FINAL REPORT

Project: Evaluation of potential mitigations of environmental impacts accruing from the BioFiltro BIDA® Systems at the J&K Dairy.

Principal Investigator: Dr. Pius Ndegwa, Biological Systems Engineering, PACCAR 348, Washington State University, PO Box 646120, Pullman; Phone: 509-335-8167; Email:ndegwa@wsu.edu

Executive Summary

The overall goal of this work was to evaluate potential mitigation of environmental impacts of installing a BioFiltro BIDA® Systems on a commercial dairy in Washington State. For this purpose, this project was divided into two tasks. Task 1 was to evaluate the differences in the water-qualities between the influents and effluents from the BioFiltro BIDA® Systems, while Task 2 focused at determining potential mitigations of air emissions accruing from installing this system on a dairy operation. The two tasks spanned six months from July 1 to December 31, 2019.

Results indicated that the Vermifilter system removed significant proportions of total nitrogen (61-91%), total ammoniacal-nitrogen (70 to 90%), and nitrate-nitrogen (60 to 86%) from the dairy wastewater. The Vermifilter, however, exhibited moderate removal efficiencies of total phosphorus (27 to 57%) but poor removal efficiencies of ortho-phosphates (-36 to 25%). The prevailing ambient temperature had a positive influence on the efficiencies of the removals of TN, TAN, and NO_3^{-1}-N. In contrast, the ambient air temperature conditions had no to little influence on removal efficiencies of either the TP or ortho-P.

Results also revealed that the Vermifilter system significantly reduced potential emissions of methane (97–100%), carbon dioxide (60–85%), and ammonia (84–110%) from treated dairy wastewater. The Vermifilter performance on the nitrous oxide emissions, however, was mixed and not conclusive. Methane and carbon dioxide emission rates increased significantly with ambient air temperature. The relationships between ammonia and nitrous oxide emissions rates with ambient air temperature were not conclusive. Ambient temperature also had little effect on the net achievable emission mitigation of all the gases examined in this study.

Methods and Materials

Task or Objective 1

In this objective, we evaluated the efficacy of this technology at reducing the concentrations of the following nutrients from the effluent from the system: Total nitrogen (TN), total ammoniacal nitrogen (TAN), nitrate nitrogen (nitrate-N), total phosphorus (TP), and orthophosphate (Ortho-P). To achieve this objective, we collected samples (at least every two weeks during the six-month period) at designated points upstream (inlet) and downstream (outlet) of the BioFiltro

BIDA® system. The samples were transported back to the laboratory located on the Washington State University campus in Pullman in cooler boxes. The samples were analyzed immediately, whenever possible, and if not, they were stored at 4°C until the day of analysis. These samples were analyzed for total nitrogen (TN), total ammonia nitrogen (TAN), and nitrate N, as the nitrogen species. The samples were also analyzed for total phosphorus (TP) and ortho-phosphate (ortho-P), which are the dominant phosphorus-species in dairy wastewater. Finally, the chemical oxygen demand (COD) of the samples were determined. Standard Analytical Methods (APHA, 1998; 2005) or modified versions of the same were used for all the laboratory analyses.

Task or Objective 2

The objective of this task was to evaluate potential air emissions mitigations courtesy of the installation of the BioFiltro BIDA® systems at the dairy for treating wastewater. The gases measured included ammonia and greenhouse gases (nitrous oxide, methane, and carbon dioxide), which are common emissions in dairy operations. To accomplish this objective, we used custom-designed dynamic chambers in which samples drawn at the inlet and outlet of the BioFiltro BIDA® system, for each measurement, were poured into (Figure 11). Measurements of emissions (ammonia and GHG) from wastewater were made using a photoacoustic IR analyzer (Model 1412, Innova AirTech Instruments, Ballerup, Denmark). In this method, the chamber headspace air is pulled into the photoacoustic IR analyzer for concentration measurements through one vent of the chamber, and the air is returned into the chamber's headspace through another vent, resulting in closed loop air circulation required for measuring cumulative gas concentrations (Joo et al. 2012; Sun et al. 2014). The gas fluxes are calculated from linear segments of concentration versus time plot, chamber volume, and emitting surface area (Parkin et al. 2003, Rochette and Eriksen- Hamel 2008, Joo et al. 2012; Sun et al. 2014).

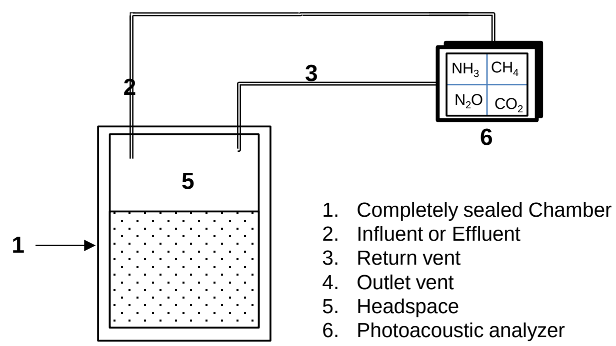

Figure 11. Schematic of the custom-made test-chamber and instrumentation used in the field studies.

