NEWTRIENT EVALUATION SUMMARY

CONSERVATION INNOVATION GRANT (CIG):

Ultrafiltration Membrane-Based Nutrient Partitioning Technology

Dairy Manure Treatment Innovations – Enhancing Water Quality and Sustainability

University Partner
Tyler Liskow
Dr. Rebecca Larson
University of Wisconsin-Madison
Nelson Institute for Environmental Studies
122 Science Hall
550 North Park St.
Madison, WI 53706

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INSIDE

BACKGROUND

Livestock operations are increasingly under pressure to minimize their environmental footprint while maintaining efficient nutrient cycling and farm productivity. A key challenge lies in the management of manure, which, while rich in nutrients valuable for crop production, can also be a contributor to water contamination and greenhouse gas emissions, as well as odor when mismanaged. Traditional land application practices often involve high volumes of manure with elevated water content, which complicates transport and storage and increases the risk of nutrient losses through runoff, leaching, or volatilization.

To address these challenges, manure processing technologies have emerged as promising solutions for separating and concentrating nutrients, extracting solids, and even producing discharge-quality water. These systems offer the potential to reduce the volume and environmental risk of manure by-products, while improving efficiency and opening opportunities for nutrient recovery or reuse. However, the effectiveness of these systems depends on their ability to consistently separate targeted constituents and meet environmental thresholds for discharge.

One such system, membrane-based nutrient partitioning technology, was evaluated in Wisconsin to assess its ability to treat manure from a 4,500-cow dairy into usable co-products—separated solids, nutrient-dense concentrates, and treated water suitable for discharge. The system integrated several treatment stages, including screw presses, a centrifuge, ultrafiltration (UF), and reverse osmosis (RO). Understanding the performance of these components both individually and in combination is essential to determining the viability of advanced manure treatment systems in commercial-scale livestock operations.

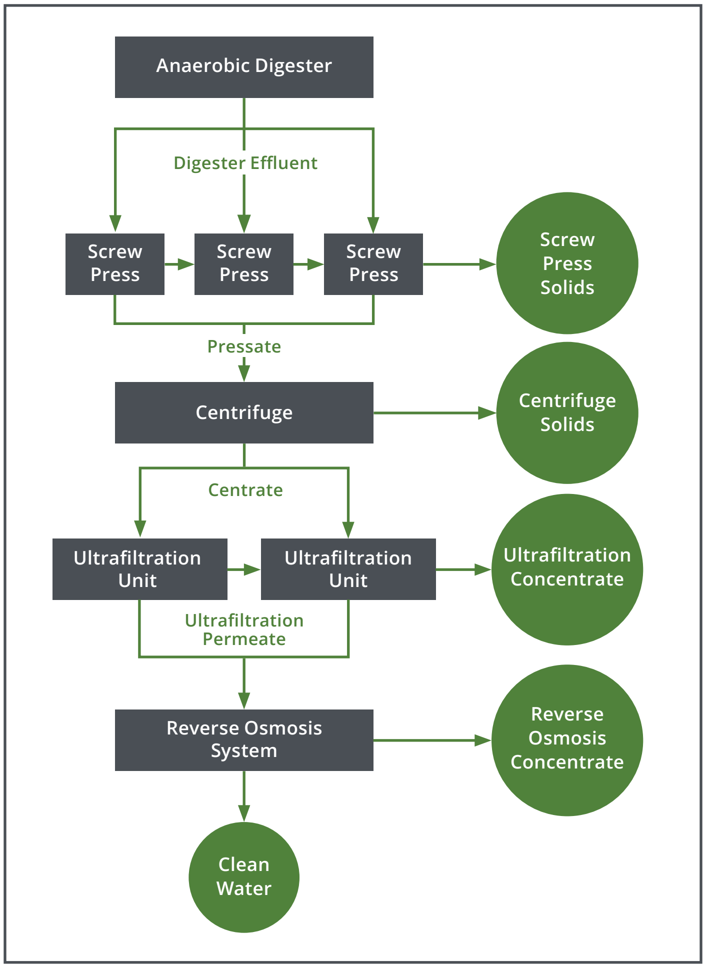
INTRODUCTION

Manure processing systems offer a promising solution by separating solids, concentrating nutrients, and treating effluent to reduce environmental risk and handling costs. Among these technologies, integrated systems that include mechanical separation and membrane filtration aim to produce value-added co-products—such as nutrient-rich concentrates, reusable solids, and treated water suitable for discharge.

This evaluation focused on a full-scale membrane-based nutrient partitioning technology installed on a 4,500-cow dairy, designed to reduce the environmental impact of manure by improving nutrient recovery and producing discharge-quality water. The study aimed to assess the system's effectiveness in partitioning key manure constituents—including total solids (TS), volatile solids (VS), total phosphorus (TP), total Kjeldahl nitrogen (TKN), total ammoniacal nitrogen (TAN, NH_4^+), and potassium (K) – and to explore its potential as a scalable solution for environmentally responsible manure management.

By examining nutrient partitioning performance and the consistency of treatment outcomes, this research contributes to a broader understanding of how advanced processing systems can support both economic and environmental goals in livestock agriculture, particularly dairy.

FIGURE 1: FLOW DIAGRAM OF THE MANURE PROCESSING SYSTEM. GREEN CIRCLES REPRESENT RECOVERED PRODUCTS.



