APPLICATION FOR COMPONENT ADDITION TO NRCS

NRCS Practice Standard 629

For Acceptance of Vermifiltration Technology

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Vermifiltration Technology

REQUEST

NRCS Practice Standard 629 Waste Treatment (CPS 629) serves as a comprehensive framework for evaluating various manure treatment technologies. Newtrient has developed a testing and reporting protocol for manure treatment technologies based on CPS 629, which has been successfully implemented at multiple sites, globally. Recognizing the advancements in sustainable waste treatment, we propose the development of a supplementary guideline tailored to *Vermifiltration* technology within the CPS 629 framework. Vermifiltration represents an innovative approach wherein composting worm beds are utilized to filter wastewater, thereby reducing its nutrient content. This technology has shown promise through a comprehensive assessment conducted at a large-scale dairy farm in central Washington, housing 6,000 cows. By adding this supplement to CPS 629, we aim to provide farmers and industry stakeholders with standardized guidelines and a proven approach to implementing worm beds for waste treatment. This will expand the range of options available under NRCS Practice Standard 629, enabling greater flexibility and promoting sustainable practices in waste management within the agricultural sector.

BRIEF DESCRIPTION OF COMPONENT CLASS

Vermifiltration, an innovative wastewater treatment technology employing a composting worm bed, offers a promising approach to nutrient reduction in wastewater. This method represents a paradigm shift in wastewater treatment, characterized by decentralization, environmental sustainability, and minimal energy demands (Arora and Saraswat, 2021).

A typical vermifiltration system comprises beds overlaid with an organic layer, typically consisting of wood shavings, earthworms, associated microbes, castings, and compost materials. Influent wastewater is evenly distributed onto these beds through a sprinkler system, while effluent is collected through a drainage basin at the base of the beds. Within this setup, earthworms and their microbial cohorts ingest and metabolize organic matter and nutrients from the incoming wastewater, facilitating an aerobic wastewater treatment process.

Notably, vermifiltration, although land-intensive, operates with significantly lower energy and operational costs compared to conventional treatment approaches. Numerous studies have examined the effectiveness of vermifiltration systems across various wastewater types, including municipal, domestic, and industrial wastewater (e.g., Lim et al., 2014; Wang et al., 2016; Lourenco and Nunes, 2017). More recently, vermifiltration technology has found application in wastewater management within livestock farming contexts, including swine (e.g., Ispolnov et al., 2021) and dairy farms (e.g., Dore et al., 2019).

DETAILED DESCRIPTION

BioFiltro's patented Biodynamic Aerobic (BIDA®) system, established in 2009 (Dore et al. 2019), represents a revolutionary vermifiltration technology. The BIDA vermifiltration system (Figure 1) comprises open concrete beds structured in layers as follows:

1. **Coarse Drainage Basin Bottom:** Lining the base of the system, a coarse drainage basin comprised of thick pallets preserves the ventilated air chamber, providing a foundation for aerobic wastewater processing.
2. **Crushed Rock Support Layer:** Above the drainage basin, a layer of crushed rock acts as a supportive substrate, providing aerobic conditions to the wood shavings layer and aiding in denitrification nitrification processes.
3. **Geotextiles:** Permeable textile material is placed between each layer of media to prevent the mixing of layers into one another and serves as a medium for microorganisms in addition to the wood shavings layer.
4. **Wood Chips and *Eisenia Andreii* Worms:** Approximately three feet of wood chips, combined with *Eisenia Andreii*, commonly known as red wriggler worms, and their associated microbes who feed off the nutrients and organic matter in wastewater, form the active filter medium within the beds.

The BIDA system incorporates aeration piping that extends from the surface to the drainage basin bottom and is supplied by a hard pipe irrigation system spanning its surface (BioFiltro, 2022).

Figure 1. BIDA System Design.

Treatment System at Royal Dairy

The wastewater treatment system at Royal Dairy is an integral component of a multi-step treatment process that seamlessly integrates both mechanical separation and vermifiltration techniques (Figure 2). Here is a breakdown of the key stages:

1. **Raw Manure Collection and Initial Separation:** Manure from the freestalls at Royal Dairy is initially flushed with recycled water into primary holding pits. This raw manure wastewater then undergoes its first separation step, passing through an initial set of 40-mil slope screens (Screen System I) designed to remove larger solids. Subsequently, the treated wastewater is channeled into a secondary holding pit.

2. **Secondary Separation:** The manure wastewater continues its journey through a sand lane to reach a second set of 40-mil slope screens (Screen System II), which further eliminate any remaining larger solids.

3. **Holding Pond:** Following secondary separation, the manure wastewater is directed to a 7-million gallon holding pond, where it remains until it's ready to enter the BIDA Equalization Tank (BIDA Inflow). The purpose of the BIDA Equalization Tank is to stabilize the manure wastewater, generating an optimal and uniform influent for the BIDA system.

4. **BIDA Vermifiltration:** An automated computer system carefully monitors the manure wastewater within the equalization tank and releases it into the BIDA bed irrigation system. Over approximately four hours, the wastewater passes

through the BIDA vermifiltration system, where the filter media and resident biota work in tandem to effectively treat excess nutrients and solids.

5. **Nutrient-Reduced Water Storage:** The resulting nutrient-reduced water from the BIDA system collects at the bottom of the beds and is then pumped into a 30-million-gallon pond (BIDA Outflow), where it is securely stored for future uses such as reuse in dairy processes, system flushes, and for irrigation purposes.

The BIDA system at Royal Dairy comprises seven concrete beds, each spanning 46,000 ft^2, utilizing the structure described earlier. With a density of 500 worms per square foot in the BIDA beds, Royal Dairy estimates that the current system can reduce excess nutrients by up to 70% and solids by up to 90% in 200,000 gallons of manure wastewater daily (Allred, 2019).

Figure 2. Royal Dairy Farm Wastewater Flow.

HOW PROPOSED SYSTEM ACCOMPLISHES PURPOSES OF THE STANDARD

Newtrient (www.newtrient.com), a company sponsored by the dairy industry with a focus on value-added and environmentally sustainable manure management, has conducted a comprehensive evaluation of technology classes in manure management and their effects on critical environmental indicators. As part of this evaluation, a thorough review of vermifiltration technology has been conducted, including quantitative analysis, a summary discussion, and references to peer-reviewed literature. The detailed findings of this review are presented in Appendix A of this application.

Building on the information presented in Appendix A, this section briefly discusses the significant effects of vermifiltration technology on key environmental indicators, such as water quality and air emissions, which align with the goals of Standard 629.

To support this discussion, Appendix B offers data from a specific commercial installation. It includes visual representations and nutrient profiles, illustrating how the integration of a vermifiltration system as part of a comprehensive manure management approach positively influences environmental outcomes.

Furthermore, Appendix C contains the final report of a study conducted by Central Washington University. This report focuses on the commercial installation, providing additional insights into the effectiveness and benefits of vermifiltration technology.

Vermifiltration systems fulfill the objectives outlined in the NRCS Practice Standard 629 Waste Treatment (CPS 629) by catering to its fundamental purposes, of which are as follows:

<u>Reducing nutrient content, organic strength</u>

Vermifiltration serves as an effective solution for managing nutrients and organic matter present in manure and agricultural waste. As wastewater traverses the filter, the collaborative efforts of worms and microorganisms lead to the breakdown of organic materials and the conversion of ammonia into harmless nitrogen gas. This process results in a substantial reduction in nutrient content, significantly enhancing the quality of the treated water contributing to the protection and preservation of local waterways, ensuring environmentally responsible management of nutrients in a way that is supportive of the overall health of the surrounding aquatic environment. Moreover, vermifiltration brings about a vital transformation of nutrients, particularly nitrogen, by utilizing the denitrification process to convert reactive nitrogen, such as ammonia, into a non-harmful form (Lai, et al., 2018). By doing so, it effectively addresses the pressing concern of nitrogen runoff and leaching, a major contributor to adverse impacts on aquatic ecosystems.

Vermifiltration also plays a pivotal role in decomposing organic matter within the wastewater. Worms and associated microorganisms collaborate to break down complex organic compounds into simpler, less potent substances, thereby reducing the organic strength of the wastewater. By effectively managing both excess nutrients and organic matter, vermifiltration actively mitigates environmental impacts associated with nutrient runoff, leaching, and the health of the aquatic environment.

Reducing odor and gaseous emissions

Particularly effective for wastewater with low suspended solid contents, the system demonstrates a substantial decrease in ammonia (NH_3) emissions. The lower gas emissions from the system bottom compared to the top suggest that nutrient adsorption and conversion processes in the woodchip layer contribute to this reduction. The efficient adsorption of NH_3 by the bioreactor, coupled with microbial transformation through nitrification and denitrification, leads to a substantial decrease in ammonia emissions. The BioFiltro system not only achieves a 90.2% reduction in ammonia emissions but also maintains lower levels of other greenhouse gases (N_2O, CO_2, and CH_4) and ethanol (BioFiltro System, 2017). This comprehensive reduction in NH_3 and Total *Kjeldahl* Nitrogen (TKN) concentrations is attributed to a combination of nitrification followed by complete denitrification to nitrogen gas (N_2), highlighting the system's effectiveness in improving air quality and environmental sustainability.

Facilitating desirable waste handling and storage

Vermifiltration technology contributes to more manageable and efficient handling and storage of agricultural waste. One of the primary ways vermifiltration achieves this is by reducing the organic strength of the waste material. As the worms and microorganisms within the filter break down complex organic compounds, the resulting treated water has a lower organic load. This reduction in organic strength means that the remaining solid waste is less viscous and easier to handle. It can be more effectively transported, spread onto fields, or placed into storage facilities without the challenges associated with high-viscosity materials.

Furthermore, vermifiltration actively contributes to the reduction of solids content in the waste. The earthworms and microorganisms play a role in breaking down organic matter, which in turn leads to a decrease in the total solids present. This reduction is advantageous when it comes to waste storage, as lower solids content means reduced sedimentation and clogging in storage systems, decreasing waste storage maintenance. It also allows for the more efficient use of storage capacity, optimizing the available space and volume for waste storage.

Producing value added byproducts that facilitate manure and waste utilization

Vermifiltration technology offers a multifaceted approach to agricultural waste management by producing valuable byproducts that enhance sustainability and provide economic advantages. One of the key byproducts is nutrient-rich worm castings, a result of organic matter decomposition by earthworms and microorganisms within the vermifiltration system. These castings serve as exceptional soil conditioners and fertilizers, improving soil structure, water retention, and nutrient availability for crops, thereby reducing the reliance on chemical fertilizers. Furthermore, the harvested earthworms themselves have a market in various sectors, contributing to additional income for farmers. Additionally, the treated water from vermifiltration, which is of significantly higher quality compared to untreated agricultural waste, can be repurposed for on-farm applications like irrigation or system flushing, reducing the need for freshwater resources and operational expenses.

RANGE OF VOLUMETRIC AND MASS FLOW CAPACITIES AS WELL AS HYDRAULIC RETENTION TIME

The following section provides an overview of key parameters related to the performance of vermifiltration systems in manure management:

- *Volumetric Flow*: Flow rate is a pivotal indicator in the operation of vermifiltration systems on dairy farms, offering valuable insights into their efficiency in managing liquid manure. The ideal flow rate for such systems hinges on a complex interplay of factors. Firstly, the volume of wastewater generated must be accurately assessed, taking into account the dairy's scale, housing type, and the number of cows on the farm. Larger dairies, naturally, produce more substantial quantities of liquid manure. Secondly, the specific treatment goals for the vermifiltration system are crucial in determining its flow rate. These objectives, whether focused on nutrient removal, solids reduction, or methane emission mitigation, profoundly influence system design and capacity. Additionally, the available physical space for the system must be considered, as the footprint of vermifiltration systems can vary based on their design. Typical U.S. dairy BIDA beds range from 50,000 to 500,000 ft^2. In a 100% manure recollection system, such as a freestall operation, the BIDA system requires 120 ft^2 per milking cow. Based on the BIDA evaluation, flow rates in vermifiltration systems for dairy farms can vary considerably, with an estimated range of 40,000 to 1,000,000 gallons per day, depending on factors like dairy size, activity, housing type, and weather-related disruptions.
- *Mass Flow*: Mass flow data plays a pivotal role in assessing the efficacy of wastewater treatment systems, particularly in the context of vermifiltration. This

data reveals how efficiently such systems remove solids and nutrients from the liquid manure stream, contributing to the broader goal of reducing environmental impacts. The BIDA evaluation at Royal Dairy (Appendix C) provides a comprehensive summary of the total mass per day of solids and nutrients at different key points within the wastewater treatment path. This data showcases the progressive purification of wastewater, leading to a reduction in solids, organic matter, and Total *Kjeldahl* Nitrogen (TKN) as it flows through the system. For instance, organic matter exhibits a significant reduction from the vermifiltration system at Royal Dairy, decreasing from an average of 23,000 lbs./day at the point of entry at the dairy barn flush pits (Screen System I Inflow) to just 9,000 lbs./day at the BIDA effluent lagoon (BIDA Outflow). This notable reduction in mass flow underscores the system's remarkable efficiency in removing organics, which is essential for minimizing environmental impacts and promoting ecological balance.

- *Hydraulic Retention Times (HRT):* At a high level, HRT is a critical parameter in the assessment of wastewater treatment systems, including vermifiltration systems. It represents the average amount of time that wastewater spends within the treatment unit, which is essential for biological and chemical processes to effectively remove organics. HRT is particularly relevant for systems like vermifiltration, where biological organisms play a crucial role in breaking down organic matter and nutrients.

  At an HRT of four hours, the BIDA System demonstrates remarkable efficiency, processing wastewater rapidly and effectively. This swift processing not only ensures virtually odorless operation but also minimizes the need for extensive storage capacity. Furthermore, the system's ability to sustain worm and bacteria biomass on cellulose media during off-seasons allows for discontinuous or seasonal operations, enhancing its flexibility and environmental sustainability.

DESIRED FEEDSTOCK CHARACTERISTICS

In vermifiltration, the successful treatment of liquid manure relies heavily on the quality and composition of the feedstock— the incoming wastewater. To optimize system performance and ensure effective organics removal, certain desired feedstock characteristics are essential considerations:

1. **Balanced Nutrient Content:** The feedstock should have a well-balanced nutrient composition, ideally matching the nutritional needs of crops or vegetation where the treated effluent will be applied. This balance ensures that excess nutrients are effectively removed and desired nutrients applied to the field are evenly distributed, preventing environmental concerns while supporting sustainable agricultural practices.

2. **Appropriate Solids Content:** An optimal feedstock should have an appropriate concentration of solids, striking a balance between not being too dilute, which may hinder treatment efficiency, and not being too concentrated. Effective wastewater treatment necessitates the preliminary separation of coarse solids to ensure optimal system performance and prevent potential issues such as clogging and reduced treatment efficiency. To achieve an effective balance, it is recommended to maintain a solids concentration of less than 1% in the feedstock. It is recommended to separate solids from the liquid waste stream using a solids separator with a 0.02” mesh size.
3. **Low Pathogen Load:** Feedstock with a low pathogen load is desirable to minimize health risks and ensure safe handling during the treatment process. Vermifiltration systems are effective at reducing pathogens, but starting with a lower load enhances overall performance.
4. **Reduced Organic Matter:** High concentrations of organic matter in the feedstock are typical in liquid manure, but the desired characteristic is a reduction of organic matter during treatment. Vermifiltration systems excel in organic matter reduction, which is vital for odor control and mitigating environmental impacts associated with nutrient runoff, leaching, and protecting the health of the aquatic environment, but commencing the treatment process with a feedstock that is low in organic matter strengthens the system’s performance further.
5. **Moderate pH Levels:** While vermifiltration can tolerate a range of pH levels, a feedstock with moderately neutral pH is generally preferred. Extreme pH values can affect worm activity and microbial processes in the treatment bed.
6. **Low-to-No Toxic Substances:** The presence of toxic substances such as heavy metals, pesticides, or industrial chemicals should be minimized in the feedstock. Vermifiltration systems primarily focus on nutrient and organic matter removal and may not effectively treat or mitigate the impact of toxic compounds.

EXPECTED SYSTEM PERFORMANCE

Vermifiltration technology presents an innovative and sustainable approach to the management of liquid manure on farms. Evaluating the performance of vermifiltration systems involves assessing various criteria that reflect their efficiency, effectiveness, and environmental benefits. By gaining insights into expected system performance, farmers and stakeholders can make informed decisions regarding the adoption and fine-tuning of vermifiltration technology in their waste management practices.

The optimal performance of the BIDA system is contingent on geographical considerations, particularly in regions with high rainfall, where covering the worm beds is advisable to prevent excess moisture and the development of anaerobic conditions.

Additionally, locations experiencing freezing temperatures should be avoided to ensure the well-being of the worms and maintain uninterrupted flow through the beds, as frozen conditions may impede the system's efficacy. Furthermore, the system may face challenges in extremely hot climates, emphasizing the need for suitable environmental conditions to maximize its effectiveness.

- *Changes in form or handling characteristics*
  - Vermifiltration technology creates substantial alterations in the physical characteristics and management protocols of liquid manure. Initially, it achieves a high degree of consistency and uniformity in the liquid manure, effectively reducing variations in its composition. This standardized effluent simplifies handling and ensures even nutrient distribution when employed as fertilizer. Additionally, vermifiltration excels in solid-liquid separation, significantly decreasing solid matter content within the liquid manure. As a result, it transforms the liquid manure into a more manageable form, simplifying its handling, transportation, storage, and field application.
- *Nutrient fate or end use projections*
  - Through vermifiltration, organic matter and nutrients undergo substantial transformations, resulting in significant reductions in solids, organic matter, and Total *Kjeldahl* Nitrogen (TKN). The effluent produced, although nutrient-reduced, carries with it the potential to influence nutrient management strategies and environmental stewardship. Data from the BIDA study at Royal Dairy show that organic matter, solids, and Total *Kjeldahl* Nitrogen (TKN) are progressively reduced as liquid manure progresses through the treatment path, highlighting the system's efficiency in nutrient removal. The downstream destiny of nutrients in vermifiltration is multifaceted, involving considerations related to environmental protection, agricultural benefits, regulatory compliance, and innovative resource utilization.
- *Macro-nutrient reductions or transformations*
  - Vermifiltration systems play a critical role in reducing macro-nutrients, particularly nitrogen and phosphorus. The BIDA study at Royal Dairy provides insights into the capacity of vermifiltration systems to manage these macro-nutrients effectively. One of the primary focal points is nitrogen reduction, with Total *Kjeldahl* Nitrogen (TKN) experiencing substantial decreases as liquid manure advances through the treatment process. The average reductions amounted to 5,800 pounds/day for solids

and 1,100 pounds/day for nitrogen, highlighting the system's efficiency in nutrient removal. However, the efficiency of nitrogen removal varied throughout the study period, ranging from 30% to 80%. Correlations between Total *Kjeldahl* Nitrogen (TKN) reduction and humidity, along with environmental factors like temperature and system shutdowns, suggested that moisture conditions significantly influenced the nutrient uptake within the vermiculture bed. These reductions underscore the vermifiltration system's efficiency in mitigating nitrogen compounds, including ammonia and organic nitrogen. While nitrogen is a central concern, vermifiltration systems hold promise for addressing another significant macro-nutrient: phosphorus. By diminishing phosphorus levels in liquid manure, these systems contribute to the mitigation of environmental issues associated with phosphorus runoff. The results indicate significant reductions in all measured macronutrients, with the exception of ash, and potassium (K). Similarly, there were statistically significant decreases in all minor nutrients, excluding sodium (Na), magnesium (Mg), and sulfur (S). Notably, sodium (Na) experienced a significant increase during this transformation.