Results and Discussion

Task 1 Results and Discussion

Figure 1 presents the concentrations of the TN in the influents and effluents of the Vermifilter system as well as the corresponding changes between the inlet and outlet during each sampling event. Figure 2, on the other hand, shows the variations of TN with the mean ambient temperature in the influents and effluents as well as the variations in percentage changes with the mean ambient temperature during the measurements. The TN concentration at the inlet was typical of flush-system dairy manure. The TN concentrations in the influent were always higher than the TN concentrations in the effluent, implying a net reduction by the system. The removal efficiencies of TN ranged between 63 and 91%. Based on Figures 2a and 2b, the concentrations of TN at both inlet and outlet were not influenced by the ambient temperature conditions. However, the removal efficiencies of the TN, from the dairy wastewater, through the system (Figure 2c), was observed to increase with increase in ambient air temperature.

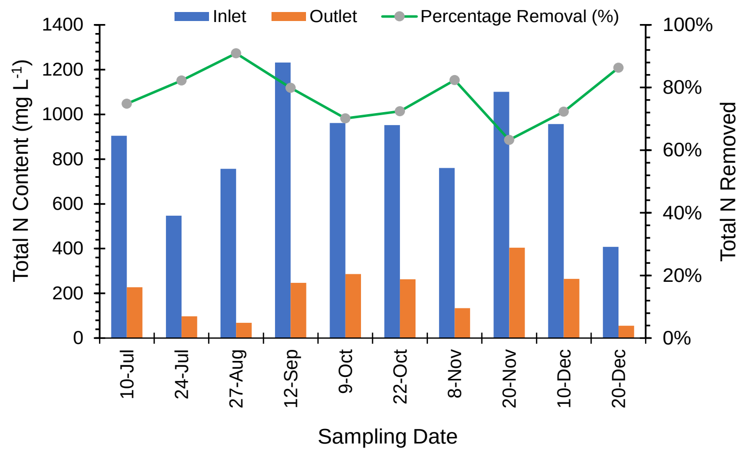

Figure 1. Concentrations of total N for influent and effluent from the Vermifilter and the corresponding percentage reduction by the system.

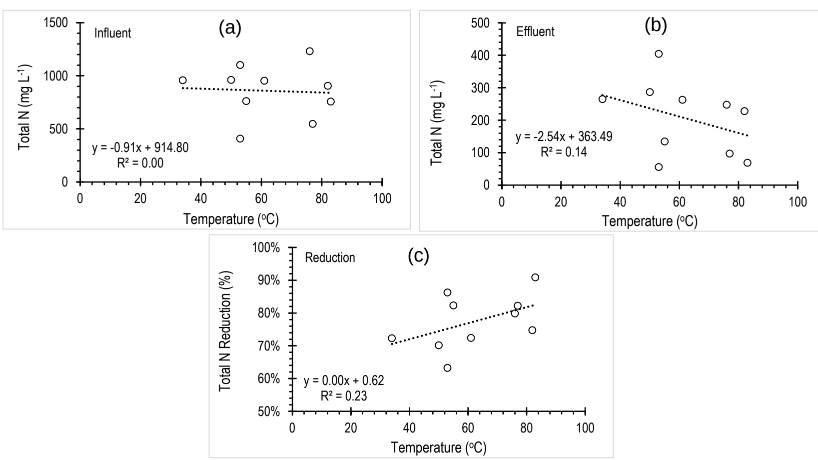

Figure 2. Effects of temperature on concentrations of total N for influent and effluent from the Vermifilter and the corresponding percentage reduction by the system.

Figure 3 presents the concentrations of TAN in the influents and effluents of the Vermifilter system as well as the corresponding percentage changes in TAN between inlet and outlet. Figure 4 shows variations of TAN with mean ambient temperature in the influent and effluent as well as the variation in percentage changes with mean ambient temperature during the measurements. The TAN concentrations at the inlet, again, were typical of that from a flush-system dairy wastewater. The TAN concentration in the influent also was always higher than the TAN concentrations in the effluent, indicating a net reduction of TAN by the system. The removal efficiencies of TAN ranged from 70 to 90%. Like the TN concentrations, the TAN concentrations (and Figures 4a and 4b), at both the inlet and the outlet also did not appear to vary substantially with the ambient temperature conditions. However, like for TN removal efficiency, the efficiency of the TAN removal by the system (Figure 4c), from the dairy wastewater, increased significantly with increase in ambient air temperature.

