). N_2O has a GWP of 298, making it a potent GHG (Stocker et al., 2013).
  - Will the vermifiltration system also favor incomplete denitrification and subsequent N_2O production?
- Methanogens sulfate-reducing bacteria are anaerobes, so they thrive in anaerobic lagoons; however, unlike anaerobic lagoons, the vermifiltration system is an aerobic environment.
  - Will the vermifiltration reduce CH_4 and H_2S emissions from lagoon water?

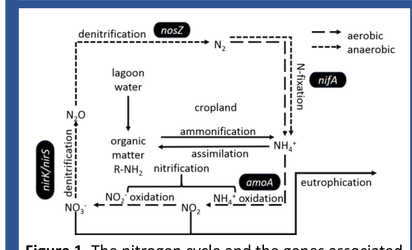

Figure 1. The nitrogen cycle and the genes associated with each conversion step

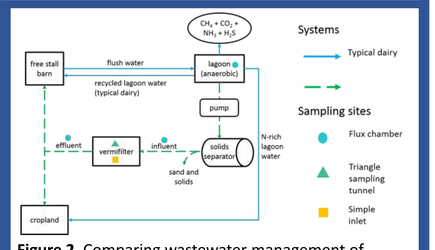

Figure 2. Comparing wastewater management of conventional dairies and the vermifilter system

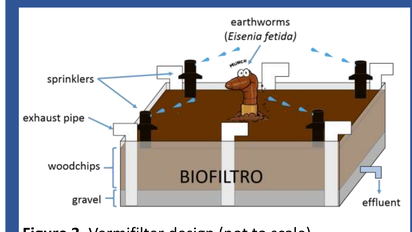

Figure 3. Vermifilter design (not to scale)

Figure 4. Vermifilter surface

Objective

To quantify the environmental impact of the vermifilter by:

1. Comparing the GHG and VOC profiles from the lagoon water (L), influent (I), effluent (E), over the surface of the filter (S), and the bottom of the filter (B).
2. Comparing the microbial communities among the sampling locations, focusing on nitrogen cycling microbes.

Study Design

Sampling

NH_3, N_2O, CO_2, CH_4, and H_2S concentrations were measured using gas analyzers in the Mobile Agricultural Air Quality Lab (MAAQ Lab) (Fig. 5ab).

Liquids (LW, I, E)

- **Gas sampling**
  5 L of each liquid was transferred to a flux chamber (Fig. 5c). Air was bubbled through each of the liquids at a rate of 10 Lpm to release emissions at a standardized rate. Gas concentrations were measured continuously for 48 hours.
- **Microbial sampling**
  10 45 mL samples were taken at each sampling site. Samples were frozen at -20°C until analysis.

Filter (T and B)

- **Gas sampling**
  Constant airflow was established over the filter as well as in the exhaust pipe to standardize gas concentration measurements. For the surface of the filter, a triangle sampling tunnel was used to capture the gases. For the bottom of the filter, an inlet was fixed to the inside an exhaust pipe. Gas concentrations were measured continuously for 18 hours.
- **Microbial sampling**
  For the surface of the filter, 3 ~0.5 kg woodchip samples were sampled from 3 random locations and frozen at - 20°C until analysis. For the bottom of the filter, no microbial sample was taken.

Figure 5. Sampling methods. (a) Mobile Agricultural Air Quality Lab parked next to the vermifilter, (b) Gas analyzers in the MAAQ Lab , (c) flux chambers for gas measurements from L, I, and E, (d) setup for B gas measurements, (e) triangle sampling tunnel for S gas measurements

Microbial analysis

- DNA will be extracted from all microbial samples for 16S rRNA analysis and functional gene analysis.
  - 16S rRNA will be used to identify the microbes present at each location.
  - Functional gene analysis will be used to test for presence of N-cycling genes (Fig. 1).