- *Pathogen reductions or eliminations*
    - The process of organic decomposition and filtration within the vermifiltration beds, along with the activity of earthworms and microorganisms, can indirectly impact pathogens. However, it's essential to note that pathogen reduction is not the primary objective of the system, and additional dedicated pathogen treatment steps may be necessary for ensuring the safety of the treated effluent, particularly in applications where pathogen reduction is a critical concern.
- *Air emissions*
    - While the primary focus of vermifiltration is typically on wastewater treatment and nutrient management, there are indirect effects on air quality that can be noteworthy. Vermifiltration systems can contribute to lowering ammonia emissions by efficiently capturing and retaining nitrogen compounds, primarily in the form of organic matter and Total *Kjeldahl* Nitrogen (TKN). The BIDA study demonstrated a reduction in TKN from an average of 1,100 pounds/day, suggesting a potential decrease in ammonia emissions. By reducing these compounds, the vermifiltration system can help mitigate odors and potentially lower the emission of methane (CH_4) and nitrous oxide (N_2O), two greenhouse gases associated with manure decomposition. Additionally, the efficient removal of organic

matter within vermifiltration systems can lead to lower emissions of volatile organic compounds (VOCs) from manure.

- *Water quality*
    - Vermifiltration removes a significant amount of commonly regulated wastewater contaminants, and nutrients such as nitrogen and phosphorus, preserving nearby waterways. When nutrient loads are reduced in the waste stream, the treated effluent, with proper storage, is suitable for sustainable reuse in agricultural irrigation, including drip irrigation, flush systems, and field application, decreasing the risk for potential contaminants and nutrient overloads in surface or groundwater. Specifically, the evaluated BIDA system remotely tracks performance and water quality parameters via sensors and controls panels, ensuring safe and sustainable water outputs.
- *Fugitive nutrient emissions*
    - Vermifiltration systems have a significant impact on reducing fugitive nutrient emissions. By substantially reducing nitrogen and phosphorus compounds, vermifiltration mitigates the risk of nutrient runoff and leaching. Additionally, vermifiltration contributes to lowering ammonia emissions and concentrations in liquid manure. Vermifiltration's capacity to reduce organic matter content in liquid manure is another critical water quality improvement. High organic matter levels can deplete dissolved oxygen in aquatic ecosystems when discharged into water bodies. Vermifiltration's organic matter reduction aids in preventing oxygen depletion, ensuring healthier aquatic environments. Finally, these systems efficiently capture and settle out sediment and suspended solids from liquid manure, thereby reducing wastewater turbidity and preventing sediment transport into water bodies.

PROCESS MONITORING AND CONTROL SYSTEM REQUIRMENTS

Process monitoring and control requirements for vermifiltration systems are essential to ensure their optimal performance and efficiency in treating liquid manure. These requirements encompass various aspects of system operation and maintenance, including:

- *Required monitoring*— Monitoring is an integral aspect of operating vermifiltration systems efficiently. Several key parameters necessitate regular assessment to ensure optimal system performance:

- Liquid Manure Flow Rates: Continuous monitoring of flow rates guarantees that the system operates within its designed capacity and is free from blockages.
- Temperature: Monitoring the temperature within vermifiltration beds is critical for maintaining ideal conditions for earthworm activity and microbial processes.
- Moisture Content: Regular monitoring of moisture content is necessary to sustain optimal conditions for earthworms and microbial activity, often achieved through automated irrigation systems.
- Nutrient Concentrations: Assessing nutrient concentrations, including nitrogen (e.g., TKN), phosphorus, and organic matter, in influent and effluent streams is crucial for evaluating nutrient removal efficiency and overall system performance.
- pH Levels: Maintaining suitable pH levels within vermifiltration beds is essential for the performance of earthworms and beneficial microorganisms, necessitating pH monitoring and potential adjustment systems.
- Dissolved Oxygen (DO): Regular DO level checks ensure the presence of aerobic conditions necessary for earthworms and microbes.
- Redox Potential (Eh): Monitoring Eh helps prevent anaerobic zones that can impede system performance.
- Earthworm Health and Activity: Periodic assessment of earthworm populations' health and activity within the vermifiltration beds is imperative for system vitality and optimal performance.
- Sediment and Solids Accumulation: Monitoring sediment and solids accumulation within the beds is essential to prevent clogging and ensure uninterrupted operation.

- *Required control*— Control mechanisms are equally vital components of vermifiltration systems to maintain their efficiency and regulatory compliance. These control measures include:
  - Flow Regulation: Implementing control valves and mechanisms to regulate liquid manure flow rates and prevent overloading or underutilization of the system.

    - Irrigation Systems: Automated irrigation systems control moisture levels within vermifiltration beds to create an optimal environment for earthworms and microbial activity.
    - pH Adjustment: pH control systems maintain the desired pH levels within the beds, ensuring earthworm and microbial health.
    - Aeration Systems: Controlled aeration systems help maintain the necessary oxygen levels in the beds to support aerobic conditions.
- *Equipment included for monitoring*— Vermifiltration systems utilize various monitoring equipment to assess critical parameters and ensure efficient operation:
    - Flow Meters: Flow meters, including electromagnetic and ultrasonic types, monitor liquid manure flow rates at various points in the system.
    - Temperature Sensors: Temperature sensors placed within vermifiltration beds continuously measure bed temperature to ensure optimal conditions.
    - Moisture Sensors: These sensors assess moisture content within the beds, often integrated with automated irrigation systems.
    - Nutrient Analyzers: Analytical equipment, such as spectrophotometers and colorimeters, quantifies nutrient concentrations, including Total *Kjeldahl* Nitrogen (TKN), phosphorus, and organic matter.
    - pH Probes: pH probes measure pH levels within the beds, and some systems feature automated pH adjustment mechanisms.
    - Dissolved Oxygen (DO) Probes: DO probes monitor oxygen levels within the beds, ensuring the presence of aerobic conditions.
    - Redox Potential (Eh) Probes: Eh probes measure redox potential to prevent the development of anaerobic zones.
    - Earthworm Health Assessment Tools: Visual or non-invasive tools assess earthworm health and activity within the beds.
    - Sediment and Solids Sensors: Sensors detect sediment and solids accumulation within the beds, helping to prevent blockages.
- *Equipment included for controlling*— Control equipment ensures that vermifiltration systems maintain optimal conditions and include:

- Control Valves: Control valves regulate liquid manure flow rates, preventing overloading or underutilization of the system.
- Irrigation Systems: Automated irrigation systems control moisture levels within vermifiltration beds, optimizing conditions for earthworms and microbes.
- pH Adjustment Systems: pH adjustment systems, often featuring dosing pumps and controllers, maintain the desired pH levels.
- Aeration Systems: Controlled aeration systems deliver oxygen to the beds, ensuring adequate aerobic conditions.
- Data-Driven Control Algorithms: These algorithms process real-time data to make automatic adjustments to system parameters.
- Alarm Systems: Automated alarm systems trigger alerts and notifications, prompting operators to take corrective actions.
- Operator Training: Well-trained operators are equipped to utilize control systems effectively and make informed decisions.

TYPICAL OPERATIONS/MAINTENANCE PLAN WITH MONITORING REQUIREMENTS AND REPLACEMENT SCHEDULE

A well-structured operations and maintenance (O&M) plan is essential to ensure the consistent performance and longevity of vermifiltration systems. Such a plan includes monitoring requirements and replacement schedules for critical components. Here's an overview of a typical O&M plan for vermifiltration systems:

Routine Inspections and Monitoring:

1. Daily Monitoring:
    - Flow Rates: Check flow meters daily to ensure consistent liquid manure flow rates.
    - Bed Conditions: Visually inspect beds for any signs of blockages, clogs, or earthworm health issues.
    - Alarm Systems: Verify the functionality of alarm systems and address any triggered alarms promptly.
2. Weekly Monitoring:
    - Nutrient Levels: Conduct nutrient analyses (TKN, phosphorus, sodium, organic matter) weekly to track removal efficiency.

- pH Levels: Monitor and adjust pH levels as needed to maintain optimal conditions.
- Moisture Content: Check moisture levels within vermifiltration beds and adjust irrigation systems.

3. Monthly Monitoring:
    - Sediment and Solids: Assess sediment accumulation and remove excess solids from the beds.
    - Dissolved Oxygen: Monitor dissolved oxygen levels to ensure adequate aeration.
    - Redox Potential: Check redox potential to prevent anaerobic conditions.
    - Biofilter Surface: Regularly inspect and, if necessary, till the biofilter surface to promote proper infiltration of manure influent and maintain efficient percolation.
4. Quarterly and Annual Tasks:
    - Earthworm Health Assessment: Conduct earthworm health assessments quarterly or annually to evaluate earthworm populations' well-being.
    - Data Analysis: Regularly analyze data logs to identify trends and make adjustments to system parameters.
5. Biennial and Triennial Maintenance:
    - Component Replacements: Replace key components like pumps, valves, and sensors every two to three years, or as per the manufacturer's recommendations.
6. Annual Review and Reporting:
    - Regulatory Compliance: Ensure compliance with environmental regulations and permit requirements. Submit required reports and documentation to relevant authorities.
    - Emergency Response/Procedures: Establish emergency response protocols to address unexpected issues, shutdowns, or system failures promptly.
7. Operator Training: Provide ongoing training for system operators to enhance their ability to troubleshoot and manage the system effectively.
8. Record Keeping: Maintain detailed records of inspections, maintenance tasks, monitoring data, downtimes, and component replacements.

Replacement Schedule:

Regular replacement of system components is crucial to prevent breakdowns and maintain efficiency. A typical replacement schedule for critical components may include:

- **Flow Meters:** Replace every 5-7 years or as per manufacturer recommendations.
- **Pumps and Valves:** Replace every 2-3 years or based on wear and tear.
- **Sensors (pH, DO, Redox, Moisture):** Replace every 2-3 years or as needed due to calibration issues or malfunction.
- **Irrigation System Components:** Replace valves, nozzles, and hoses every 2-3 years.
- **Alarm Systems:** Upgrade or replace components as technology evolves or as they become outdated.
- **Earthworm Health Assessment Tools:** Replace as needed to maintain accurate assessments.

The O&M plan's effectiveness relies on a combination of routine monitoring, proactive maintenance, and a commitment to regulatory compliance. Regular inspections, data analysis, and timely component replacements contribute to the sustained success of vermifiltration systems in managing liquid manure while minimizing environmental impact.

CHEMICAL INFORMATION

In vermifiltration systems, the primary focus is on biological and physical processes rather than chemical treatments. These systems rely on earthworms and beneficial microorganisms to break down and transform organic matter and nutrients in liquid manure. Therefore, the use of chemicals is generally minimal or absent in traditional vermifiltration processes.

ESTIMATED INSTALLATION AND OPERATION COST

Industry averages provide a general estimate of the expenses involved in acquiring and installing vermifiltration technology. It is important to note that these costs are subject to variation based on specific project requirements, scale, and market conditions.

Equipment and Installation Capital Costs

The equipment and installation costs for vermifiltration technology can vary widely based on the scale of the project, specific site requirements, and the technology's complexity. Typically, these costs include expenses related to acquiring necessary equipment such as tanks, pumps, pipes, vermiculture beds, and filtration systems. Installation costs encompass labor, excavation, construction, and system setup. As of

2024, in a 100% manure recollection system, such as a freestall operation, capital costs for the BIDA system range from $2,000 to $3,000 per milking cow.

<u>Operation and Maintenance Costs (O&M)</u>
As of 2024, the operational costs under the BIDA system in a 100% manure recollection system, such as a freestall operation, span from $75 to $150 per milking cow per year.

- ***Electrical—*** Vermifiltration systems require electricity to power components such as pumps, aerators, and monitoring equipment. The exact electricity requirements depend on the size of the system, the intensity of aeration needed, and the level of automation for monitoring and control, but can be estimated to consume .001 to .003 kWh of electricity per gallon treated.

  The BIDA system exhibits remarkable energy efficiency, necessitating a minimal electricity input for the precise irrigation of wastewater across its surface area. The energy demand primarily stems from the activation of irrigation pumps, which exclusively engage during facility discharges. This activity occurs for approximately five hours a day, specifically on the days when the facility is active. Notably, this energy consumption pattern stands in stark contrast to conventional methods, where significant fossil fuel usage is essential for tasks such as sludge removal and lagoon cleaning.

- ***Labor—*** The specific labor requirements depend on the system's design, the expertise of the operators, and the volume of wastewater being treated. Labor requirements for vermifiltration systems involve regular monitoring of system components, routine maintenance tasks such as filter cleaning and pipe inspections, occasional interventions including adjusting aeration rates, record-keeping of system performance and issues, and providing proper training to system operators. Monitoring is essential for daily or weekly checks, maintenance tasks occur monthly or quarterly, and interventions are conducted as needed. Operators need to maintain detailed records to track system health effectively. Properly trained staff ensures efficient operation, early issue identification, and appropriate responses to system challenges, ensuring the vermifiltration system functions optimally.

- ***Maintenance Replacement—*** Vermifiltration systems require periodic maintenance and replacement of essential components, ensuring their longevity and efficiency. This includes replacing worn-out filters, pumps, aeration systems, and any other elements prone to wear and tear. Additionally, filter bed material and possibly worms should be replaced every 18 months, to enhance the system's reliability and effectiveness. Regular maintenance and replacement are integral to sustaining the system's performance over time, ensuring uninterrupted wastewater treatment and minimizing downtime. Properly scheduled replacements enhance the system's reliability and effectiveness, contributing to its long-term operational success.

EXAMPLE WARRANTY

A standard warranty for vermifiltration systems should encompass protection against defects in material and workmanship for a predetermined period after installation, typically ranging from a few years. This coverage ensures that essential components like pumps, filters, and aeration systems are free from manufacturing defects. The warranty should guarantee repair or replacement of faulty parts without additional charges to the customer. However, it is essential to note that damages resulting from incorrect installation, misuse, or unauthorized alterations should not be included in the coverage. To maintain the warranty's validity, regular system maintenance, including filter replacements and routine inspections, should be the responsibility of the system owner. Customers are usually expected to provide proof of purchase and grant access to authorized technicians for inspections and repairs. A comprehensive warranty aims to instill confidence in customers by assuring the system's proper functionality throughout the specified timeframe.

BioFiltro doesn't just provide equipment warranties; they take it a step further by guaranteeing specific effluent water quality parameters.

RECOMMENDED RECORD KEEPING

Comprehensive record-keeping serves as a valuable resource for system optimization, troubleshooting, and demonstrating compliance with regulatory requirements. The following are recommended record-keeping practices for a vermifiltration system:

1. **System Performance Logs:** Maintain detailed records of daily or weekly system performance, including downtimes, temperatures, moisture, flow rates, aeration schedules, and any irregularities observed during operation.
2. **Maintenance Records:** Document all maintenance activities, including filter replacements, component inspections, observance of earthworm health and activity, sediment and solids accumulation, and repairs. Note the date, nature of the maintenance, and the individuals responsible for the task.
3. **Intervention Reports:** Record any interventions made, such as adjustments to aeration rates, worm population replenishments, or system recalibrations. Describe the issue, the action taken, and its impact on the system.
4. **Sampling and Testing Data:** Keep records of water quality samples, including parameters like pH, dissolved oxygen, and nutrient levels. Regular testing data helps track the system's effectiveness and adherence to regulatory standards.

5. **Component Lifecycle Tracking:** Maintain a log of each component's installation date and expected lifespan. This record helps anticipate replacements and ensures timely upgrades, preventing unexpected system failures.
6. **Warranty and Service Agreements:** Organize and store all warranty documents, service agreements, and correspondence with system providers. This information is crucial for warranty claims and scheduled service visits.
7. **Training and Certification Records:** Document training sessions attended by system operators, noting the topics covered and certifications obtained. Well-trained staff ensures effective system management.
8. **Regulatory Compliance Records:** Stay updated with local regulations and maintain records demonstrating the system's compliance with environmental standards and permits. This documentation is essential for regulatory audits and inspections.
9. **System Modifications:** Record any modifications made to the system's design or components, along with the rationale behind the changes. Clear documentation aids in troubleshooting and future system upgrades.
10. **Incident Reports:** If any incidents, such as system malfunctions or environmental impacts, occur, create detailed incident reports. Include descriptions, nature of the incident, actions taken, and preventive measures implemented to avoid similar incidents in the future.

ALTERNATIVES FOR THE USE OF BYPRODUCTS

Byproducts from a vermifiltration system can be repurposed in various ways, promoting both sustainable practices and waste reductions. Here are some alternatives for utilizing vermifiltration system byproducts:

1. **Organic Fertilizer:** Worm castings, rich in nutrients, serve as an excellent organic fertilizer. They enhance soil structure, improve water retention, and promote plant growth. When not utilized on-farm, worm castings offer the potential for additional income for the farm to be sold as organic fertilizer.
2. **Soil Amendment:** Vermicompost can be mixed with soil to enhance its fertility, providing essential nutrients and improving overall soil health. Supplemental income for the farm may be accumulated by selling vermicompost as a soil conditioner to gardeners, nurseries, and other farms.
3. **Biopesticides:** Vermicompost extracts have natural pest repellent properties, making them useful in eco-friendly pest management practices.