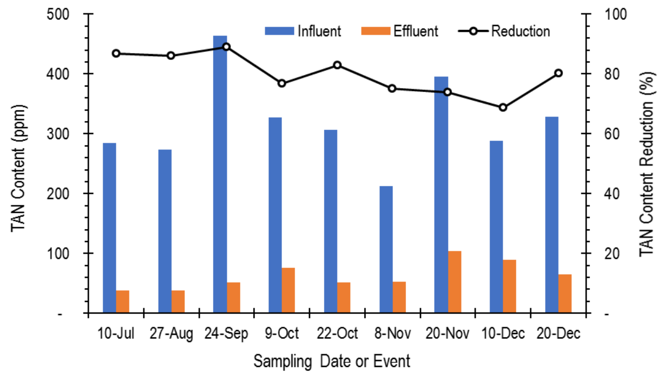

Figure 3. Concentrations of total ammoniacal N (TAN) in the influent and effluent of the Vermifilter and the corresponding percentage reduction by the system.

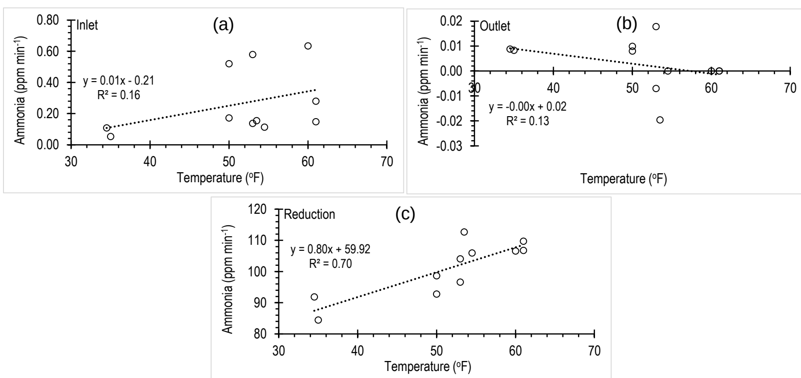

Figure 4. Effects of temperature on concentrations of total ammoniacal N (TAN) in the influent and effluent of the Vermifilter and the corresponding percentage reduction by the system.

Our results for removal efficiencies of TN and TAN compare well with values reported in previous similar studies (Lai et al., 2018; Pasha et al., 2018). Lai et al. (2018), studying a similar pilot-scale system in California, observed removal efficiencies of 56% for the TKN and 68% for the ammonia nitrogen (TAN), while Pasha et al. (208) reported the following removal efficiencies: 99.7% for TKN; 98% for TAN; and 97% for NO^{3-1}-N.

Figure 5 presents the concentrations of nitrate-N (NO_3^{-1}-N) in the influents and effluents of the Vermifilter system as well as the corresponding changes of NO_3^{-1}-N between inlet and outlet. Figure 6, on the other hand, shows the variations of NO_3^{-1}-N with mean ambient temperature in the influent and effluent as well as the variation in percentage changes with mean ambient temperature during the measurements. The NO_3^{-1}-N concentrations at the inlet were higher than the typical wastewater from manure flush-system dairy. The latter

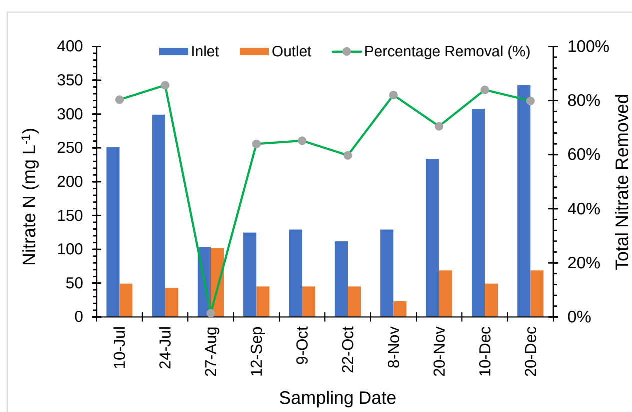

Figure 5. Concentrations of nitrate N for influent and effluent from the Vermifilter and the corresponding percentage reduction by the system.

observations may be attributed to the recycling of effluent back to be mixed with fresh influent. The NO_3^{-1}-N concentrations in the influent also were often higher than the NO_3^{-1}-N concentrations in the effluents, indicating mostly a net reduction in the NO_3^{-1}-N by the system. Other during one sampling event, the efficiencies of removal of NO_3^{-1}-N, by the system, ranged between 60 to 86%. The NO_3^{-1}-N concentrations (and Figures 6a and 6b), at both the inlet and the outlet also did not appear to vary substantially with the ambient temperature. Unlike TN and TAN, however, the removal efficiency of NO_3^{-1}-N by the system (Figure 6c), from the dairy wastewater, seemed to decline slightly with increase in ambient air temperature.