Results and Discussion

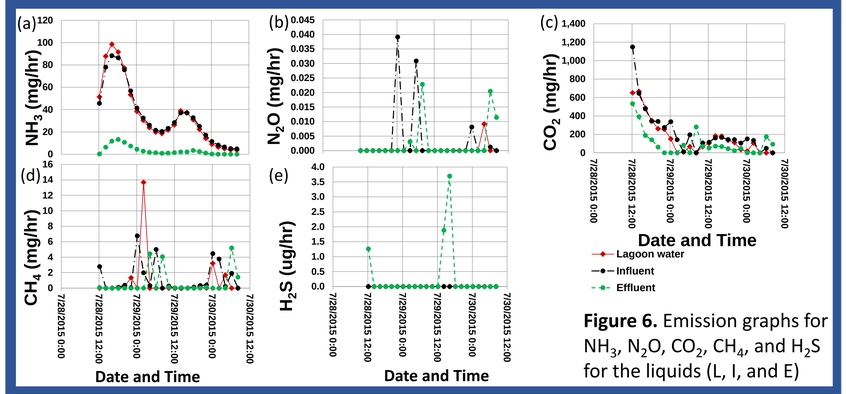

Figure 6. Emission graphs for NH_3, N_2O, CO_2, CH_4, and H_2S for the liquids (L, I, and E)

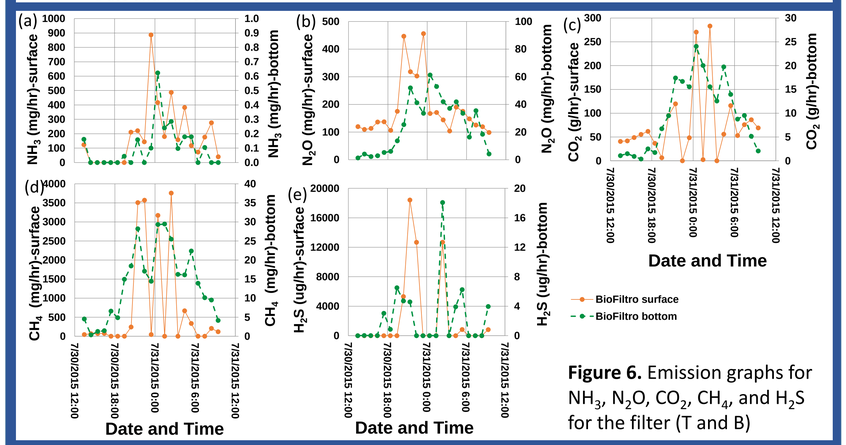

Figure 6. Emission graphs for NH_3, N_2O, CO_2, CH_4, and H_2S for the filter (T and B)

The vermifilter reduces NH_3 emissions from lagoon water without increasing N_2O emissions.

- **Liquids:** The L and I had similar NH_3 emission profiles, but the E had lower NH_3 emissions compared to the L and I (Fig. 6a). Unlike NH_3, N_2O emissions were similar among the L, I, and E (Fig. 6b).
- **Filter:** Although the B NH_3 and N_2O emissions were on a much smaller scale than the T, both the B and T emissions for NH_3 and N_2O followed a similar temporal pattern (Fig. 7ab).
- The vermifilter removes 15.5 kg of NH_3 per day, reflecting a 90.2% removal efficiency.
- The vermifilter appears to enhance complete denitrification to N_2, but more research is needed to further support this finding.

The vermifilter does not affect CO_2, CH_4, or H_2S emissions from lagoon water.

- **Liquids:** All three liquids had similar CO_2, H_2S, and CH_4 emission profiles (Fig. 6cde).
- **Filter:** Like NH_3 and N_2O, CO_2, CH_4, and H_2S emissions from B were lower than S, but followed a similar temporal pattern (Fig. 7cde).

Work in Progress

Microbial analysis

Future Directions

- Repeat study in winter to check for seasonal effect
- Optimize microbial communities to favor more efficient denitritication
- Analyze the effect of the vermifiltration system on pathogen loading of lagoon water
- Effects of land application of effluent on soil emissions

References

Drake, H. L. and M. A. Horn. 2007. As the worm turns: the earthworm gut as a transient habitat for soil microbial biomes. Annu Rev Microbiol 61:169-189.

Horn, M. A., R. Mertel, M. Gehre, M. Kastner, and H. L. Drake. 2006. In vivo emission of dinitrogen by Stocker, T., D. Qin, G. Plattner, M. Tignor, S. Allen, J. Boschung, A. Nauels, Y. Xia, B. Bex, and B. Midgley. 2013. IPCC, 2013: climate change 2013: the physical science basis. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change.

Stocker, T., D. Qin, G. Plattner, M. Tignor, S. Allen, J. Boschung, A. Nauels, Y. Xia, B. Bex, and B. Midgley. 2013. IPCC, 2013: climate change 2013: the physical science basis. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change.

Zhang, R. 2001. Biology and engineering of animal wastewater lagoons. Biological and Agricultural Engineering Department University of California, Davis.