4. **Biogas Production:** Organic matter from vermifiltration can be used in anaerobic digesters to produce biogas, a renewable energy source used for heating and electricity.
5. **Worm Farming:** Cultivating earthworms for sale can create additional revenue streams. Worms can be sold to gardeners, farmers, or fishing enthusiasts.
6. **Aquaponics and Hydroponics:** Vermicompost tea, a liquid extract from worm castings, serves as a nutrient-rich solution for aquaponic and hydroponic systems, supporting plant growth without soil.

INDEPENDENT VARIFIABLE DATA DEMONSTRATING RESULTS/CREDENTIALS

Appendix A is a summary of the independent review of peer-reviewed and technical data available for this class of technology and is available through Newtrient. The Newtrient work involves an internal peer-review, comprised of ten national experts in the field of manure management, with the final output presently being prepared for external peer-review and publication. While the reference list is not a complete listing of all related peer-reviewed literature it does highlight key references specific to this class of technology and how it relates to key performance indicators within this NRCS Standard 629.

Appendix B is a summary of data obtained during a Newtrient-managed third-party review of a BioFiltro BIDA® System at Royal Dairy in Royal City, Washington. The information was from a 15-week analysis of the system and its performance by Central Washington University —the work has not been peer-reviewed.

Appendix C is the complete Central Washington University report detailing the third-party review at Royal Dairy in Royal City, Washington.

CONTACT INFORMATION—VENDOR

While not an absolute conclusive list, the list below identifies vendors that are active in the application of this class of technology on manure projects within the US.

1. **BioFiltro**
   Address: 2911 E. Barstow Ave, M/S OF 144 Fresno, CA
   Phone: 509-527-0526
   Website: https://biofiltro.com/
   Contact: info@biofiltro.com
   Company Information: BioFiltro designs, engineers, builds, and can also maintain onsite cost-effective wastewater treatment solutions to ensure that dairies comply with their nutrient management plans. Farmers can purchase just the design, a design/build, or a full service “Wastewater as a Service” package; the

latter of which encompasses a flat monthly fee that includes the design, build, and operations of the plant for a set term.

CONTACT INFORMATION—USER

Commercial facilities presently operating in the U.S. with this class of technology are identified below. The list is a best effort but not inclusive of all installations. BioFiltro is an international wastewater filtration company with offices in the United States of America, New Zealand, and Chile. There are 154 plants in 8 countries successfully treating 2.8 billion gallons of wastewater annually.

Dairies
Fanelli Dairy Farm – Hilmar, CA
Fresno State University – Fresno, CA
Royal Dairy – Royal City, WA

Food Processors

Moody Dunbar, Inc. – Johnson City, TN (headquarters)
Refresco – Walla Walla, WA
Taylor Brothers Farms – Yuba City, CA

Municipal Waste

U.S. Customs and Border Protection – Calexico, CA

Wineries

Abbott Claim – Carlton, OR
Aonair Wine – St. Helena, CA
Ehler's Estate – St. Helena, CA
Fetzer Vineyards – Hopland, CA
Lynmar Estate – Sebastopol, CA
Michael Ros Winery – Fredericksburg, TX
Northstar – Walla Walla, WA
O'Neill Vintners & Distillers – Parlier, CA
Peltier Winery & Vineyards – Acampo, CA
Wise Villa Winery – Lincoln, CA

OTHER CONSIDERATIONS

The NRCS documentation specifies that a third-party review shall contain 15 specific items that comprise the report above, but as part of working with the farm and the technology provider during the 15-week evaluation period there are often other important and valuable learnings that may be helpful for NRCS and others as they consider this technology. Below is a list of Other Considerations that should be included in the evaluation of this technology:

During the study period, the efficiency of the BIDA system in nitrogen removal exhibited significant variations, ranging from 30% to 80%. Factors such as humidity and wetting and drying events appeared to influence the system's nutrient uptake. Notably, higher nitrogen removal immediately following a brief shutdown in September hinted at the impact of drying conditions during that period. The BIDA system's operational consistency faced challenges due to variable flow rates, intermittent shutdowns, and irregular irrigation patterns across the BIDA beds. Fluctuations in temperature and humidity, from warm fall days to freezing December temperatures, further contributed to system variability.

Additionally, an increase in sodium (Na) concentration was observed in the liquid manure along the wastewater treatment flow path, particularly across the BIDA bed. This rise in Na levels might be attributed to evaporation and the lack of biological sodium uptake. An anomalous spike in Na concentrations in samples from a holding tank for BIDA effluent indicated a concentrated Na source introduced into the wastewater, either within the BIDA beds or the holding tank itself.

It may be beneficial to explore a better understanding of coarse solids removal before entering the BIDA system. Setting an upper limit to solids content could be crucial to ensure sustained performance of the BIDA system. Notably, there appears to be a gap in existing studies or reviews directly addressing this aspect, indicating a potential area for further research and consideration in optimizing the system's functionality.

These considerations provide additional insights into the evaluation of the vermifiltration technology beyond the specific items outlined in the NRCS documentation, allowing for a comprehensive assessment of its suitability and potential benefits for various livestock operations.

CONCLUSION

Vermifiltration technology presents a significant advancement in sustainable waste management for dairy operations, offering a range of tangible benefits that enhance environmental responsibility and operational efficiency. By harnessing the natural filtration capabilities of composting worm beds, vermifiltration stands as a practical and effective solution tailored to the specific needs of dairy farming.

Compared to traditional methods, vermifiltration, in association with other separation technologies upstream of the vermifiltration system, demonstrates impressive performance. The system efficiently filters wastewater, substantially reducing nutrient content without resorting to chemical additives. Its adept removal of organic matter, pathogens, and suspended solids ensures thorough wastewater treatment. Additionally, vermifiltration conserves water by recycling manure liquid, promoting responsible water management practices.

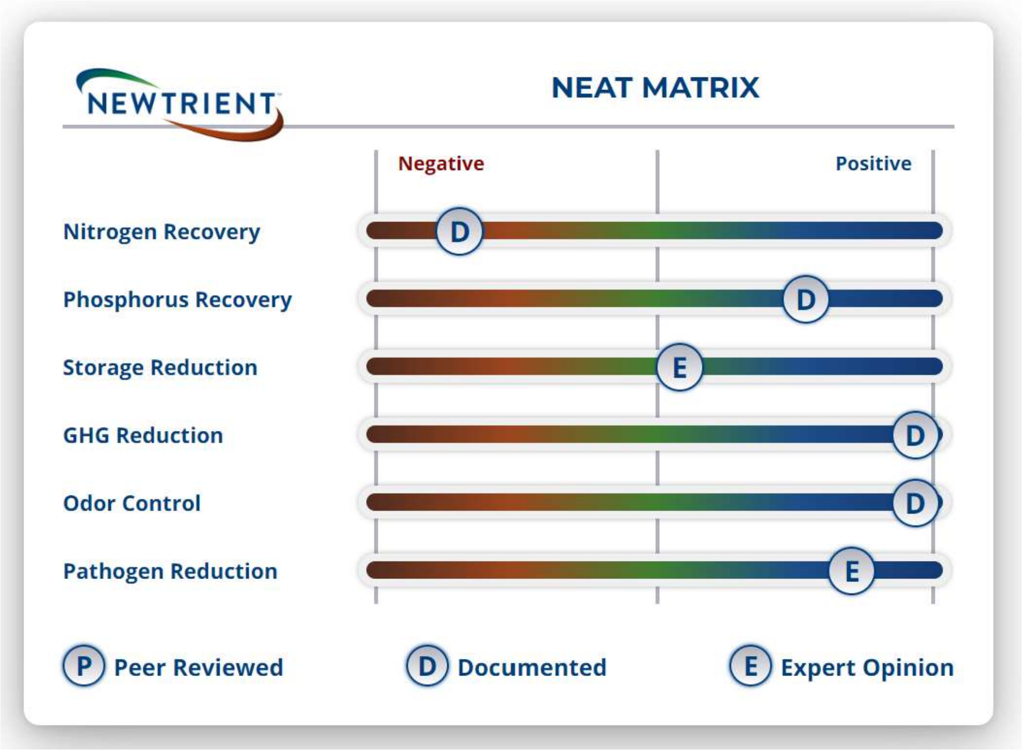
A key strength of vermifiltration lies in its adaptability and scalability, making it suitable for operations of varying sizes. By concentrating nutrients into solid form, vermifiltration reduces waste volume, easing storage and transportation challenges. These nutrient-rich solids serve valuable purposes as bedding material or soil amendments, contributing to a sustainable agricultural ecosystem.

Moreover, vermifiltration seamlessly aligns with regulatory requirements, enabling dairy farmers to meet environmental compliance standards effectively. Its straightforward setup and reduced maintenance demands translate into significant cost savings. Vermifiltration empowers dairy operations, allowing them to optimize waste management, adhere to regulations, and minimize their environmental footprint.

In summary, vermifiltration emerges as a crucial tool in the dairy industry's pursuit of efficient, environmentally conscious waste management practices. Its ability to balance economic viability, environmental sustainability, and operational excellence positions it as a fundamental technology, paving the way for a more responsible future in dairy farming.

Appendix A

NEWTRIENT CRITICAL INDICATOR ANALYSIS— NITRIFICATION DENITRIFICATION



Overall Summary

Vermifiltration technology represents a novel approach to wastewater management in the dairy industry. By utilizing the power of earthworms and beneficial microorganisms, this innovative system significantly improves the manure treatment process, providing a sustainable solution to dairy wastewater challenges.

Key Features:

1. **Efficient Contaminant Removal:** Vermifiltration systems excel in removing contaminants from wastewater, with total suspended solids (TSS) reduction averaging around 85%. This high efficiency ensures the production of cleaner water for reuse or safe disposal.
2. **Water Recycling:** One of the key advantages of vermifiltration technology is its ability to facilitate on-farm water recycling. Treated water, boasting substantial reductions in TSS and nitrogen (N) load, can be effectively reused in dairy

processes or for irrigation purposes, conserving water and reducing environmental impact.

3. **Greenhouse Gas (GHG) Emission Reduction:** By minimizing the production of methane (CH_4) emissions through the reduction of total suspended solids (TSS), vermifiltration systems play a significant role in mitigating greenhouse gas emissions. This reduction contributes positively to environmental sustainability efforts.
4. **Low Energy Consumption:** Vermifiltration technology stands out for its minimal energy requirements. Typically, these systems utilize electricity solely for wastewater irrigation, resulting in a low carbon footprint associated with energy usage.
5. **Carbon Sequestration and Soil Health:** Vermifiltration systems yield high-quality vermicompost, a nutrient-rich organic fertilizer. Vermicompost enhances soil health, promotes plant growth, and aids in carbon sequestration, making it an environmentally friendly alternative to synthetic fertilizers.
6. **Economic Viability:** Beyond environmental benefits, vermifiltration technology offers economic advantages. Farmers can generate income by selling vermicompost, worms, and worm castings while also potentially participating in carbon offset markets, bolstering their financial sustainability.

Applications: Vermifiltration technology finds applications beyond dairy wastewater management. It is adaptable for various organic waste treatment scenarios, such as agricultural runoff, aquaculture, food processing wastewater, and municipal sewage. Its versatility makes it a valuable asset in sustainable waste management practices across different sectors.

Future Implications: As the agricultural sector faces increasing pressure to adopt eco-friendly practices, vermifiltration technology stands at the forefront of sustainable wastewater management. Continued research and development in this field holds the potential to revolutionize how industries manage their organic waste, promoting environmental conservation and resource efficiency.

References

Allred, J., 2019, "Dairy Lagoon Nutrient Extraction with Vermicomposting." Presented at the World Organic Recycling Council (WORC) Annual Conference, Vancouver, WA. https://static1.squarespace.com/static/585c2db75016e175c9d685b7/t/5bef12f44d7a9c8d998d1484/1542394624079/

Arora, S., Saraswat, S., 2021, "Vermifiltration as a Natural, Sustainable and Green Technology for Environmental Remediation: a New Paradigm for Wastewater Treatment Process." CRGSC 4, 100061.

BioFiltro System. (2017). BioFiltro System (BIDA® System) Fanelli Dairy, Hilmar, CA. Study Prepared by: Dr. Frank Mitloehner. Date of Case Study: September 11, 2017. Retrieved from https://www.newtrient.com/wp-content/uploads/Biofiltro_BIDA-System_Fanelli-Dairy_Case-Study_Prf2.pdf

BioFiltro, Inc., 2022, "BioFiltro: Worm Powered Wastewater Solutions: Home." 2022, https://biofiltro.com/.

Combs, S.M., Hoskins, B., Jarman, J., Kovar, J.L., Watson, M.E., Wolf, A.M., Wolf, N., 2023, "Recommended Methods of Manure Analysis (A3769)", University of Wisconsin-Extension, Cooperative Extension Publishing,

Dore, S., Deverel, S., Iacobelli, A., Sjögren, M., 2019, "White Paper: The Biofiltro BIDA® Wastewater Treatment System." HydroFocus. Inc.

Ispolnov, K., Aires, L.M.I., Lourenco,N.D., Vieira, J.S., 2021, "A Combined Vermifiltration-Hydroponic System for Swine Wastewater Treatment." *Appl. Sci.* 2021, *11*(11), 5064. doi.org/10.3390/app11115064

Lai, E., Hess, M., Mitloehner, F., 2018, Profiling of the microbiome associated with nitrogen removal during vermifiltration of wastewater from a commercial dairy. Frontiers in microbiology, 9, p.1964.

Lim, S.L., Wu, T.Y., Clarke, C., 2014, "Treatment and Biotransformation of Highly Polluted Agro-Industrial Wastewater from a Palm Oil Mill into Vermicompost using Earthworms. J. Agric. Food Chem. 62 (3), 691–698.

Lourenco, N., Nunes, L.M., 2017, "Optimization of a Vermifiltration Process for Treating Urban Wastewater. Ecol. Eng. 100, 138–146.

Wang, L.M., Zhang, Y.M., Luo, X.Z., Zhang, J.B., Zheng, Z., 2016, Effects of Earthworms and Substrate on Diversity and Abundance of Denitrifying Genes (nirs and nirk) and

Denitrifying Rate during Rural Domestic Wastewater Treatment. Bioresour. Technol. 212, 174–181.

Appendix B

Third-Party Review of BioFiltro Biodynamic Aerobic (BIDA®) System at Royal Dairy – Royal City, WA (Report Summary)

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Lisa Matthews
Central Washington University
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Ellensburg, WA 98926, USA

JANUARY 2024

BACKGROUND
The efficient utilization of dairy manure, a valuable agricultural by-product traditionally used to fertilize crops and maintain cattle well-being, presents a pressing challenge for farmers. Exploring optimal export avenues and on-farm management strategies is essential. Currently, there is a need for balance in manure management to prevent potential overapplication of manure nutrients onto fields, which could contribute to increased nitrate levels in local groundwater aquifers. To address this multifaceted issue, innovative solutions are imperative. Farmers require novel approaches to manure management that enhance water quality, preserve water resources, ensure compliance with regulatory standards, and support economic viability, necessitating a strategic reevaluation of current practices.

In response to this need, vermifiltration technology has emerged as a valuable alternative, providing a decentralized and environmentally friendly approach to wastewater treatment. At the forefront of this innovation is Royal Dairy, a sustainable dairy farm in Grant County, Washington. With a herd of approximately 6,000 milking cows, the farm faced the challenge of managing significant volumes of liquid manure. Recognizing the need for a sustainable solution, Austin Allred, the owner of Royal Dairy, implemented a pioneering wastewater treatment system in collaboration with BioFiltro, a leading bioremediation company. This system, known as the Biodynamic Aerobic (BIDA®) System, utilizes composting worm beds to efficiently remove excess nutrients from liquid manure while generating valuable worm casting compost.

This study examined the efficiency of the vermifiltration system at Royal Dairy, analyzing its nutrient reduction capabilities in detail. By monitoring the system's performance over several months and under varying conditions, this evaluation aimed to provide valuable insights into the potential of vermifiltration as a sustainable solution for managing wastewater in large-scale agricultural operations. Through sampling and analysis, this study sheds light on the practicality and effectiveness of vermifiltration pertaining to the dairy industry.

INTRODUCTION
In recent years, vermifiltration has emerged as a promising technology for wastewater treatment, particularly in various agricultural settings. This innovative approach utilizes composting worm beds to filter wastewater, reducing its nutrient load significantly, and operates with minimal energy requirements (Arora and Saraswat, 2021). The process (Figure 1) involves applying influent wastewater via a sprinkler system, evenly over beds of high carbon source organic material, inhabited by earthworms, microbes,

castings, and compost products. These organisms metabolize organic matter and nutrients from the influent, transforming it into a nutrient-rich soil amendment. Effluent is removed from the beds through a drainage basin located at their base and stored in a holding pond until reuse. Vermifiltration has gained attention for its efficacy in municipal, domestic, and industrial wastewater treatment, and more recently, in livestock farming contexts such as swine and dairy farms.

The vermifiltration process at Royal Dairy involves several stages, from the initial mechanical separation of solids to the final nutrient reduction in the BIDA beds. The technology's efficacy lies in the symbiotic relationship between earthworms, microbes, and the influent wastewater. As the wastewater passes through the vermifiltration beds, organic matter and nutrients are digested and transformed, leading to a significant reduction in nutrient content. This process not only yields nutrient-reduced water suitable for efficient and sustainable irrigation but also produces high-quality worm casting compost, providing circularity to the farm.

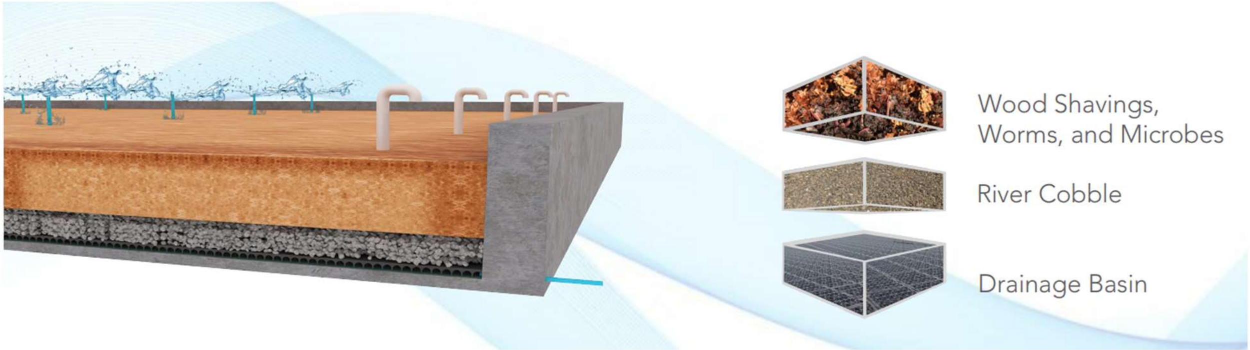

Figure 1. BIDA® System diagram.
Source: Biofiltro (2018). Case Study: Royal Dairy.