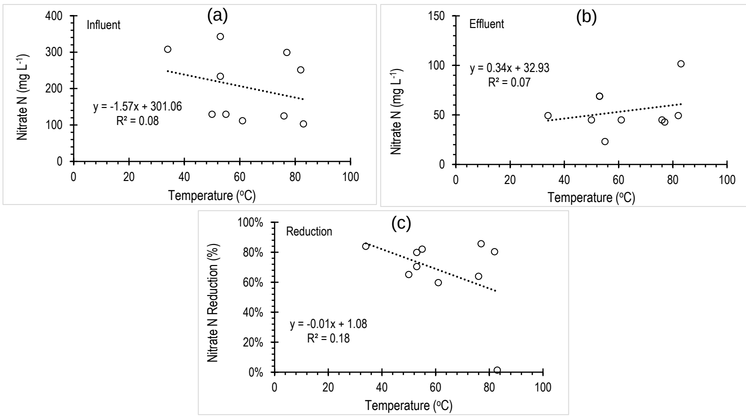

Figure 6. Effects of temperature on concentrations of nitrate N for influent and effluent from the Vermifilter and the corresponding percentage reduction by the system.

Figure 7 presents the concentrations of total phosphorus (TP) in the influents and effluents of the Vermifilter system as well as the corresponding changes of the TP between inflow- and outflow-wastewaters. Figure 8 shows the effect of ambient temperature on the changes in TP in the influents and effluents and the effect on removal efficiency of TP. The TP concentrations in the influents also were always higher than the TP concentrations in the effluents, indicating a net reduction in TP attributable to the Vermifilter system. The removal efficiencies of TP ranged from 27 to 57%. The TP concentrations (and Figures 8a and 8b), at both the inlet and the outlet tended to decrease with increase the ambient temperature. The ambient temperature, however, did not seem to affect the TP removal efficiency from the wastewater passing through the system (Figure 8c).

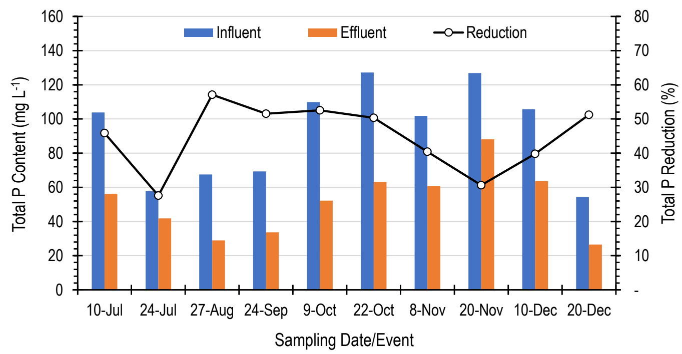

Figure 7. Concentrations of total phosphorus for influent and effluent from the Vermifilter and the corresponding percentage reduction by the system.

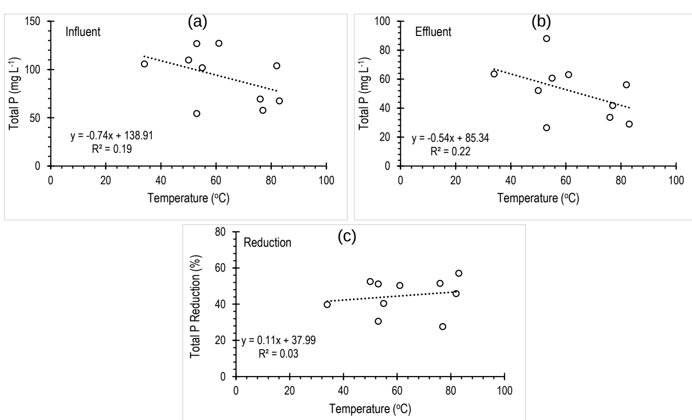

Figure 8. Effects of temperature on concentrations of total phosphorus for influent and effluent from the Vermifilter and the corresponding percentage reduction by the system.

Figure 9 shows the concentrations of ortho-phosphorus (ortho-P) in the influents and effluents of the Vermifilter system as well as the corresponding changes in concentrations between the inlet and outlet during nine sampling events. Figure 10 reveals the variations of ortho-P with mean ambient temperature for corresponding influents and effluents as well as the variation in percentage changes in ortho-P with mean ambient temperature during each sampling event. The ortho-P concentrations results were mixed, higher at inlet during some events and higher at the effluent during the other sampling events. The net reduction or gain in the ortho-P ranged from -36 to 25%. The ortho-P concentrations (and Figures 10a and 10b), at both the inlet and the outlet seemed to decrease with increase in the ambient temperature. The ambient air temperature did not significantly influence the removal efficiency of the ortho-P from the dairy wastewaters (Figure 10c). In contrast, earlier studies by Pasha et al. (2018) reported significantly lower phosphorus removal efficiencies of 13.7%.