TREATMENT SYSTEM AT ROYAL DAIRY

The wastewater treatment system at Royal Dairy involves multiple stages, including mechanical separation and vermifiltration (Figure 2). Initially, raw manure from the free stalls is flushed with water and directed to primary holding pits. From there, the manure wastewater is pumped through the first set of 40-mil slope screens (Screen System I) to remove larger solids. It then moves to a secondary holding pit and travels through a sand lane to a second set of 40-mil slope screens (Screen System II) for further separation. The clarified wastewater is stored in a 7-million gallon holding pond before entering the BIDA Equalization Tank (BIDA Inflow). Within the BIDA Equalization Tank, manure wastewater is stabilized to create a more optimal, uniform influent for the BIDA system. An automated system monitors the wastewater, releasing it via sprinkler to the BIDA bed irrigation system. In the BIDA beds, the water undergoes treatment for approximately four hours, where filter media and biota reduce excess nutrients and solids. The treated water drains to the bottom of the bed and is pumped into a 30-million-gallon pond (BIDA Outflow) for future use. The Royal Dairy BIDA system comprises seven 46,000 ft^2 concrete beds and utilizes 500 worms/ft^2. This system can effectively reduce excess nutrients and solids in 200,000 gallons of manure wastewater per day by up to 70% and 90%, respectively, as estimated by Royal Dairy (Allred, 2019).

Figure 2. Royal Dairy Farm Wastewater Flow.

METHODOLOGY

Central Washington University (CWU) conducted a 15-week monitoring trial of the Royal Dairy BIDA system from August 15 to December 23, 2022. Liquid manure and compost samples were collected three times weekly from various points in the system. Liquid manure samples were taken at five locations, where they were then mixed and stored in 16-oz. bottles. Solid compost samples were collected using a pitchfork and placed in plastic bags.

During the study, operational changes occurred, impacting the study's duration and sampling locations. Flow interruptions in the BIDA system due to freezing temperatures led to adjustments in sampling procedures, requiring the collection of BIDA Outflow samples from an underground mixing pit. This pit contained effluent from two out of seven system beds, and the collected samples were stagnant and had been sitting in the pit. BIDA system overloading incidents led to a shutdown from September 10-13, and maintenance on the 7-million-gallon lagoon that feeds the BIDA's equalization tank occurred from October 26 to November 11. Consequently, the study was extended by three weeks to achieve a full 15 weeks of sampling, concluding with final samples taken on December 23, 2022.

Samples were transported to A&L Great Lakes Laboratories for analysis, following recommended methods of manure analysis. Various tests, including pH, moisture content, solids percentage, macro and micro-nutrient concentrations, and organic matter, were conducted on liquid manure and solid compost samples. Statistical analyses were performed using R software and XLSTAT. Methods included identifying outliers, normality tests, non-parametric tests for differences between sampling locations, and trend analyses. Efficiency was evaluated in terms of nutrient load, converting concentrations to lb./day using manure density and 24-hour flow data. The study focused on characterizing the wastewater pathway and evaluating the BIDA system's efficiency, providing valuable data for understanding its performance in nutrient reduction.

DISCUSSION OF RESULTS

KEY BENEFITS OF VERMIFILTRATION

The study conducted at Royal Dairy in central Washington provides valuable insights into the application of vermifiltration technology. This comprehensive analysis evaluated the efficiency of a full-scale vermifiltration system in reducing nutrient loads from liquid manure.

Performance: Although operational variability took place during the study, the effectiveness of the BIDA system in reducing nutrients is evident through substantial decreases in several measured parameters, as the liquid manure progresses from the BIDA Inflow to the BIDA Outflow. Notable reductions in organic carbon (OC), Total *Kjeldahl* Nitrogen (TKN), ammonia-nitrogen (NH_4), phosphorus (P), and calcium (Ca) were documented throughout the BIDA system (Table 1); however, other nutrients such as potassium (K) and sodium (Na) did not experience reductions. Despite the limitations of percent change calculations, which do not consider influent concentration and system usage, they offer a comprehensive overview of nutrient reductions, ranging from 45% to 67% across various elements. These findings underscore the pivotal role of the BIDA system in efficiently diminishing nutrient loads, contributing to a more sustainable wastewater treatment process at Royal Dairy. In humid climates, it is advisable to cover the BIDA system to prevent potential issues such as excess moisture and leaching through the bed.

Table 1. Concentrations for Selected Nutrients for BIDA Inflow and Outflow and Percent Change.

	BIDA Influent			BIDA Effluent			Change (In-Out)	
	Median	Ave	Std dev	Median	Ave	Std dev	Ave	Std dev
Parameter	wt %	wt %	wt %	wt %	wt %	wt %	%	%
Organic Carbon	0.57	0.59	0.15	0.29	0.31	0.09	45	19
Total Kjeldahl Nitrogen	0.14	0.15	0.02	0.075	0.07	0.03	51	18
Ammonia-Nitrogen	0.07	0.08	0.01	0.03	0.02	0.01	67	14
Phosphorus	0.02	0.02	0.003	0.011	0.01	0.004	46	25
Potassium	0.169	0.17	0.02	0.17	0.17	0.04	-2	25
Calcium	0.06	0.06	0.01	0.03	0.02	0.01	56	28
Sodium	0.11	0.12	0.02	0.15	0.16	0.02	-30	29

Reduction in Nutrients: The vermifiltration system emerged as a pivotal component of the wastewater treatment process, demonstrating substantial nutrient reduction capabilities. Statistical analyses reveal significant decreases in organic carbon (OC), Total *Kjeldahl* Nitrogen (TKN), ammonia-nitrogen (NH_4), phosphorus (P), and calcium (Ca) as the liquid manure traverses from the BIDA Inflow to the BIDA Outflow. However, it's crucial to consider that there is a notable increase in sodium (Na) of approximately 30%, which contrasts with the reductions observed in other vital nutrients. Notably, the BIDA system's impact on nitrogen reduction is substantial, with TKN showing a 51% average decrease.

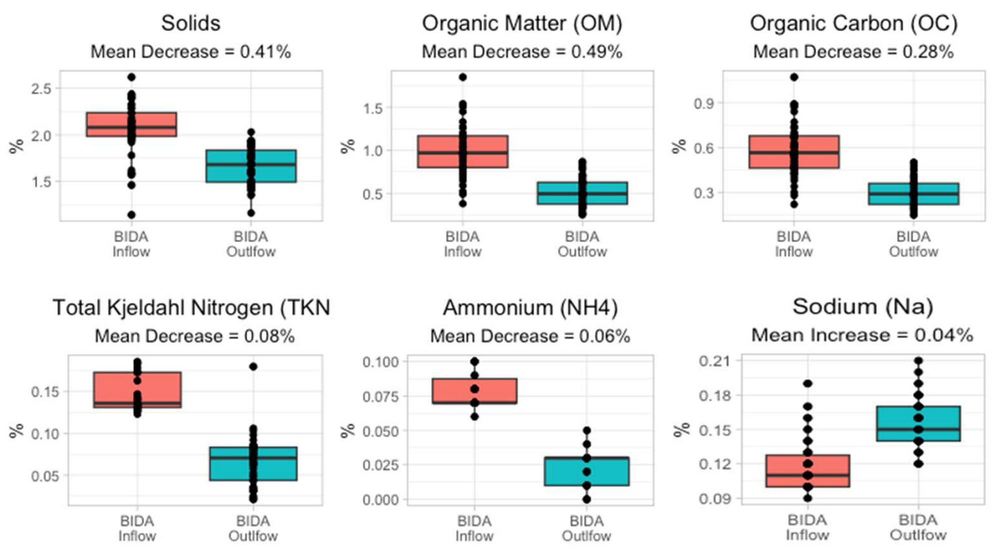

Figure 3. Box Plots Showing Change in Nutrient Concentrations Across BIDA System.

By effectively minimizing total nitrogen concentrations, the treated effluent becomes more suitable for reuse on the dairy, specifically for irrigation and flush water. This reuse aligns with sustainable water management practices, allowing the dairy to optimize its water resources, protect water quality, and promote a closed-loop system.

Furthermore, the benefits of reducing total nutrients in the effluent extend beyond the immediate operational considerations of the dairy. The treated water, now containing lower nutrient loads, contributes to the protection and preservation of local waterways, ensuring environmentally responsible management of nutrients in a way that is supportive of the overall health of the surrounding aquatic environment. This dual-purpose achievement—enhancing on-site water reuse while safeguarding downstream water quality—reflects a comprehensive and sustainable approach to dairy wastewater management.

Reduction in Solids: Beyond its capacity for nutrient reduction, the BIDA system demonstrates notable efficacy in attenuating solid content within the liquid manure. The system achieves a notable decrease in solids from 41,000 lbs./day at the first set of screens to 27,000 lbs./day upon exiting the BIDA system, reflecting a reduction of 14,000 lbs./day or a 34% reduction in solid content (Table 2). This decrease encompasses the contribution of the BIDA beds, where a specific reduction of 5,800 lbs./day occurs.

Solid separation is an essential pre-treatment that simultaneously generates valuable fiber, providing the option to utilize it on the dairy as bedding, compost, or fertilizer or market it for sale. Without this preliminary step, the sprinklers are prone to clogging, leading to an uneven application of lagoon water onto the filter surface, highlighting the importance of effective solids removal for the optimal functioning of the treatment process. Additionally, an excess of solids in the effluent may accumulate in the BIDA bed, potentially diminishing the inflow into the bed by sealing or "blinding" the surface. This could result in anaerobic conditions and significantly impair the overall performance of the system. The combined efforts of these treatment components underscore the efficacy of Royal Dairy's system approach to mitigating solids and emphasize the specific contributions of each stage in the overall reduction process.

Table 1. Total Mass per Day of Solids and Nutrients along Wastewater Treatment Path.

	Total Solids (1000 lbs./day)			**Organic Matter (1000 lbs./day)**			**Total Kjeldahl Nitrogen (1000 lbs./day)**		
	median	***ave***	***stdev***	***median***	***ave***	***stdev***	***median***	***ave***	***stdev***
Screen I Inflow	41	41	23	20	23	14	2.5	2.4	1.4
Screen I Outflow	41	38	21	20	20	11	2.5	2.3	1.4
Screen II Outflow	38	36	17	19	19	9	2.6	2.5	1.3
BIDA Inflow	35	33	15	24	16	8	3.3	2.3	1.0
BIDA Outflow	27	27	14	8	9	6	1.1	1.2	0.7

EVALUATION KEY ISSUES AND CHALLENGES

Operational Variability: The operational dynamics of the BIDA system displayed inconsistency during the study period, marked by fluctuating flow rates and two extended shutdowns, one lasting nearly a month. Irrigation patterns across the BIDA beds were irregular, with certain beds receiving more frequent irrigation than others. Moreover, the study observed substantial changes in temperature and humidity, transitioning from unseasonably warm conditions with low humidity in early fall to freezing temperatures and higher humidity in December. These dynamic environmental shifts likely played a role in the observed variability in BIDA system efficiency.

Operational adjustments were necessitated throughout the study, impacting both its duration and specific sampling locations. Interruptions in the flow through the BIDA system and lagoon maintenance prompted the field researcher to collect samples from an underground mixing pit. These samples, stagnant and residing in the pit for some time, posed challenges. Overloading incidents and dairy lagoon maintenance further extended the study by three weeks to ensure a comprehensive 15-week sampling period.

Inconsistent Nitrogen Removal Efficiency: The efficiency of the BIDA system in nitrogen removal displayed significant variability, ranging from approximately 30% to 80%. A correlation between Total *Kjeldahl* Nitrogen (*TKN*) reduction and humidity, coupled with wetting and drying events, underscored the sensitivity of the vermiculture bed's nutrient uptake to moisture conditions in the compost material. Notably, the higher nitrogen removal efficiency observed immediately after a brief shutdown in September suggested the potential impact of the drying process during that period.

Sodium Concentration in Wastewater Treatment: The analysis revealed a notable increase in sodium (Na) concentration within the liquid manure along the wastewater treatment flow path. This rise is likely attributed to a combination of evaporation and the absence of biological uptake of sodium. Interestingly, a significant reduction in sodium concentration was observed across the inclined screens, indicating the potential retention of sodium in the filter bed. Subsequently, samples collected from a holding tank for BIDA effluent exhibited anomalously high Na concentrations. These findings raise questions about the mechanisms of sodium accumulation within the BIDA beds and its release during effluent application, warranting further investigation into the source and dynamics of sodium in the wastewater treatment process.

IMPLICATIONS

Key findings underscored the substantial role of the vermifiltration system in reducing solids and nutrients at Royal Dairy. However, operational inconsistencies, varying weather conditions, and anomalies in nutrient concentrations posed challenges to consistent efficiency.

To further explore and refine these insights, future studies could delve into seasonal trends in nutrient reduction, examining their correlation with weather conditions, particularly humidity. Additionally, a comparative analysis of efficiency and irrigation patterns, incorporating periodic short-term shutdowns for bed drying, could provide deeper insights. Measures of biological uptake, emissions from BIDA beds, and a detailed examination of compost composition, particularly sodium accumulation, could contribute to a more comprehensive understanding of nutrient fluxes. Lastly, investigating worm density and soil health over time and across seasons, coupled with a comparison to BIDA efficiency, would offer valuable insights into the interplay between biological factors and system performance. For additional information on the vendor, environmental impacts, financial implications, and BioFiltro vermifiltration technology, visit the BioFiltro Vendor Snapshot on the Newtrient website.

REFERENCES

Allred, J., 2019, “Dairy Lagoon Nutrient Extraction with Vermicomposting.” Presented at the World Organic Recycling Council (WORC) Annual Conference, Vancouver, WA. https://static1.squarespace.com/static/585c2db75016e175c9d685b7/t/5bef12f44d7a9c8d998d1484/1542394624079/

Arora, S., Saraswat, S., 2021, “Vermifiltration as a Natural, Sustainable and Green Technology for Environmental Remediation: a New Paradigm for Wastewater Treatment Process.” CRGSC 4, 100061.

Biofiltro. (2018). Case Study: Royal Dairy. Retrieved from https://biofiltro.com/wp-content/uploads/2023/11/Case-Study-Royal-Dairy_Jan2018.pdf

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Appendix C

Third-Party Review of BioFiltro BIDA® System at Royal Dairy in Royal, WA (Full Report)

BioFiltro BIDA® System Efficacy in Removing Nutrients from Manure Wastewater at Royal Dairy

Royal Dairy, Royal City, Grant County, Washington

Prepared By: Dr. Carey Gazis & Lisa Matthews

Central Washington University

February 2023

Abstract

Vermifiltration is a promising emerging technology in which a composting worm bed is used to filter wastewater and reduce its nutrient load. This study monitored the efficiency of a full-scale vermifiltration system at a large (6000 cows) dairy farm in central Washington. Between August and December 2022, liquid manure samples were collected regularly from five locations along the wastewater flow path, including the influent and effluent to the vermifiltration system. These samples along with solid compost samples from the vermifiltration bed were analyzed for a suite of nutrients. Flow through the vermifiltration system was shut down for an extended period in mid-October to mid-November due to maintenance of the holding lagoon from which the vermifiltration system draws the influent liquid manure. Weather and manure flow conditions were significantly different before and after this shutdown.

Analytical results for liquid manure indicate that the vermifiltration system is responsible for the bulk of the nutrient reduction of the entire wastewater treatment system, with average concentration reductions in the range of 45% to 70% for most nutrients. Sodium (Na) is a noted exception that increases in concentration along the wastewater flow path. This increase in sodium is likely due to evaporation and some contamination from Na salts within the vermifiltration holding tanks or beds. Total Kjeldahl Nitrogen (TKN) reductions across the vermifiltration system generally range from 30% to 80% with a mean of ≈60%. This corresponds to a TKN removal rate of 1100 pounds per day. When divided over the entire area of the vermifiltration system, this corresponds to a TKN removal rate per unit bed area of 0.0044 lb/ft2/day. There is a significant correlation between humidity and percent reduction in TKN. Other factors that may influence the efficiency of the BIDA system are short and long-term system shutdowns and related drying and wetting of beds, precipitation events, total flow through the system, nutrient load of BIDA influent, and biotic health within the vermifiltration bed.

Background

Vermifiltration

Vermifiltration, a technology in which a composting worm bed is used to filter wastewater, is a promising treatment method to reduce nutrients in wastewater. Vermifiltration is considered to be a new paradigm for wastewater treatment because it is decentralized, environmentally sustainable, and does not require high energy inputs (Arora and Saraswat, 2021). A vermifiltration system consists of a bed or beds of sediment overlain by an organic layer that typically consists of wood shavings, earthworms, and associated microbes, castings, and compost products. Influent wastewater is applied evenly to the beds via a sprinkler system; effluent is removed through a drainage basin at the base of the beds. The earthworms and their community of organisms ingest and digest organic matter and nutrients from the influent wastewater thus providing an aerobic wastewater treatment process. Although this is a land-intensive process, it requires lower energy and operational expenditures than conventional treatment methods. A number of studies have analyzed the efficacy of vermifiltration systems for municipal, domestic, and industrial wastewater (e.g., Lim et al., 2014; Wang et al., 2016; Lourenco and Nunes, 2017). More recently, the technology is being tested and used for wastewater management in livestock farming, including swine (e.g., Ispolnov et al., 2021) and dairy farms (e.g., Dore et al., 2022).

Royal Dairy

Royal Dairy in Grant County, Washington, has been owned and operated as a sustainable dairy by Austin Allred since 2016. The dairy comprises approximately a mixed herd of 6000 milking cows in free stall barns with a manure-flush system and outdoor lots. Allred was the first farmer in Washington state to employ a full-scale biologically based wastewater treatment system, earning him the 2018 Outstanding Dairy Farm Sustainability Award by the Innovation Center for U.S. Dairy (Dairy Farmers of Washington 2018). The system, designed by California-based bioremediation company BioFIltro, uses vermifiltration to simultaneously remove excess nutrients from the liquid manure from this large dairy and generate thousands of cubic yards of worm casting compost biannually. Treated water is suitable for irrigation or reuse at the dairy, while the worm casting compost is sold as a nutrient-rich soil amendment.

BioFiltro BIDA® System Overview

BioFiltro's Biofilter Dynamic Aerobic (BIDA) system was patented in 2009 (Dore et al. 2019). The BIDA vermifiltration system (Figure 1) consists of open concrete beds containing: 1) a coarse drainage basin bottom, 2) a river cobble support layer, and 3) approximately 3 feet of wood chips mixed with Eisenia andreii (red wriggler worms) and accompanying microbes (Figure 1). The system includes aeration piping extending from the surface to the drainage basin bottom and is fed by a hard pipe irrigation system extending across its surface (BioFiltro, 2022).

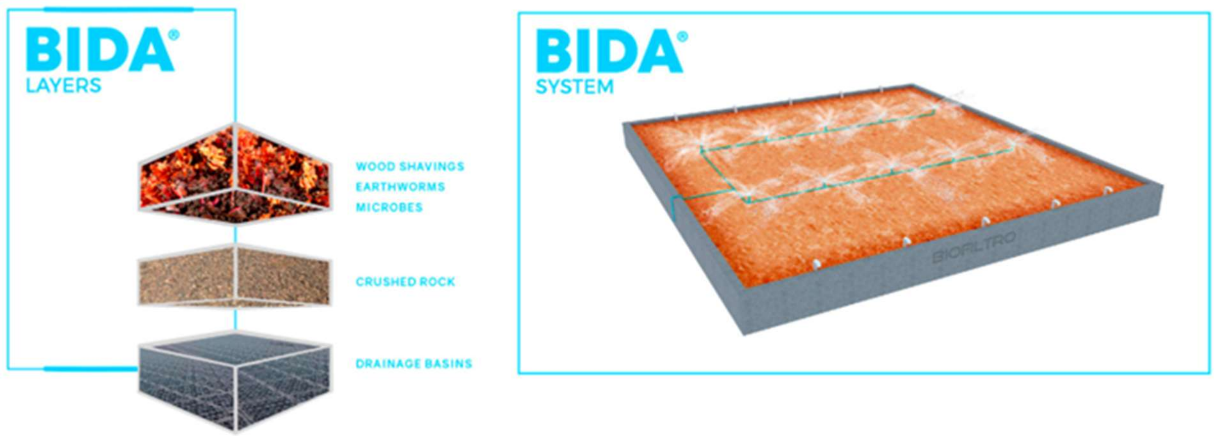


Figure 1. BIDA System Design (from BioFiltro, 2022).

Figure 2. Royal Dairy Farm Wastewater Flow.

Treatment System at Royal Dairy

The wastewater treatment system at Royal Dairy is part of a multi-step treatment process that relies on both mechanical separation and vermifiltration (Figure 2). Raw manure from the free stalls is flushed with water into primary holding pits. This manure wastewater is pumped from the primary holding pits through an initial set of 40-mil slope screens (Screen System I) to remove larger solids before entering a secondary holding pit. The manure wastewater is further filtered as it travels via sand lane to a second set of 40-mil slope screens (Screen System II), which remove any remaining larger solids. The manure wastewater is then released to 7-million gallon holding pond, where it is held until it enters the BIDA Equalization Tank (BIDA Inflow). From this point, an automated computer system monitors the manure wastewater and releases it from the equalization tank to the BIDA bed irrigation system. The water passes through the BIDA system, where excess nutrients and solids are treated by the filter media and biota over approximately four hours. The resulting nutrient-reduced water that drains to the bottom of the bed is then pumped to a 30-million-gallon pond (BIDA Outflow), where it is stored for future use. The BIDA system at Royal Dairy consists of seven 46,000 ft2 concrete beds with the structure described above. Royal Dairy estimates that the current system can reduce excess nutrients and solids in 200,000 gallons of manure wastewater per day by up to 70% and 90%, respectively, using 500 worms/ft2 in the BIDA beds (Allred 2019).

Study Methods

Sampling Procedure

Central Washington University (CWU) was contracted by Newtrient, LLC to monitor the Royal Dairy BIDA system for fifteen weeks. Liquid manure and solid compost samples were collected three times per week beginning August 15, 2022 and ending on December 23, 2022. Typically, samples were collected on Monday, Wednesday, and Friday at 11:45 a.m. Liquid manure samples were collected from five sites along the overall water pathway (Figure 3 and 4):

1.) Inflow Screen System I, from the primary holding pit;

2.) Outflow Screen System I, from secondary holding pit, after the first set of screens;

3.) Outflow Screen System II, pipe entering 7-million-gal holding pond after second screen system;

4.) Inflow BIDA, equalization tank that feeds BIDA system;

5.) Outflow BIDA, a pipe entering the 30-million-gallon nutrient-reduced water lagoon.

For each liquid manure sample, three samples were collected at several depths using a 1-liter beaker on an extendable pole. These samples were mixed in a bucket to create a composite sample that was then collected in an individual 16-oz. bottle. On each sampling date, a solid compost sample, ≈0.25 gallons in volume, was collected at approximately one foot depth from the BIDA beds using a pitchfork and drain spade and placed in a plastic freezer bag. Field notes regarding date, time of sampling, weather at time of sampling, and any noticeable changes in the Royal Dairy BIDA system were recorded.

Figure 3. Sampling Locations at Royal City Dairy.

Figure 4. Photos of Sample Collection. Left, collecting manure sample at BIDA equilibration tank; right, collecting compost sample from BIDA bed.

Laboratory Methods

Liquid manure and compost samples were transported on ice to CWU and frozen solid. Each week, a set of samples was shipped in foam lined boxes with ice packs each week to A&L Great Lakes Laboratories (A&L) in Fort Wayne, Indiana, a Department of Agriculture certified manure testing laboratory. A list of analyses is given in Table 1. The laboratory methods used by A&L and their quality control procedures are detailed on their web page (A&L Laboratories, 2023). In general, they follow methods described in Recommended Methods of Manure Analysis A3769 (Combs et al., 2003). Examples of manure and compost analysis results from A&L Laboratories are given at the end of this report.

Table 2. Analyses Performed at A&L Great Lakes Laboratories

Liquid Manure	**Solid Compost**
Aluminum (Al)(ppm)	Aluminum (Al) (%)
Ammonium Nitrogen (N-NH_4) (%)	Ash (%)
Ash (%)	Calcium (Ca) (%)
Calcium (Ca) (%)	Carbon: Nitrogen (C: N)
Copper (Cu)(ppm)	Copper (Cu)(mg/kg)
Iron (Fe)(ppm)	Iron (Fe) (%)
Manganese (Mn)(ppm)	Manganese (Mn)(mg/kg)
Magnesium (Mg) (%)	Magnesium (Mg) (%)
Organic Carbon (OC) (%)	Moisture at 70°C (%)
Organic Matter (OM) (%)	Organic Matter (OM) (%)
Organic Nitrogen (ON) (%)	pH
Phosphorus (P) (%)	Phosphate (P_2O_5) (%)
Potassium (K) (%)	Phosphorous (P) (%)
Sodium (Na) (%)	Potash (K2O) (%)
Sulfur (S) (%)	Potassium (K) (%)
Total Kjeldahl Nitrogen (TKN) (%)	Sodium (Na) (%)
Total Moisture (%)	Solid Compost
Total Solids (%)	Soluble Salts (dS/m)
Zinc (Zn)(ppm)	Sulfur (S) (%)
	Total Nitrogen (TN) (%)
	Total Organic Carbon (TOC) (%)
	Total Solids (%)
	Zinc (Zn)(mg/kg)

Modifications Made During the Study

Operational changes arose during the study that necessitated changes to its duration and the exact sampling locations. Flow through the BIDA system and into the 30-million-gallon water lagoon was halted on several occasions during the study, requiring the field researcher to obtain the BIDA Outflow sample from an underground mixing pit between the BIDA beds and the pond. The mixing pit contained effluent from two out of the seven system beds and the samples that were collected were not flowing and had resided in the pit for a period of time. The BIDA system experienced some overloading that required a shutdown from September 10-13, and the dairy conducted maintenance on the 7 million gallon lagoon that feeds the BIDA's equalization tank from October 26 to November 11. As a result, the study was extended an additional three weeks in order to accomplish a full 15 weeks of sampling. Final samples were taken on December 23, 2022.

Data Analysis

Various statistical methods were used to analyze the data, using R software (R Core Team 2022) and XLSTAT, a statistics add-on to Excel software. The goal of this statistical analysis was both to characterize the entire wastewater path and to assess the efficiency of the BIDA system. Methods used include:

- Descriptive statistics of entire manure and compost datasets and manure by sampling site
- Identification of outliers using Tukey's 1.5IQR method (Tukey, 1977)
- Anderson-Darling test for normality on BIDA Inflow and Outflow samples (Gross and Ligges, 2015)
- Non-parametric Kruskal-Wallis tests to determine statistical significance of differences between distributions for sampling locations (Kruskal and Wallis, 1952)
- Dunn Test to make pair-wise comparisons between parameters at BIDA Inflow and BIDA Outflow (Dinno, 2017)
- Mann Kendall trend test to discern trends with time (Kendall, 1975)
- Kendall correlation tests to find any correlations between efficiency and other parameters (Kendall, 1975)

Efficiency is frequently reported as percentage reduction of the concentration of each nutrient. However, this does not account for the size of the system and its nutrient load. In order to assess efficiency in terms of nutrient load, nutrient amounts were converted from percentages or parts per million (ppm) to lb/day, using the assumed density for manure of 8.33 lb/gal provided by A&L and the prior 24-hour flow (gal/day). These 24-hour flows were calculated by adding the hourly flow for the hour of sample collection and the preceding 23 hours. The hourly flows were obtained from a meter that measures flow coming into the equilibration tank that feeds the BIDA irrigation system. That meter was calibrated during installation in July 2017. In cases where the data was incomplete, the average hourly flow for the available data in the previous 24 hours was multiplied by 24 (except for one case when the flow was shut off during the missing interval).

Results & Discussion

Weather and Flow Conditions During Sampling Period

The temperature, relative humidity, and precipitation during the sampling period are shown in Figure 4. This data is from a weather station in Moses Lake, which is 23 miles southwest of Royal City (Weather Underground, 2023). In general, the weather in 2022 was unseasonably warm throughout September and the beginning of October with average temperatures in the 60s and 70s. More typical temperatures followed, with temperatures were mostly below freezing for the final four weeks of sampling in late November to December. The total precipitation during the sampling interval was 1.69 inches. This precipitation was scattered throughout October-December with two larger events, 0.48 inches on 11/30-12/1 and 0.32 inches on 12/9-12/10. In both of these larger events, precipitation fell as snow and values given are snow water equivalents (SWE). Relative humidity generally follows temperature and precipitation trends with lower humidity, around 30-50% in September; higher humidity of around 70-90% occur in late November to December, with the exception of one unseasonably cold spell in mid-December.

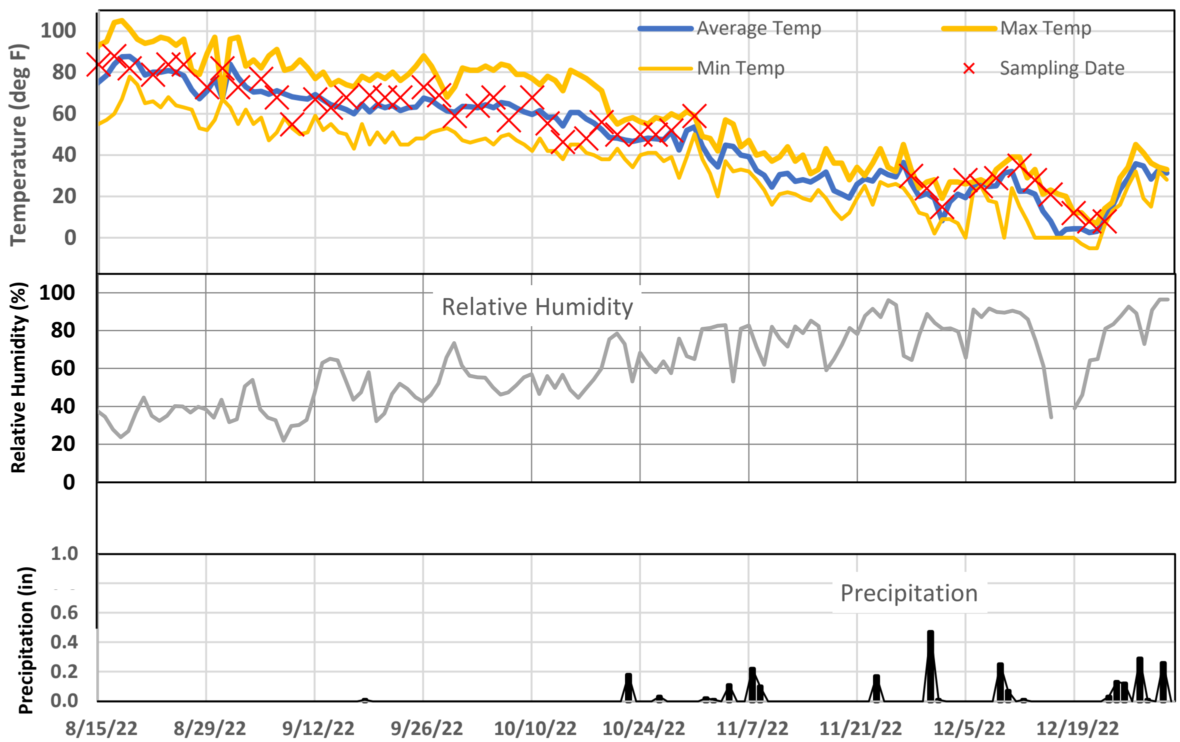


Figure 5. Temperature, Humidity, and Precipitation at Moses Lake for August-December 2022 (from Weather Underground, 2023). Upper plot – Temperature range with average in blue, red x's are sampling time and temperature; Middle plot – Average relative humidity; Lower plot – Daily precipitation.

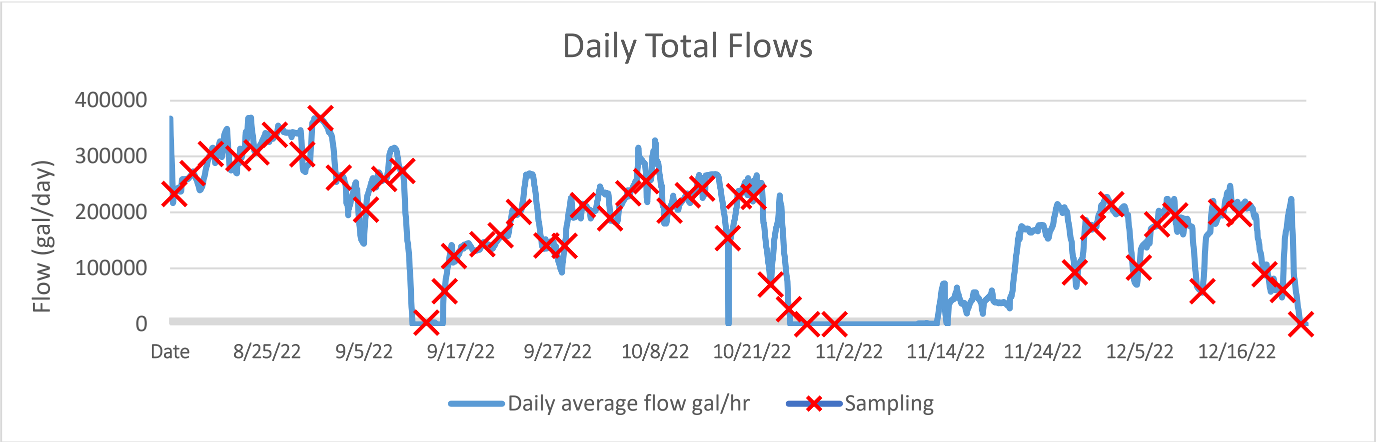


Figure 6. BIDA System Flow During Sampling Period. Blue line is 24-hour totals, red x's are sampling times.

Daily flows through the BIDA system, calculated based on hourly data from the flow meter just upstream of the BIDA equilibration tank, are shown in Figure 6. The highest flows were in August and early September at around 300,000 gal/day. There was one short shutdown in mid-September and a prolonged shutdown from mid-October to mid-November. Daily flows after late November fluctuated around 150,000 gal/day until the system was again shutdown on December 21, just before the final sampling date. At this time, prolonged freezing temperatures required system shut down to avoid irrigation pipe damage.

Outlier Analysis and Removal

Prior to data analysis to determine trends in space and time and correlations, outlier identification was performed on each parameter for all sites using Tukey's 1.5IQR method. In this method all values lying one and one-half times the inter-quartile range outside the first and third quartiles are flagged. This method flagged a large number of measurements because of the broad distribution of values for each parameter. Among these flagged values, two sets of values stood out as extreme and were removed prior to the statistical analysis:

1. Measurements of TKN and ON are anomalously high for seven samples that were collected on 9/28 and 9/30. On 9/28 there was an overflow at station 1, near the first set of screens. It is unclear whether these anomalous measurements are related to that change in the system or whether they represent contamination or a faulty laboratory measurement.
2. Seven of the BIDA outflow samples that were collected from the mixing pit coming out of the BIDA system had anomalous high Na concentrations. We suspect that these values are the result of retention in the holding pit and contamination either from salt buildup within the pit or from addition of chemicals there.

In addition to these outliers, analyses from three collection dates when water was not flowing through the BIDA system were removed from analysis of BIDA Inflow versus BIDA Outflow and from statistical analysis of mass flow calculations. These dates were 10/28, 10/31, and 12/23.

No outliers were removed from the compost measurements.

Variation in Liquid Manure Nutrients and Changes along System

The overall load of solids through the wastewater management system at Royal Dairy through time is shown in Figure 7. The average flow of solids entering the first set of screens (System I Inflow) is 41,000 lb/day. This is reduced to an average of 27,000 lb/day coming out of the BIDA system into the final lagoon, the end of the wastewater treatment path. There is a similar decrease in Organic Matter (OM) and Total Kjeldahl Nitrogen (TKN) (Table 2).