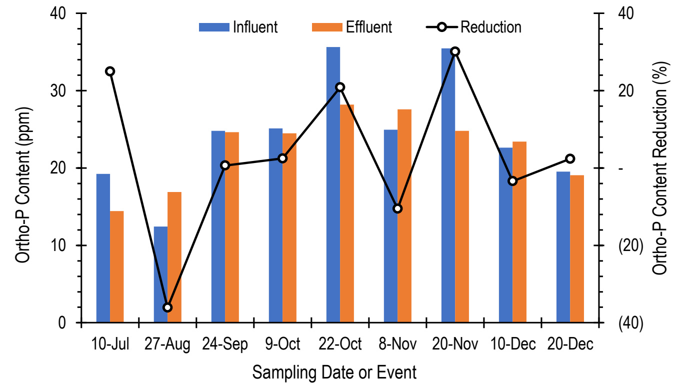

Figure 9. Concentrations of Ortho-phosphorus in the influents and effluents from the Vermifilter and the corresponding percentage reduction by the system.

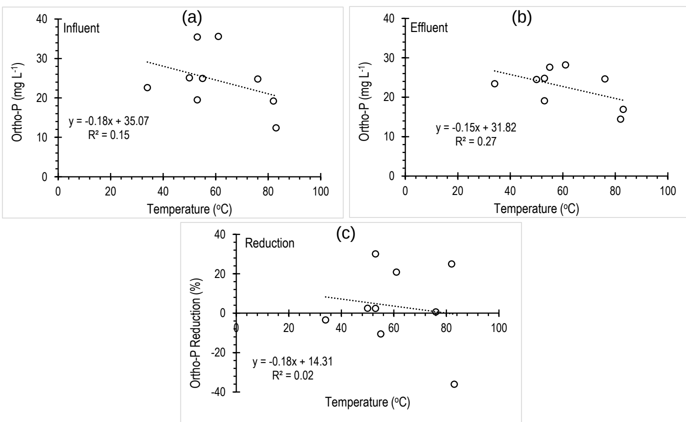

Figure 10. Effects of temperature on concentrations of ortho-phosphorus in influents and effluents from the Vermifilter and the corresponding percentage reduction by the system.

Task 2 Results and Discussion

Figure 12 shows the relative methane emission rates at both the inlet and outlet and the percentage reduction in methane emission rates between untreated and treated dairy wastewater during 11 sampling events. Results indicated that relative methane emission rates from untreated wastewater were always significantly higher than that from treated wastewater. The Vermifilter reduced relative methane emissions by between 97 and 100%. Figure 13 shows the effect of ambient air temperature on relative methane emission rates for the untreated and treated wastewaters and the variation of the percentage reduction with ambient air temperature. The relative emission rates, from both the untreated and treated wastewater, increased with increase in ambient air temperature conditions. Ambient air temperature did not seem to influence the level of reduction in methane emissions.

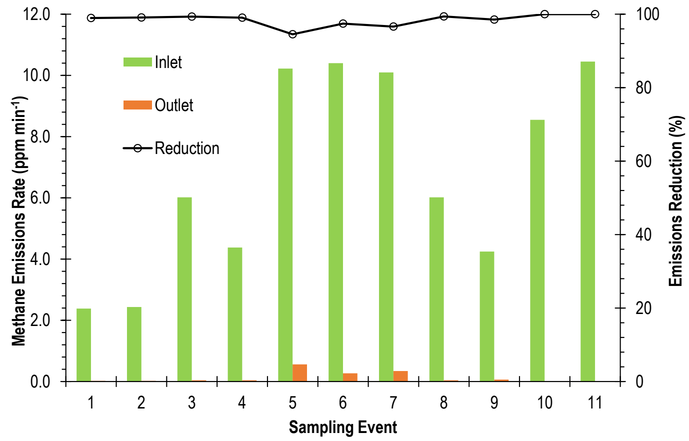

Figure 12. Emission Rates of Methane at the inlet and outlet of the Vermifilter system and methane emission reduction.