Statistical analysis demonstrated significant changes in manure nutrient loads from point of entry at the dairy barn flush pits (Screen System I Inflow) to the BIDA effluent lagoon (BIDA Outflow). Medians of measured parameters at the five sites along the wastewater stream are shown in Figure 8. Non-parametric Kruskal-Wallis rank sum testing revealed statistically significant reductions in organic matter (OM), organic carbon (OC), Total Kjeldahl Nitrogen (TKN), ammonium (NH_4), organic nitrogen (ON), phosphorus (P), aluminum (Al), calcium (Ca), copper (Cu), iron (Fe), and zinc (Zn) from beginning to end of the Royal Dairy system. Sodium (Na) demonstrated a statistically significant increase through the system.

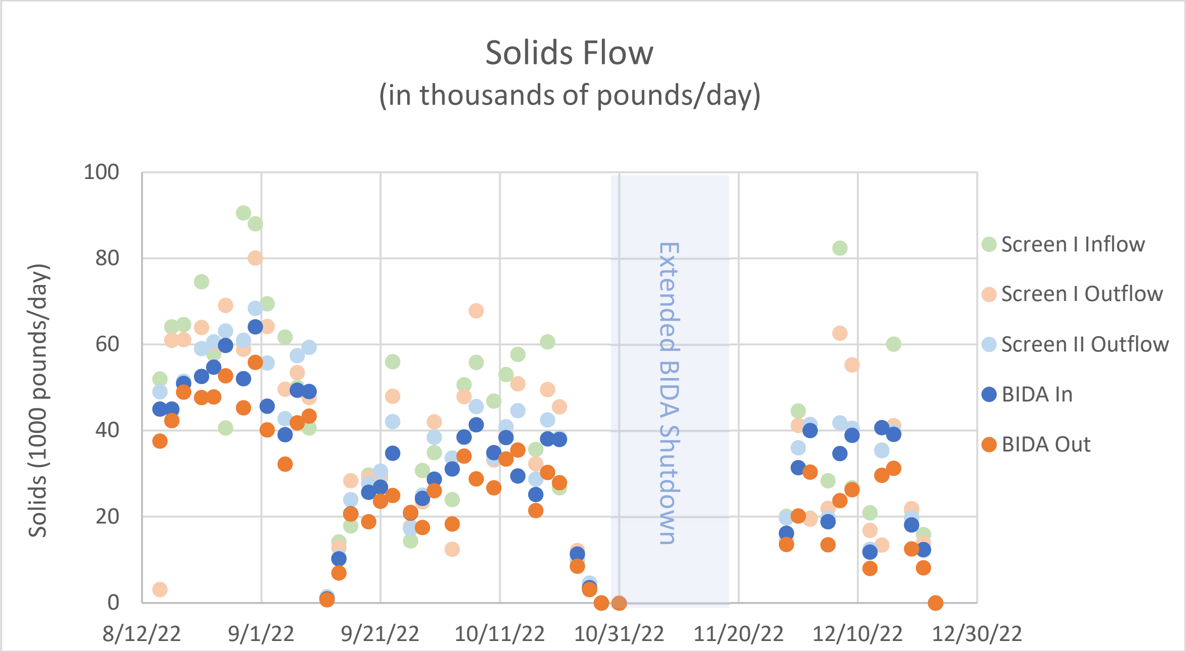


Figure 7. Total Flow of Solids Past Each Sampling Location During the Sampling Period. Different colored circles are different sampling sites identified in legend. Light blue shaded area shows time interval of extended BIDA shutdown.

Table 3. Total Mass per Day of Solids and Nutrients along Wastewater Treatment Path

	Total Solids (1000 lb/day)			Organic Matter (1000 lb/day)			Total Kjeldahl Nitrogen (1000 lb/day)		
	median	***ave***	***stdev***	***median***	***ave***	***stdev***	***median***	***ave***	***stdev***
Screen I Inflow	41	41	23	20	23	14	2.5	2.4	1.4
Screen I Outflow	41	38	21	20	20	11	2.5	2.3	1.4
Screen II Outflow	38	36	17	19	19	9	2.6	2.5	1.3
BIDA Inflow	35	33	15	24	16	8	3.3	2.3	1.0
BIDA Outflow	27	27	14	8	9	6	1.1	1.2	0.7

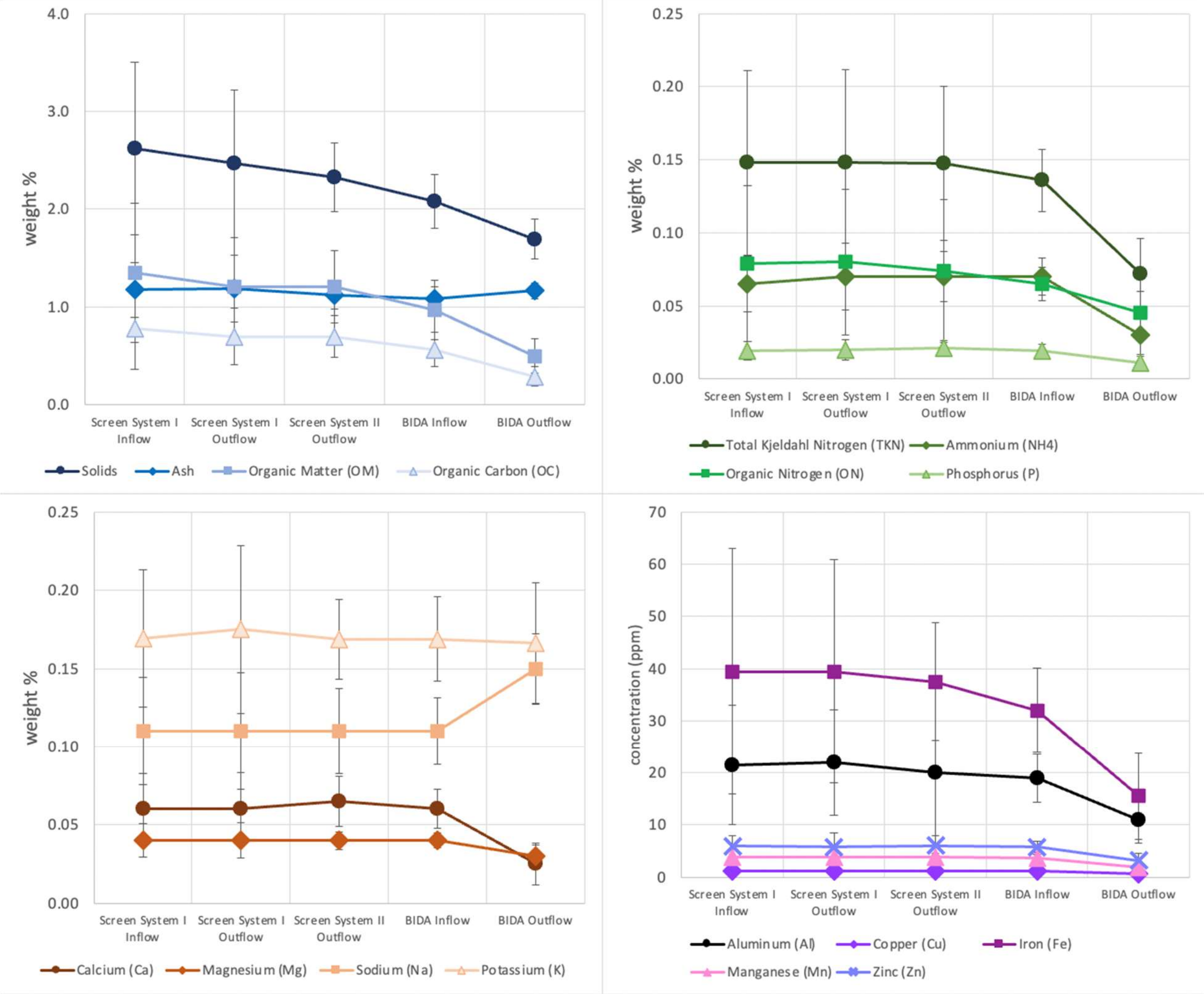


Figure 8. Medians of Measured Parameters at Each Sampling Site. Error bars are 1 standard deviation.

The increase in dissolved Na concentration along the wastewater flow path is the opposite trend of solids and organic-derived nutrients, which are removed from the waste stream, particularly in the BIDA beds. The increase in Na concentration is likely due in part to evaporation during the treatment process, particularly in holding tanks and lagoons. Preferential removal of other constituents through screens, filtration, and biological uptake will also serve to increase the Na concentration. The considerable increase of Na across the BIDA bed and the high-Na outliers suggest that there is an input of Na into the waste stream at or near the BIDA bed. One possible explanation is that evaporation in the beds has caused a build-up of Na-rich salts in the bed. Analyses of the compost do not support this explanation in that Na concentrations are not high in the beds, and they do not display any increasing trend with time. As stated earlier, the anomalously high Na measurements for samples collected in the holding tanks for BIDA effluent suggest that there is an input of Na in or near those tanks.

Analysis of time trends in manure composition was performed using a Mann Whitney trend test. There are statistically significant increases in time for all measured parameters except for Ash, K, Na, Mg, Cu, Fe, and Mn. Ash, K, and Na display statistically significant decreases over the course of the study while Mg, Cu, Fe, and Mn have no significant trend. These time trends coincide with the shift in weather and flow conditions that occurred over the course of the study. In addition, the extended BIDA shutdown and removal of the vermifiltration system from the overall wastewater circulation system likely contributed to the increased concentrations of most constituents in that recirculated water entering the flush cycle had higher loads of solids and nutrients.

Efficiency of BIDA System

The BIDA system alone accounts for much of the statistical significance in nutrient reduction in the wastewater system. Non-parametric Kruskal-Wallis tests performed solely on values of manure from point of entry at the BIDA Equalization Tank (BIDA Inflow) to the post-BIDA treatment lagoon (BIDA Outflow) showed statistically significant reductions in all measured parameters except solids, ash, and potassium (K), and all minor nutrients except sodium (Na), magnesium (Mg) and sulfur (S). Sodium (Na) increased by a statistically significant amount as described above.

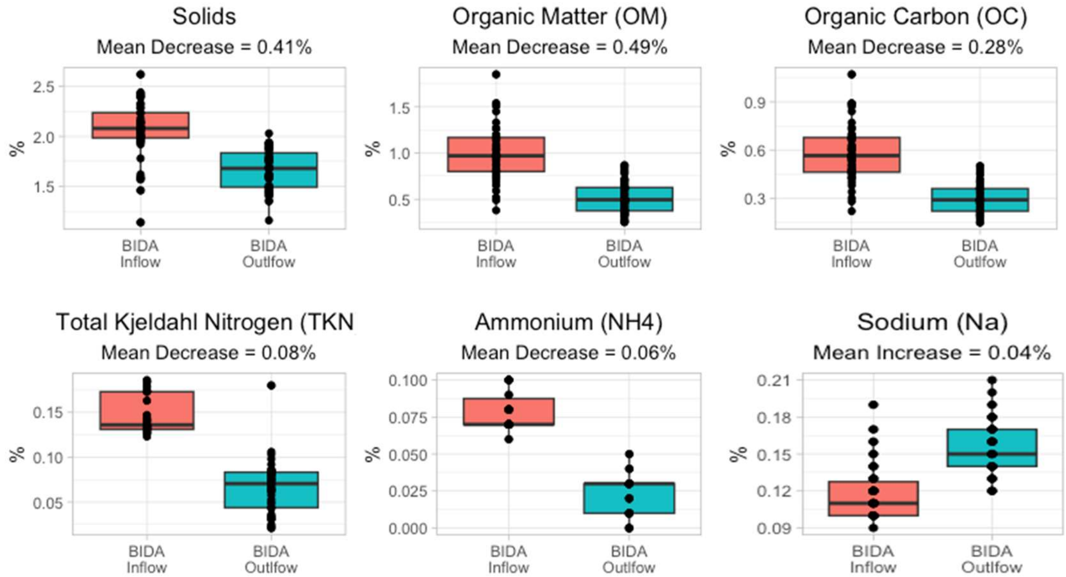


Figure 9. Box Plots Showing Change in Nutrient Concentrations Across BIDA System.

Table 4. Concentrations for Selected Nutrients for BIDA Inflow and Outflow and Percent Change

	BIDA Influent			BIDA Effluent			Change (In-Out)	
	Median	Ave	Std dev	Median	Ave	Std dev	Ave	Std dev
Parameter	wt %	wt %	wt %	wt %	wt %	wt %	%	%
Organic Carbon	0.57	0.59	0.15	0.29	0.31	0.09	45	19
Total Kjeldahl Nitrogen	0.14	0.15	0.02	0.075	0.07	0.03	51	18
Ammonia-Nitrogen	0.07	0.08	0.01	0.03	0.02	0.01	67	14
Phosphorus	0.02	0.02	0.003	0.011	0.01	0.004	46	25
Potassium	0.169	0.17	0.02	0.17	0.17	0.04	-2	25
Calcium	0.06	0.06	0.01	0.03	0.02	0.01	56	28
Sodium	0.11	0.12	0.02	0.15	0.16	0.02	-30	29

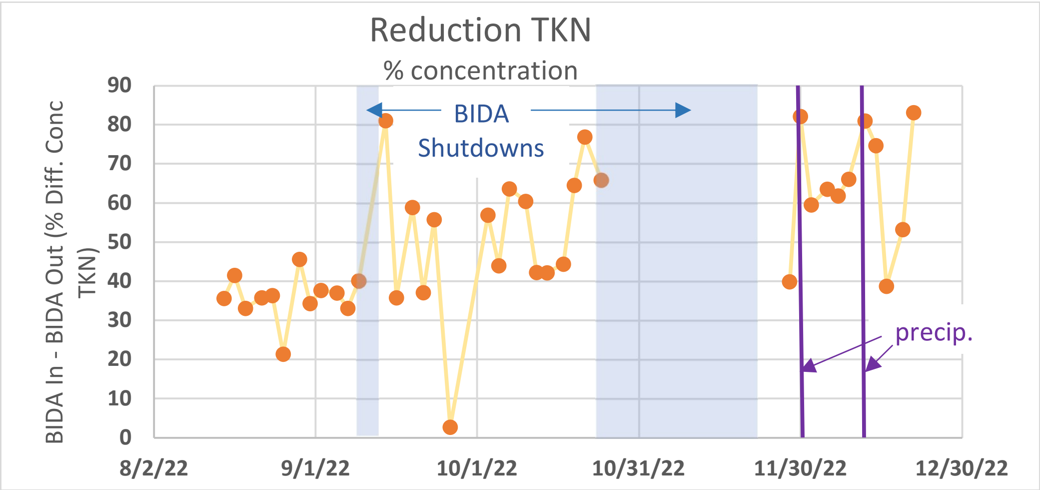
One common measure used to describe the efficiency of a vermifiltration system is the reduction in nutrient concentrations across the system reported as a percent change in concentration. Table 3 presents average influent and effluent concentrations and percent change for several nutrients. These average changes are decreases ranging from 45 to 67% except for potassium, which does not change, and sodium, which displays a 30% increase. The percent change in nitrogen, approximately 60%, is considerably less than the measured values of ≈95% reported for Royal Dairy in 2015 and 2017 (Dore et al., 2019). However, the 2015 measurement was for a much smaller pilot BIDA system and the 2017 measurement was made immediately after the larger system, 200,000 ft^2 in area, was installed. The current BIDA system is 50% larger than the initial 2017 system.

Percent change calculations do not account for three factors: 1) how high the influent concentration is entering the system, 2) the volume of liquid that is flowing through the system, 3) the size of the vermifiltration system. To account for these factors, another way to describe the nutrient reduction across the BIDA system is as daily totals in units of pounds/ft^2/day, expressing the total mass of nutrient removed per unit area of BIDA bed each day. To convert to this measure, BIDA inflows and outflows were converted from weight percentages or parts per million (ppm) to lb/ft^2/day, using the assumed density for manure of 8.33 lb/gal provided by A&L laboratory, the prior 24-hour flow and the 310,000 ft^2 surface area of the BIDA system at Royal Dairy:

$$daily\ total \left(\frac{lb\ nutrient}{ft^2 * day}\right) = mass \left(\frac{lb\ nutrient}{lb\ manure}\right) \times density \left(\frac{lb\ manure}{gal}\right) \times flow \left(\frac{gal}{day}\right) \div BIDA\ area\ (ft^2)$$

Graphs showing reduction of TKN as a percent change and as lbs./ft^2/day are shown in Figure 10. By this second measure, daily reductions in TKN range from around 0.0015 to 0.007 lbs./ft^2/day. It should be noted though that the BIDA system at Royal Dairy was not irrigated to its full capacity during the sampling period in that the entire area of the BIDA system was not typically irrigated. In some cases, only two out of the seven beds were being irrigated. As such, using the entire BIDA area in the denominator of the daily total calculation might tend to underestimate the efficiency. That is, if only 50% of the total 310,000 ft^2 area were being used, this range of values would be doubled, becoming 0.003 to 0.014 lb/ft^2/day. Irrigation is rotated through the different beds so that the entire system is used, but it is likely that a more complete and uniform irrigation pattern would increase the TKN reduction.

Correlation analysis between these two efficiency measures and the other parameters revealed the strongest correlation between humidity and percent TKN reduction (Figure 11). Both percent TKN reduction and humidity have an inverse correlation with air temperature. These correlations might suggest that the biological activity in the BIDA beds is enhanced at higher humidity and lower air temperature. However, the TKN difference in lb/ft^2/day does not correlate with any other parameter and there are a number of confounding factors that might have an effect. The extended BIDA system shutdown occurred between a period of higher temperatures and lower humidity and a period of higher temperatures and humidity. During the shutdown, the BIDA bed likely dried. Because of recirculating the water within the farm, the nutrient load of BIDA influent also built up during the shutdown. After the shutdown, flows through the system were reduced from pre-shutdown flows. Therefore, a more likely explanation of the correlations with humidity and temperature are that the BIDA system was more efficient on average after the long system shutdown due to one or more of the changes that occurred.



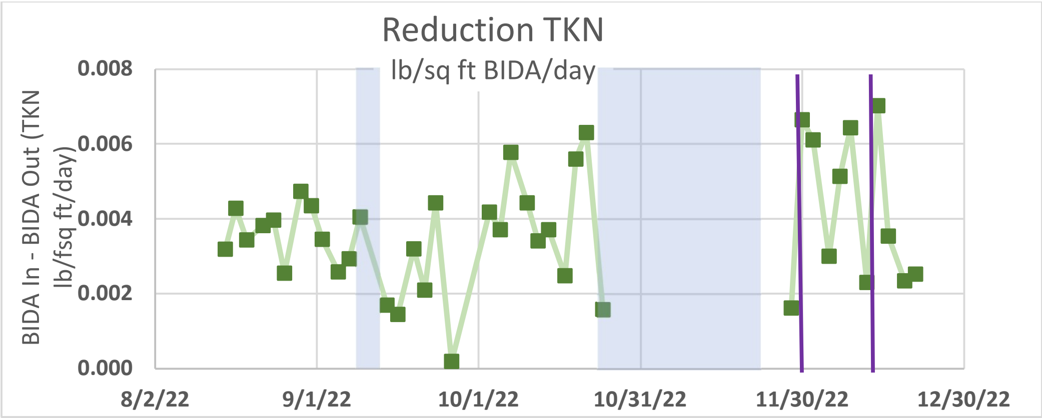


Figure 10. Measures of Nitrogen Efficiency of BIDA System. Upper graph – TKN concentration reduction as a percent of the influent concentration; lower graph – total TKN mass removed per square foot of BIDA bed per day. Purple lines are major precipitation events, shaded blue rectangles are periods when BIDA system was shut down.

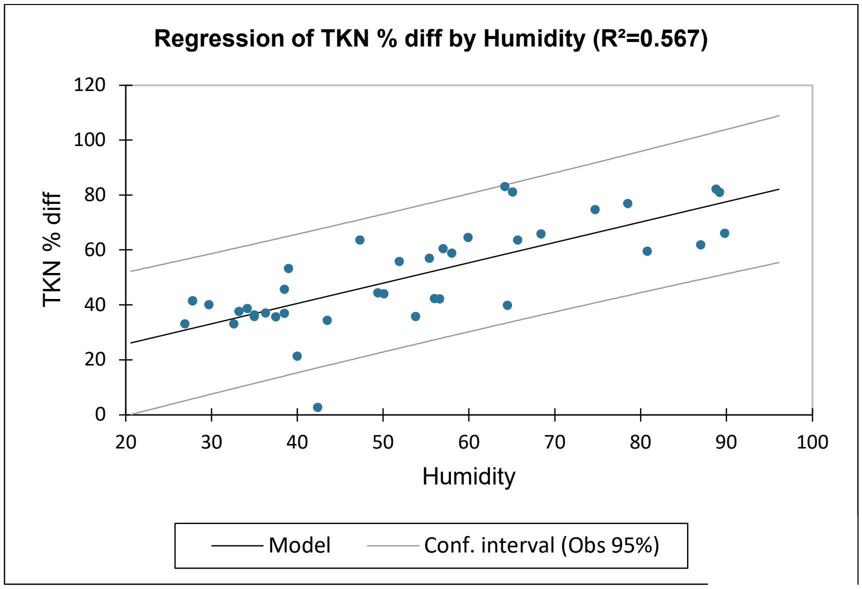


Figure 11. Correlation between TKN Reduction in BIDA System and Humidity

Nutrients in the BIDA® Beds

Each day that liquid manure was sampled, a single sample of compost from one of the BIDA beds was collected. Box plots showing concentration distributions for selected parameters in compost are shown in Figure 12. All parameters other than moisture are presented here using the dry weight concentration.

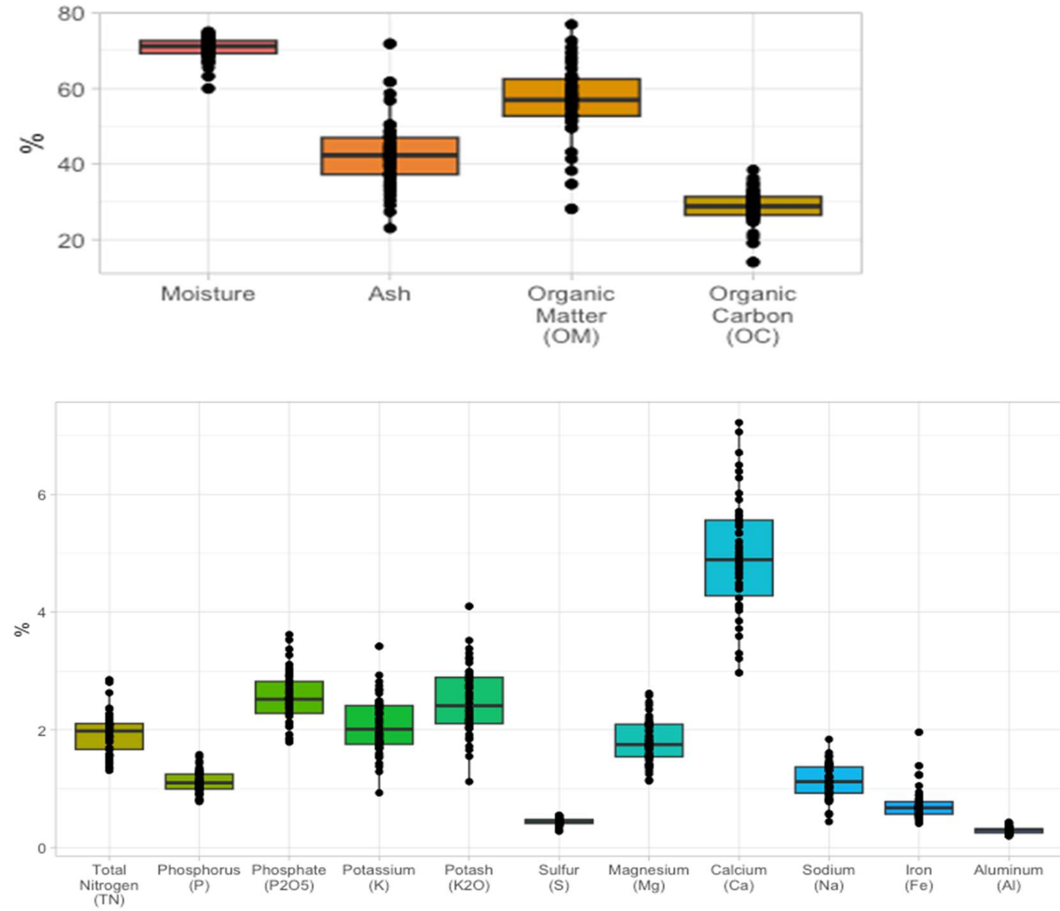


Figure 12. Box Plots of Nutrient Concentrations in Compost (Dry Weight %).

Time trend analysis revealed that most of the measured parameters did not change significantly in concentration over the course of this study. Parameters which did exhibit a significant change in concentration in the compost were P, Mg, Ca, Mn, and Zn, which all increased significantly over the sampling period. Although not statistically significant, there is also an apparent increase in the N content of compost over the study period. Accumulation of nutrients within the BIDA bed should be expected for nutrients which are removed by the BIDA bed based on mass balance considerations unless they are released as gases or sequestered at a different level of the bed than that which was sampled. It is possible that other nutrients which were reduced have accumulated in the BIDA bed, but not to the extent that it is measurable and statistically significant. Furthermore, if the concentration of a given nutrient within the removed load (BIDA In – BIDA Out) is similar to the existing concentration in the BIDA bed, then the accumulation of that nutrient would only be detectable if the total mass of that nutrient within the BIDA bed were measured through time instead of concentration.

Comparison with Other Studies

As the vermifiltration technology continues to be developed for dairy farm systems, it is useful to compare studies of efficiency in nutrient reduction from different dairy farms. Here, we compare four studies (Table 4):

1. A small pilot study in a dairy farm in Yakima County (Miito et al., 2021)
2. A system that serves 10% of the wastewater at Fanelli Dairy in Hillmar, CA (Dore et al., 2022)
3. A small system at a commercial dairy in San Joaquin valley (Lai et al., 2018)
4. Royal Dairy, a large dairy in central Washington with a system that serves the entire farm (this study)

Table 5. Comparison with Nitrogen Reduction at Other Farms

Study site*	# cows	flow gal/day	bed size sq ft	Nitrogen influent mg/L**	Nitrogen effluent mg/L**	Nitrogen mass change lb/day	Nitrogen conc. change %	Nitrogen change per area $lb/ft^2/day$	comments
Yakima County farm	3000	1500	130	860 ± 250	198 ± 58	8.3	77	0.064	small test unit
Fanelli Dairy Hillmar, CA	1500	8000	5800	810 ± 80	74 ± 15	49	91	0.0085	BIDA system serves 10% of system
San Joaquin Valley farm CA	1300	80,000	5800	269	118	100	56	0.017	commercial dairy, small system
Royal Dairy Royal City, WA	6000	200,000	310,000	1470 ± 210	660 ± 300	1100	55	0.0044	BIDA serves entire farm

*Data sources: Yakima farm – Miito et al., 2021; Fanelli Dairy – Dore et al., 2022; Central CA – Lai et al., 2018; Royal Dairy – this study.
**Nitrogen measured as TKN for Fanelli Dairy and Royal Dairy, TN by persulfate method for Yakima farm; units reported as mg/L for ease of comparison with literature.

In comparing these three previous studies to the Royal Dairy, the most striking contrast is the size and load of the Royal Dairy system. The system supports wastewater from more cows, has a higher wastewater flow, covers a much larger area, and has significantly higher nutrient load in its influent. The vermifiltration bed (BIDA bed) in particular is approximately 50 times larger than the systems at the two California farms. The percent nitrogen reduction at Royal Dairy is lower than two of the three other farms, probably partly the result of the much larger size of the system and the added complexity of irrigating the larger area. In contrast, the total amount of nitrogen removed by the vermifiltration system at Royal Dairy, 1100 pounds/day, is over ten times larger than any of the other farms.

The nitrogen mass change per square foot per day calculated for Royal Dairy is on the low end of the observed range in the four studies. This is largely the result of the much larger size of the vermifiltration bed, which goes into the denominator of the calculation. If the BIDA bed at Royal Dairy had achieved 100% removal of nitrogen and all of the influent entering the system during the study period were removed, this maximum achievable nitrogen reduction rate would be 0.0078 $lb/ft^2/day$, still below the values observed in the much smaller systems (0.0085 to 0.064 $lb/ft^2/day$). We conclude that this measure of efficiency is most useful when comparing systems of similar size or comparing a single system's efficiency through time.

As stated above, if Royal Dairy is functionally only using a fraction of their total square footage, these calculated rates would increase accordingly. If only half of the BIDA area is used, the maximum achievable reduction rate per area would be doubled, 0.016 $lb/ft^2/day$ for the current influent, comparable to the reduction rate at the farm in San Joaquin Valley and higher than the reduction rate at Fanelli Dairy.

Conclusions

Key Findings

- Royal Dairy's wastewater treatment process incorporates a large-scale vermifiltration system that is responsible for the bulk of the reduction of solids and nutrients from its wastewater. Over the course of this study, the vermifiltration system reduced solids by an average of 5800 pounds/day and nitrogen by an average of 1100 pounds/day.

- The efficiency of the BIDA system in removing nitrogen varied considerably over the study period, ranging from around 30% to 80%. A correlation between TKN reduction and humidity and a correspondence in time with other wetting and drying events suggest that the nutrient uptake of the vermiculture bed is sensitive to the moisture conditions in and around the compost material. In particular, higher nitrogen removal efficiency immediately after a short shutdown in September may be due to the drying that occurred during that time.

- The operation of the BIDA system during this study was not consistent. Flow rates were variable through time with two periods of shutdown, one of which lasted for nearly one month. The irrigation patterns across the BIDA beds were also not regular with some beds being irrigated more frequently than others. In addition, temperature and humidity changed considerably over the course of the study, from unseasonably warm temperatures and low humidity in the early fall to freezing temperatures and higher humidity in December. These changing conditions likely contributed to the variability in the BIDA efficiency.

- There was an increase in Na concentration in the liquid manure through the wastewater treatment flow path, particularly across the BIDA bed. This increase in Na is probably due in part to evaporation and lack of biological uptake of sodium. A significant increase across the BIDA bed and anomalously high Na concentrations in samples collected in a holding tank for BIDA effluent indicate that there is a more concentrated source of Na that is being added to the wastewater in the BIDA beds or the holding tank itself.

Suggestions for Future Research

The results of this study suggest that an irrigation system that spreads liquid manure across the entire area of BIDA system might produce greater nutrient reductions through vermifiltration. Irregularities such as the long shutdown and non-uniform irrigation reduce the overall efficiency of the system. Increased nitrogen reduction immediately after a short (2-day) shutdown suggests that there may be benefit to allowing beds to dry periodically, particularly during the hot summer months. Royal Dairy is in the process of improving their BIDA irrigation system, providing an opportunity to determine the effects of irrigation changes on vermifiltration efficiency. Future studies to explore some of our findings might include:

- Analysis of seasonal trends in nutrient reduction and their relationship to weather, particularly humidity.

- Comparison between efficiency and irrigation patterns, including periodic short-term shutdowns to dry the BIDA bed.
- Measures of biological uptake and emissions from the BIDA beds to better understand nutrient fluxes.
- A more detailed study of the BIDA bed compost composition with depth and through time with an emphasis on Na composition and accumulation.
- Measures of worm density and soil health through time and seasonally and comparison with BIDA efficiency.

References

A & L Laboratories, 2023, "A & L Great Lakes Laboratories." https://algreatlakes.com/ accessed Feb. 2023.

Allred, J., 2019, "Dairy Lagoon Nutrient Extraction with Vermicomposting." Presented at the World Organic Recycling Council (WORC) Annual Conference, Vancouver, WA. https://static1.squarespace.com/static/585c2db75016e175c9d685b7/t/5bef12f44d7a9c8d998d1484/1542394624079/

Arora, S., Saraswat, S., 2021, "Vermifiltration as a Natural, Sustainable and Green Technology for Environmental Remediation: a New Paradigm for Wastewater Treatment Process." CRGSC 4, 100061.

BioFiltro, Inc., 2022, "BioFiltro: Worm Powered Wastewater Solutions: Home." 2022, https://biofiltro.com/.

Combs, S.M., Hoskins, B., Jarman, J., Kovar, J.L., Watson, M.E., Wolf, A.M., Wolf, N., 2023, "Recommended Methods of Manure Analysis (A3769)", University of Wisconsin-Extension, Cooperative Extension Publishing,

Dairy Farmers of Washington, 2018, "Washington State Farmer Awarded for Environmental Stewardship." 2018. https://www.wadairy.org/wasustainabilityaward2018/.

Dinno, A., 2017, "Dunn.Test: Dunn's Test of Multiple Comparisons Using Rank Sums."

Dore, S., Deverel, S., Iacobelli, A., Sjögren, M., 2019, "White Paper: The Biofiltro BIDA® Wastewater Treatment System." HydroFocus. Inc.

Gross, J. and Ligges, U., 2015, "Nortest: Tests for Normality." Dortmund, Germany: Statistik. Iowa State University, 1993. Livestock Waste Facilities Handbook. Ames, IA: Midwest Plan Service.

Ispolnov, K., Aires, L.M.I., Lourenco,N.D., Vieira, J.S., 2021, "A Combined Vermifiltration-Hydroponic System for Swine Wastewater Treatment." *Appl. Sci.* 2021, *11*(11), 5064. doi.org/10.3390/app11115064

Kendall, M.G., 1975, Rank correlation methods, 4th ed. Charles Griffin, London.

Kruskal, W., Wallis, W.A., 1952, "Use of ranks in one-criterion variance analysis". Journal of the American Statistical Association. 47 (260): 583–621. doi:10.1080/01621459.1952.10483441.

Lai, E., Hess, M., Mitloehner, F., 2018, Profiling of the microbiome associated with nitrogen removal during vermifiltration of wastewater from a commercial dairy. Frontiers in microbiology, 9, p.1964.

Lim, S.L., Wu, T.Y., Clarke, C., 2014, "Treatment and Biotransformation of Highly Polluted Agro-Industrial Wastewater from a Palm Oil Mill into Vermicompost using Earthworms. J. Agric. Food Chem. 62 (3), 691–698.

Lourenco, N., Nunes, L.M., 2017, "Optimization of a Vermifiltration Process for Treating Urban Wastewater. Ecol. Eng. 100, 138–146.

R Core Team, 2022, "R: A Language for Environment for Statistical Computing" and "Stats." Vienna, Austria: R Foundation for Statistical Computing.

Thompson. W.H., Leege, P.B., Watson, M.E., Millner, P.D., eds., 2001, Test Methods for the Examination of Composting and Compost. USDA.

Tukey, J.W., 1977, Exploratory data analysis. Addison-Wesely.

Wang, L.M., Zhang, Y.M., Luo, X.Z., Zhang, J.B., Zheng, Z., 2016, Effects of Earthworms and Substrate on Diversity and Abundance of Denitrifying Genes (nirs and nirk) and Denitrifying Rate during Rural Domestic Wastewater Treatment. Bioresour. Technol. 212, 174–181.