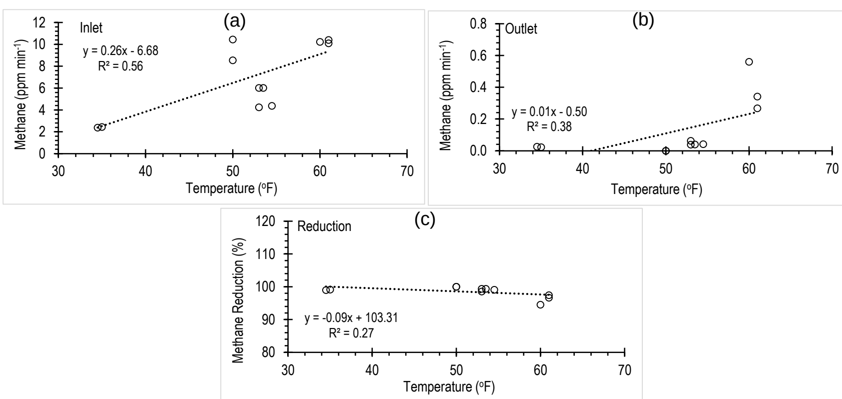

Figure 13. Effects of temperature on the methane emission rates at the inlet and outlet of the Vermifilter system as well as on the emission reduction.

Figure 14 shows relative carbon dioxide emission rates at both the inlet and outlet of the Vermifilter and the percentage reduction in carbon dioxide emission rates between untreated and treated dairy wastewater during the 11 sampling events. Evidently, the relative carbon dioxide emission rates from untreated wastewater were also significantly higher than for treated wastewater. The Vermifilter reduced relative carbon dioxide emissions by between 60 and 85%. Figure 15 reveals

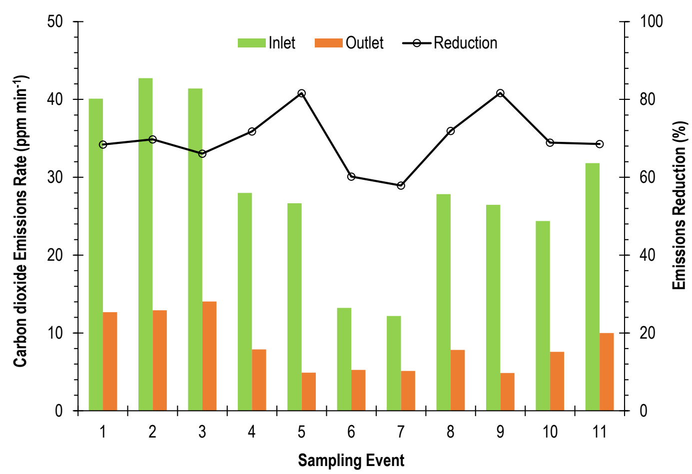

Figure 14. Emission Rates of carbon dioxide at the inlet and outlet of the vermifilter system and methane emission reduction.

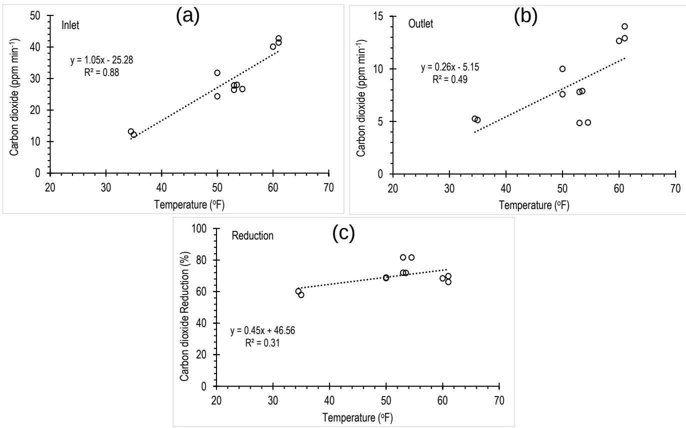

Figure 15. Effects of temperature on emission Rates of carbon dioxide at the inlet and outlet of the vermifilter system and on emission rate reduction.

the effect of ambient air temperature on relative carbon dioxide emission rates for the untreated and treated wastewater and the variation of the percentage reduction with ambient air temperature. The relative emission rates, from both the untreated and treated wastewater, also significantly increased with increase in ambient air temperature conditions. The ambient temperature had some positive effect on the level of carbon dioxide mitigation accruing from wastewater treatment in the Vermifilter.

Figure 16 shows relative nitrous oxide emission rates at both the inlet and outlet and the percentage reduction in nitrous oxide emission rates between untreated and treated dairy wastewater during 11 sampling events. Mixed results were observed for the relative nitrous oxide emission rates from untreated- and treated-wastewaters. The net relative emissions rates of nitrous oxide varied between emissions by between -220 and 400%. These large variations were attributed to the significantly low relative emissions rates varying from -0.13 to 0.21 ppm s^{-1}. Small errors in measurements of such low relative emission rates manifests in significantly amplified errors in the results. Figure 17 shows the effect of ambient air temperature on relative nitrous oxide emission rates for the untreated and treated wastewater and the variation of the percentage reduction with

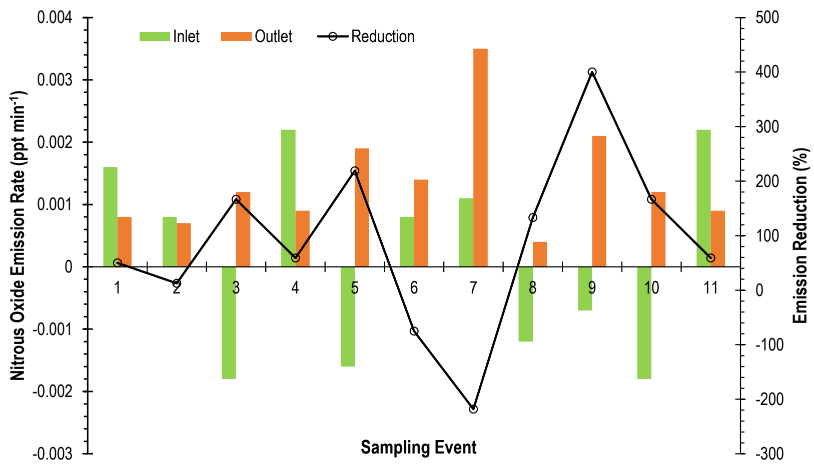

Figure 16. Emission Rates of nitrous oxide at the inlet and outlet of the Vermifilter system as well as on emission reduction.

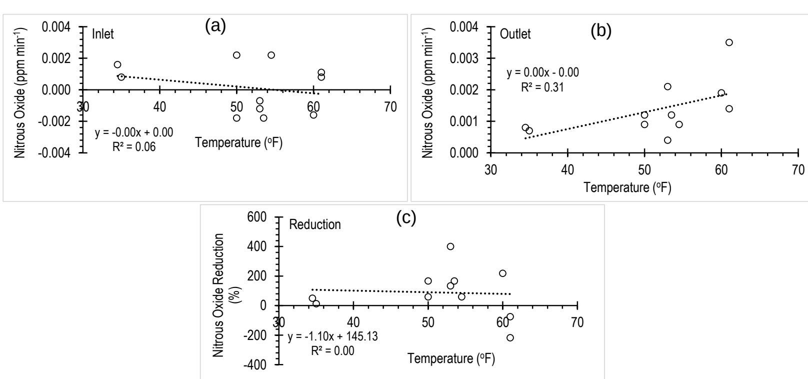

Figure 17. Effects of temperature on the Emission Rates of nitrous oxide at the inlet and outlet of the Vermifilter system as well as on emission reduction.

ambient air temperature. The relative emission rates, from untreated wastewater did not seem be affected by the temperature. However, the relative emission rates from the treated wastewater tended to increase with the increase in ambient air temperature conditions. Ambient air conditions did not seem to significantly affect the Vermifilter level of nitrous oxide emissions mitigation.

In contrast, previous similar studies, conducted in California, reported mitigation of ammonia emissions but potential increases in emissions of methane, carbon dioxide, and nitrous oxide from treated wastewater compared to untreated wastewater (Lai et al., 2018).

Figure 18 shows relative ammonia emission rates at both the inlet and outlet and the percentage reduction in ammonia emission rates between untreated and treated dairy wastewater during the 11 sampling events. Results indicated that relative ammonia emission rates from untreated wastewater were significantly higher than for the treated wastewater. The Vermifilter reduced relative ammonia emissions by between 84 and 110%. Relative ammonia emission rates from treated wastewaters undetectable in most cases. Figure 19 shows the effect of ambient air temperature on relative ammonia emission rates for the untreated and treated wastewater and the variation of the percentage reduction with ambient air temperature. The prevailing ambient air temperature did not seem to affect the relative emission rates from either the untreated or the treated wastewater. However, ammonia emissions mitigations increased with increased in the ambient air temperature. The results obtained in this study were similar to the 90.2% reduction in ammonia emissions reported in previous similar studies (Lai et al (2018).

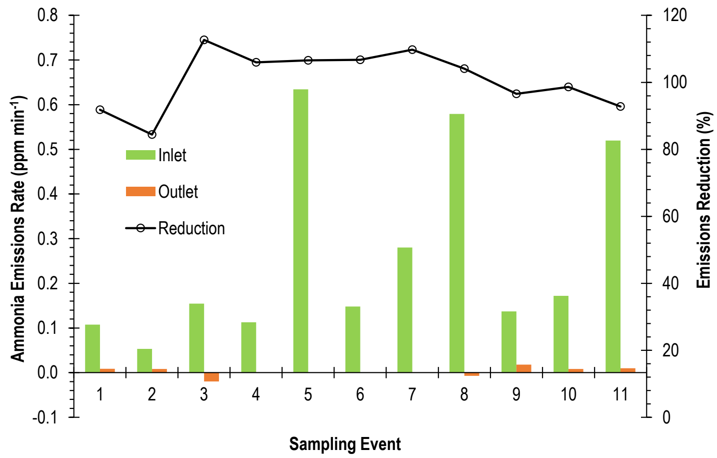

Figure 18. Emission Rates of ammonia at the inlet and outlet of the Vermifilter system as well as on emission reduction.