To: NEWTRIENT LLC - SIG GRANT
11510 LAURIE DR
WHEATFIELD, IN 46392-7364

From: CWU GEOLOGY DEPT
BIOFILTRO ROYAL DAIRY
PROJECT

Attn: MARK STOERMAN

Purchase Order: CWU GEOLOGY DEPT

Lab Number: 51169
Sample ID: SCREEN SYSTEM I INFLOW KS
Manure Type: DAIRY, LIQUID PIT (20)

Date Sampled: 11/28/2022
Date Received: 12/12/2022
Date Reported: 12/14/2022 Page: 1 of 10

MANURE ANALYSIS

Analysis	Unit	Analysis Result (As Received)	Pounds Per 1,000 Gal **	First Year Availability @ Pounds Per 1,000 Gal
Moisture	%	97.40	8113	
Solids	%	2.60	217	
Ash @ 550 C	%	1.06	88.5	
Organic Matter (LOI @ 550 C)	%	1.54	128.0	
Organic Carbon (LOI @ 550 C)	%	0.89	74.3	
Carbon:Nitrogen Ratio (C:N)	-		5.3:1	
Nitrogen, Total Kjeldahl (TKN)	%	0.169	14.1	9.5 *
Nitrogen, Ammonium (NH_4-N)	%	0.090	7.5	7.5 *
Nitrogen, Organic (N)	%	0.079	6.6	2.0 *
Phosphorus (P)	%	0.026	5.0 (as P_2O_5)	5.0 * (as P_2O_5)
Potassium (K)	%	0.121	12.1 (as K_2O)	12.1 * (as K_2O)
Sulfur (S)	%	0.02	1.7	0.9 #

@ Estimate of first-year availability does not account for incorporation losses. Consult MWPS-18, "Livestock Waste Facilities Handbook" for additional information.
* Source: MWPS-18, Livestock Waste Facilities Handbook, 1993 # Source: A3411, "Manure Nutrient Credit Worksheet", University of Wisconsin
** Manure density assumed to be 8.33 lb/gallon

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* Source: MWPS-18, Livestock Waste Facilities Handbook, 1993 # Source: A3411, "Manure Nutrient Credit Worksheet", University of Wisconsin
** Manure density assumed to be 8.33 lb/gallon

Report Approved By: David Henry - Agronomist / Technical Services - CCA Approval Date: 12/14/2022

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Purchase Order: CWU GEOLOGY DEPT

Lab Number: 51169
Sample ID: SCREEN SYSTEM I INFLOW KS
Manure Type: DAIRY, LIQUID PIT (20)

Date Sampled: 11/28/2022
Date Received: 12/12/2022
Date Reported: 12/14/2022 Page: 2 of 10

MANURE ANALYSIS

Analysis	Unit	Analysis Result (As Received)	Pounds Per 1,000 Gal **	First Year Availability @ Pounds Per 1,000 Gal
Magnesium (Mg)	%	0.04	3.5	1.8 #
Calcium (Ca)	%	0.08	6.4	3.7 #
Sodium (Na)	%	0.09	7.5	
Aluminum (Al)	ppm	26	0.2	
Copper (Cu)	ppm	1.5	<0.1	<0.1 #
Iron (Fe)	ppm	49	0.4	0.3 #
Manganese (Mn)	ppm	4.2	<0.1	<0.1 #
Zinc (Zn)	ppm	8.0	0.1	<0.1 #

@ Estimate of first-year availability does not account for incorporation losses. Consult MWPS-18, "Livestock Waste Facilities Handbook" for additional information.
* Source: MWPS-18, Livestock Waste Facilities Handbook, 1993 # Source: A3411, "Manure Nutrient Credit Worksheet", University of Wisconsin
** Manure density assumed to be 8.33 lb/gallon

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From: CWU GEOLOGY DEPT
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Attn: MARK STOERMAN

Purchase Order: CWU GEOLOGY DEPT

Lab Number: 51170
Sample ID: SCREEN SYSTEM I OUTFLOW KS
Manure Type: DAIRY, LIQUID PIT (20)

Date Sampled: 11/28/2022
Date Received: 12/12/2022
Date Reported: 12/14/2022 Page: 3 of 10

MANURE ANALYSIS

Analysis	Unit	Analysis Result (As Received)	Pounds Per 1,000 Gal **	First Year Availability @ Pounds Per 1,000 Gal
Moisture	%	98.13	8174	
Solids	%	1.87	156	
Ash @ 550 C	%	0.70	58.2	
Organic Matter (LOI @ 550 C)	%	1.17	97.5	
Organic Carbon (LOI @ 550 C)	%	0.68	56.6	
Carbon:Nitrogen Ratio (C:N)	-		4.4:1	
Nitrogen, Total Kjeldahl (TKN)	%	0.153	12.7	7.3 *
Nitrogen, Ammonium (NH_4-N)	%	0.060	5.0	5.0 *
Nitrogen, Organic (N)	%	0.093	7.7	2.3 *
Phosphorus (P)	%	0.019	3.6 (as P_2O_5)	3.6 * (as P_2O_5)
Potassium (K)	%	0.096	9.6 (as K_2O)	9.6 * (as K_2O)
Sulfur (S)	%	0.02	1.4	0.9 #

@ Estimate of first-year availability does not account for incorporation losses. Consult MWPS-18, "Livestock Waste Facilities Handbook" for additional information.
* Source: MWPS-18, Livestock Waste Facilities Handbook, 1993 # Source: A3411, "Manure Nutrient Credit Worksheet", University of Wisconsin
** Manure density assumed to be 8.33 lb/gallon

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Lab Number: 51170
Sample ID: SCREEN SYSTEM I OUTFLOW KS
Manure Type: DAIRY, LIQUID PIT (20)

Date Sampled: 11/28/2022
Date Received: 12/12/2022
Date Reported: 12/14/2022 Page: 4 of 10

MANURE ANALYSIS

Analysis	Unit	Analysis Result (As Received)	Pounds Per 1,000 Gal **	First Year Availability @ Pounds Per 1,000 Gal
Magnesium (Mg)	%	0.03	2.6	1.4 #
Calcium (Ca)	%	0.06	5.0	2.7 #
Sodium (Na)	%	0.07	5.5	
Aluminum (Al)	ppm	19	0.2	
Copper (Cu)	ppm	1.0	<0.1	<0.1 #
Iron (Fe)	ppm	35	0.3	0.2 #
Manganese (Mn)	ppm	3.1	<0.1	<0.1 #
Zinc (Zn)	ppm	5.6	<0.1	<0.1 #

@ Estimate of first-year availability does not account for incorporation losses. Consult MWPS-18, "Livestock Waste Facilities Handbook" for additional information.
* Source: MWPS-18, Livestock Waste Facilities Handbook, 1993 # Source: A3411, "Manure Nutrient Credit Worksheet", University of Wisconsin
** Manure density assumed to be 8.33 lb/gallon

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Attn: MARK STOERMAN

Purchase Order: CWU GEOLOGY DEPT

Lab Number: 51171
Sample ID: SCREEN SYSTEM II OUTFLOW KS
Manure Type: DAIRY, LAGOON (21)

Date Sampled: 11/28/2022
Date Received: 12/12/2022
Date Reported: 12/14/2022 **Page:** 5 of 10

MANURE ANALYSIS

Analysis	Unit	Analysis Result (As Received)	Pounds Per 1,000 Gal**	First Year Availability @ Pounds Per 1,000 Gal
Moisture	%	97.45	8118	
Solids	%	2.55	212	
Ash @ 550 C	%	0.95	78.8	
Organic Matter (LOI @ 550 C)	%	1.60	133.7	
Organic Carbon (LOI @ 550 C)	%	0.93	77.5	
Carbon:Nitrogen Ratio (C:N)	-		5.1:1	
Nitrogen, Total Kjeldahl (TKN)	%	0.183	15.2	10.0 *
Nitrogen, Ammonium (NH4-N)	%	0.100	8.3	8.3 *
Nitrogen, Organic (N)	%	0.083	6.9	1.7 *
Phosphorus (P)	%	0.027	5.1 (as P_2O_5)	5.1 * (as P_2O_5)
Potassium (K)	%	0.144	14.4 (as K_2O)	14.4 * (as K_2O)
Sulfur (S)	%	0.02	2.0	0.9 #

@ Estimate of first-year availability does not account for incorporation losses. Consult MWPS-18, "Livestock Waste Facilities Handbook" for additional information.
* Source: MWPS-18, Livestock Waste Facilities Handbook, 1993 # Source: A3411, "Manure Nutrient Credit Worksheet", University of Wisconsin
** Manure density assumed to be 8.33 lb/gallon

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Lab Number: 51171
Sample ID: SCREEN SYSTEM II OUTFLOW KS
Manure Type: DAIRY, LAGOON (21)

Date Sampled: 11/28/2022
Date Received: 12/12/2022
Date Reported: 12/14/2022 Page: 6 of 10

MANURE ANALYSIS

Analysis	Unit	Analysis Result (As Received)	Pounds Per 1,000 Gal **	First Year Availability @ Pounds Per 1,000 Gal
Magnesium (Mg)	%	0.04	3.6	1.8 #
Calcium (Ca)	%	0.08	6.4	3.7 #
Sodium (Na)	%	0.11	9.0	
Aluminum (Al)	ppm	22	0.2	
Copper (Cu)	ppm	1.3	<0.1	<0.1 #
Iron (Fe)	ppm	41	0.3	0.2 #
Manganese (Mn)	ppm	4.1	<0.1	<0.1 #
Zinc (Zn)	ppm	6.9	0.1	<0.1 #

@ Estimate of first-year availability does not account for incorporation losses. Consult MWPS-18, "Livestock Waste Facilities Handbook" for additional information.
* Source: MWPS-18, Livestock Waste Facilities Handbook, 1993 # Source: A3411, "Manure Nutrient Credit Worksheet", University of Wisconsin
** Manure density assumed to be 8.33 lb/gallon

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PROJECT

Attn: MARK STOERMAN

Purchase Order: CWU GEOLOGY DEPT

Lab Number: 51172
Sample ID: BIDA SYSTEM INFLOW EQ TANK KS
Manure Type: DAIRY, LIQUID PIT (20)

Date Sampled: 11/28/2022
Date Received: 12/12/2022
Date Reported: 12/14/2022 Page: 7 of 10

MANURE ANALYSIS

Analysis	Unit	Analysis Result (As Received)	Pounds Per 1,000 Gal **	First Year Availability @ Pounds Per 1,000 Gal
Moisture	%	97.91	8156	
Solids	%	2.09	174	
Ash @ 550 C	%	1.05	87.2	
Organic Matter (LOI @ 550 C)	%	1.04	86.9	
Organic Carbon (LOI @ 550 C)	%	0.61	50.4	
Carbon:Nitrogen Ratio (C:N)	-		3.7:1	
Nitrogen, Total Kjeldahl (TKN)	%	0.163	13.6	9.9 *
Nitrogen, Ammonium (NH4-N)	%	0.100	8.3	8.3 *
Nitrogen, Organic (N)	%	0.063	5.2	1.6 *
Phosphorus (P)	%	0.020	3.8 (as P_2O_5)	3.8 * (as P_2O_5)
Potassium (K)	%	0.121	12.1 (as K_2O)	12.1 * (as K_2O)
Sulfur (S)	%	0.02	1.6	0.9 #

@ Estimate of first-year availability does not account for incorporation losses. Consult MWPS-18, "Livestock Waste Facilities Handbook" for additional information.
* Source: MWPS-18, Livestock Waste Facilities Handbook, 1993 # Source: A3411, "Manure Nutrient Credit Worksheet", University of Wisconsin
** Manure density assumed to be 8.33 lb/gallon

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Attn: MARK STOERMAN

Purchase Order: CWU GEOLOGY DEPT

Lab Number: 51172
Sample ID: BIDA SYSTEM INFLOW EQ TANK KS
Manure Type: DAIRY, LIQUID PIT (20)

Date Sampled: 11/28/2022
Date Received: 12/12/2022
Date Reported: 12/14/2022 Page: 8 of 10

MANURE ANALYSIS

Analysis	Unit	Analysis Result (As Received)	Pounds Per 1,000 Gal **	First Year Availability @ Pounds Per 1,000 Gal
Magnesium (Mg)	%	0.04	3.2	1.8 #
Calcium (Ca)	%	0.06	4.7	2.7 #
Sodium (Na)	%	0.10	8.5	
Aluminum (Al)	ppm	18	0.2	
Copper (Cu)	ppm	1.1	<0.1	<0.1 #
Iron (Fe)	ppm	31	0.3	0.2 #
Manganese (Mn)	ppm	3.2	<0.1	<0.1 #
Zinc (Zn)	ppm	5.8	<0.1	<0.1 #

@ Estimate of first-year availability does not account for incorporation losses. Consult MWPS-18, "Livestock Waste Facilities Handbook" for additional information.
* Source: MWPS-18, Livestock Waste Facilities Handbook, 1993 # Source: A3411, "Manure Nutrient Credit Worksheet", University of Wisconsin
** Manure density assumed to be 8.33 lb/gallon

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From: CWU GEOLOGY DEPT
BIOFILTRO ROYAL DAIRY
PROJECT

Attn: MARK STOERMAN

Purchase Order: CWU GEOLOGY DEPT

Lab Number: 51173
Sample ID: BIDA SYSTEM OUTFLOW KS
Manure Type: DAIRY, LAGOON (21)

Date Sampled: 11/28/2022
Date Received: 12/12/2022
Date Reported: 12/14/2022 Page: 9 of 10

MANURE ANALYSIS

Analysis	Unit	Analysis Result (As Received)	Pounds Per 1,000 Gal **	First Year Availability @ Pounds Per 1,000 Gal
Moisture	%	98.24	8183	
Solids	%	1.76	147	
Ash @ 550 C	%	1.14	95.1	
Organic Matter (LOI @ 550 C)	%	0.62	51.5	
Organic Carbon (LOI @ 550 C)	%	0.36	29.9	
Carbon:Nitrogen Ratio (C:N)	-		3.7:1	
Nitrogen, Total Kjeldahl (TKN)	%	0.098	8.2	5.2 *
Nitrogen, Ammonium (NH4-N)	%	0.050	4.2	4.2 *
Nitrogen, Organic (N)	%	0.048	4.0	1.0 *
Phosphorus (P)	%	0.013	2.5 (as P_2O_5)	2.5 * (as P_2O_5)
Potassium (K)	%	0.110	11.0 (as K_2O)	11.0 * (as K_2O)
Sulfur (S)	%	0.02	1.3	0.9 #

@ Estimate of first-year availability does not account for incorporation losses. Consult MWPS-18, "Livestock Waste Facilities Handbook" for additional information.
* Source: MWPS-18, Livestock Waste Facilities Handbook, 1993 # Source: A3411, "Manure Nutrient Credit Worksheet", University of Wisconsin
** Manure density assumed to be 8.33 lb/gallon

To: NEWTRIENT LLC - SIG GRANT
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From: CWU GEOLOGY DEPT
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PROJECT

Attn: MARK STOERMAN

Purchase Order: CWU GEOLOGY DEPT

Lab Number: 51173
Sample ID: BIDA SYSTEM OUTFLOW KS
Manure Type: DAIRY, LAGOON (21)

Date Sampled: 11/28/2022
Date Received: 12/12/2022
Date Reported: 12/14/2022 Page: 10 of 10

MANURE ANALYSIS

Analysis	Unit	Analysis Result (As Received)	Pounds Per 1,000 Gal **	First Year Availability @ Pounds Per 1,000 Gal
Magnesium (Mg)	%	0.03	2.9	1.4 #
Calcium (Ca)	%	0.03	2.4	1.4 #
Sodium (Na)	%	0.13	10.9	
Aluminum (Al)	ppm	12	0.1	
Copper (Cu)	ppm	2.0	<0.1	<0.1 #
Iron (Fe)	ppm	16	0.1	0.1 #
Manganese (Mn)	ppm	2.0	<0.1	<0.1 #
Zinc (Zn)	ppm	4.0	<0.1	<0.1 #

@ Estimate of first-year availability does not account for incorporation losses. Consult MWPS-18, "Livestock Waste Facilities Handbook" for additional information.
* Source: MWPS-18, Livestock Waste Facilities Handbook, 1993 # Source: A3411, "Manure Nutrient Credit Worksheet", University of Wisconsin
** Manure density assumed to be 8.33 lb/gallon

Report Number
F22346-6532
Account Number
63570

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3505 Conestoga Dr.
Fort Wayne, IN 46808
260.483.4759
algreatlakes.com

To: NEWTRIENT LLC - SIG GRANT
11510 LAURIE DR
WHEATFIELD, IN 46392-7364

For: CWU GEOLOGY DEPT
BIOFILTRO PROJECT

Attn: MARK STOERMAN
Sample ID: SOLIDS SAMPLE KS
Lab Number: 51223

Purchase Order: CWU GEOLOGY DEPT
Date Sampled: 11/28/2022
Date Received: 12/12/2022
Date Reported: 12/15/2022 **Page:** 1 of 6

COMPOST ANALYSIS

Analysis	Unit	Analysis Result	Dry Basis Result	Analysis Method
Moisture @ 70 C	%	72.31		TMECC 03.09-A
Solids	%	27.69		TMECC 03.09-A
Total Nitrogen (N)	%	0.73	2.63	TMECC 04.02-D
Phosphorus (P)	%	0.36	1.31	TMECC 04.03-A
Phosphate (P2O5)	%	0.83	3.00	TMECC 04.03-A
Potassium (K)	%	0.38	1.38	TMECC 04.04-A
Potash (K2O)	%	0.46	1.66	TMECC 04.04-A
Sulfur (S)	%	0.12	0.45	TMECC 04.05-S
Magnesium (Mg)	%	0.62	2.24	TMECC 04.05-MG
Calcium (Ca)	%	1.56	5.64	TMECC 04.05-CA
Sodium (Na)	%	0.16	0.58	TMECC 04.05-NA
Iron (Fe)	%	0.19	0.70	TMECC 04.05-FE
Aluminum (Al)	%	0.10	0.35	TMECC 04.07-AL
Copper (Cu)	mg/kg	18	65	TMECC 04.05-CU
Manganese (Mn)	mg/kg	119	430	TMECC 04.05-MN

TMECC - Test Methods for the Examination of Composting and Compost (TMECC), The U.S. Composting Council.

-COMPOST

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Report Approved By: [signature] Approval Date: 12/15/2022

David Henry - Agronomist / Technical Services - CCA

@ Estimate of first-year availability does not account for incorporation losses. Consult MWPS-18, "Livestock Waste Facilities Handbook" for additional information.
* Source: MWPS-18, Livestock Waste Facilities Handbook, 1993 # Source: A3411, "Manure Nutrient Credit Worksheet", University of Wisconsin
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COMPOST ANALYSIS

Analysis	Unit	Analysis Result	Dry Basis Result	Analysis Method
Zinc (Zn)	mg/kg	104	377	TMECC 04.05-ZN
pH	-	8.3		TMECC 04.11-A
Soluble Salts	dS/m	6.03		TMECC 04.10-A
As @ 550 C	%	10.83	39.10	TMECC 03.02-B
Organic Matter (LOI @ 550 C)	%	16.86	60.90	TMECC 05.07-A
Total Organic Carbon (C)	%	8.43	30.45	TMECC 04.01-A
Carbon:Nitrogen Ratio (C:N)	-	11.6:1	11.6:1	TMECC 05.02-A

TMECC - Test Methods for the Examination of Composting and Compost (TMECC), The U.S. Composting Council.

-COMPOST