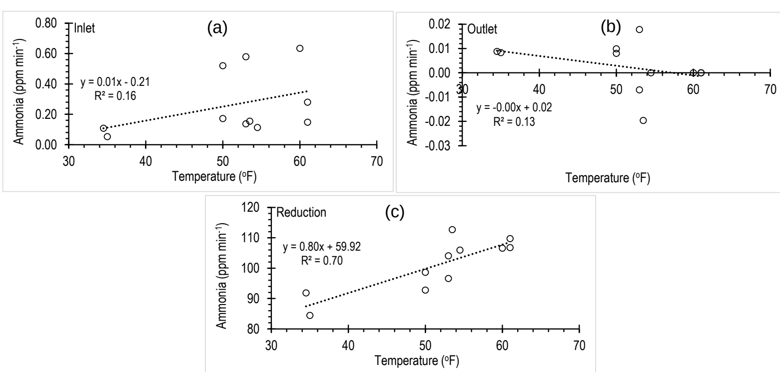

Figure 19. Effect of temperature on emission rates of ammonia at the inlet and outlet of the vermifilter system as well as on emission reduction.

Task or Objective 3

We will prepare two manuscripts for potential publication in peer refereed journals in the field based on data collected from this project. One manuscript will focus on the dynamics of nutrients (nitrogen, phosphorus, and associated species) in the dairy wastewater as well as the effect of treating on wastewater strength (with respect to chemical oxygen demand), while the other manuscript will focus on potential air emissions mitigations from operation of this system on a dairy.

Finally, depending on funding, we also expect to present the results obtained in this project in either seminars, national or international conferences.

CONCLUSIONS

The Vermifilter system removed significant proportions of total nitrogen (61-91%), ammoniacal-nitrogen (70 to 90%), and nitrate-nitrogen (60 to 86%) from the dairy wastewater. The Vermifilter exhibited moderate removal efficiencies of total phosphorus (27 to 57%) but poor removal efficiencies of ortho-phosphates (-36 to 25%). The prevailing ambient temperature had a positive influence on the efficiencies of the removals of TN, TAN, and NO_3^{-1}-N. In contrast, the ambient air temperature conditions had no to little influence on removal efficiencies of either the TP or ortho-P.

The Vermifilter system significantly reduced potential emissions of methane (97 and 100%), carbon dioxide (60 and 85%), and ammonia (84 and 110%) from treated dairy wastewater. The Vermifilter performance on the nitrous oxide emissions was mixed and not conclusive. Methane and carbon dioxide emission rates increased significantly with ambient air temperature. The relationships between ammonia and nitrous oxide emissions rates with ambient air temperature were not conclusive. Ambient temperature also had little effect on the net achievable emission mitigation of all the gases examined in this study.

References

APHA. 2005. Standard Methods for Examinations of Water and Wastewater, 21st ed. APHA, AWWA and WEF DC, Washington.

APHA. 1998. Standard methods for the examination of water and wastewater. 20th ed. American Public Health Assoc., NW, Washington, DC.

Lai, E., M. Hess, F.M. Mitloehner. 2018. Profiling of the Microbiome Associated With Nitrogen Removal During Vermifiltration of Wastewater From a Commercial Dairy. *Frontiers in microbiology*, *9*, 1964.

Joo, H.J., P.M. Ndegwa, J. Harrison, E. Whitefield, A.J. Heber, J.Q. Ni. 2012. Emissions of ammonia and greenhouse gases (GHG) from anaerobically digested and undigested dairy manure systems. ASABE Annual International Meeting**.** Paper number 121337962; Dallas, Texas, Jul. 29 – Aug. 1.

Pasha, M.F.K., D. Yeasmin, D. Zoldoske, B. Kc, J. Hernandez. 2018. Performance of an Earthworm-Based Biological Wastewater-Treatment Plant for a Dairy Farm: Case Study. *Journal of Environmental Engineering*, *144*(1), 04017086.

Parkin, T., A. Mosier, J. Smith, R. Venterea, J. Johnson, D. Reicosky, et al. 2003. USDA-ARS GRACEnet chamber-based trace gas flux measurement protocol. Washington DC: USDA-ARS.

Rochette, P., N.S. Eriksen-Hamel. 2008. Chamber measurements of soil nitrous oxide flux: are absolute values reliable? *Soil Science Society of America Journal*, 72(2), 331–342.

Sun, F., J.H. Harrison, P.M. Ndegwa, K. Johnson. 2014. Effect of manure treatment on ammonia emissions during storage under ambient environment. *Water, Air, & Soil Pollution* 225(9).