The Process

The membrane-based nutrient partitioning system operates through a coordinated sequence of treatment stages, each designed to progressively separate and refine manure constituents to improve handling, nutrient recovery, and water reuse. In the system evaluated, manure **first** undergoes anaerobic digestion (AD), a pre-treatment step that stabilizes organic matter, reduces odors and pathogens, and enhances downstream separation efficiency. Although AD is not a required component of all membrane-based nutrient partitioning systems, its inclusion in this configuration (Figure 1) improves nutrient recovery and overall system performance. In other designs, raw or minimally processed manure may flow directly into the solid-liquid separation stage, depending on operational goals and available infrastructure.

The **second stage** involves mechanical separation, where digested manure passes through three screw presses operating in parallel to remove coarse, fibrous solids. These solids, composed mainly of undigested fiber and organic matter, typically contain a lower proportion of TP, as much of the phosphorus (P) remains in the liquid or is associated with finer particles. The remaining liquid is treated with a centrifuge to remove finer particles and additional nutrient fractions. Together, the screw press and centrifuge remove approximately 50% of TS, VS, and TP.

Next, in the UF stage, the clarified liquid flows through two UF units in parallel. These membrane filters eliminate suspended solids, bacteria, and colloidal particles, producing a cleaner stream that reduces the nutrient and pathogenic load on the final polishing step. This stage is essential for protecting the RO membranes and improving the system's overall efficiency.

In the **fourth stage,** the ultrafiltered liquid enters the RO unit (Aqua Innovations Nutrient Concentration System), where dissolved salts, nitrogen—primarily in the form of NH_4^+—and K are partitioned. This results in two distinct outputs: a nitrogen- and potassium-rich concentrate and a clean water effluent that approaches or meets discharge quality (depending on regulatory requirements). The RO step is key to enabling on-farm water reuse and reducing the volume of material requiring land application.

Finally, the **fifth stage** focuses on product management. Separated solids and nutrient concentrates are stored and managed on-farm, often used for land application aligned with crop nutrient demands. The clean water can be reused or discharged, depending on its quality and applicable regulatory guidelines.

METHODOLOGY

This evaluation was conducted on a commercial-scale manure processing system in Middleton, Wisconsin, serving five dairy farms with a combined herd of approximately 4,500 cows. The system includes AD, mechanical separation (screw presses and centrifuge), and membrane filtration using UF and RO. While the AD and mechanical units are operated by one entity, the UF and RO units—part of the Aqua Innovations Nutrient Concentration System—are managed separately.

Over a 37-week period (July 2023 to March 2024), 45 sampling events were conducted to evaluate system performance and nutrient separation efficiency. Samples were collected at key points between treatment stages to track nutrient and solids reduction throughout the process. Due to equipment failures and maintenance, some sampling events were delayed, and certain components were offline for portions of the study.

Each sampling event included collection of liquid, slurry, and solid samples, along with flow and output rate data. Samples were sent to A&L Great Lakes Laboratories and analyzed using the M7 Manure Analysis Package plus pH, which included TS, VS, TKN, NH_4^+, P, K, and other parameters. Treated water samples were evaluated using the W2 Water Analysis Package plus NH_4^+, capturing metrics such as Sodium Adsorption Ratio (SAR), Total Dissolved Solids (TDS), hydrogen ion concentration (pH), and nutrient concentrations.

DISCUSSION OF RESULTS

The evaluation of the membrane-based nutrient partitioning system revealed meaningful progress toward more efficient and environmentally responsible manure management. The multi-stage approach—combining mechanical and membrane separation—enabled significant reductions in solids, P, and dissolved nutrients like NH_4^+ and K, while producing a cleaner water stream suitable for reuse or discharge. Although system reliability was impacted by mechanical failures, the performance data collected during operational periods highlight both the potential benefits and practical limitations of this technology. The following sections outline the system's most significant advantages, as well as the key operational and logistical challenges that must be addressed for successful long-term implementation.

Key Benefits of Ultrafiltration Membrane-Based Nutrient Partitioning Systems

Effective Multi-Stage Nutrient and Solids Separation with High Throughput Capacity: The manure processing system demonstrated strong performance in separating nutrients and solids across its multi-stage design. Operating at average influent flow rates of 126 gallons per minute (GPM) into the screw press and 116 GPM into the centrifuge (Figure 2), the system has the potential to treat approximately 145,000 gallons per day via the screw press and 134,000 gallons per day through the centrifuge—equivalent to manure from ~7,800 and ~7,100 cows, respectively. The separation index (SI) for solids and P improved substantially when the screw press and centrifuge were operated in series, achieving high-efficiency benchmarks. Removal efficiency (RE) also followed this trend, with VS and P removal reaching high-efficiency thresholds (>0.53) after UF and RO stages. While centrifuge solids had the highest nutrient concentrations—0.78% total nitrogen (N) and 0.46% P_2O_5 (Table 1)—the liquid fractions, especially the RO concentrate rich in plant-available N, represent the most agronomically efficient products for targeted nutrient application. These results highlight the system's effectiveness in optimizing both nutrient recovery and agronomic value across multiple output streams.

FIGURE 2: SCREW PRESS AND CENTRIFUGE INPUT FLOW RATES RECORDED DURING SAMPLING EVENTS.

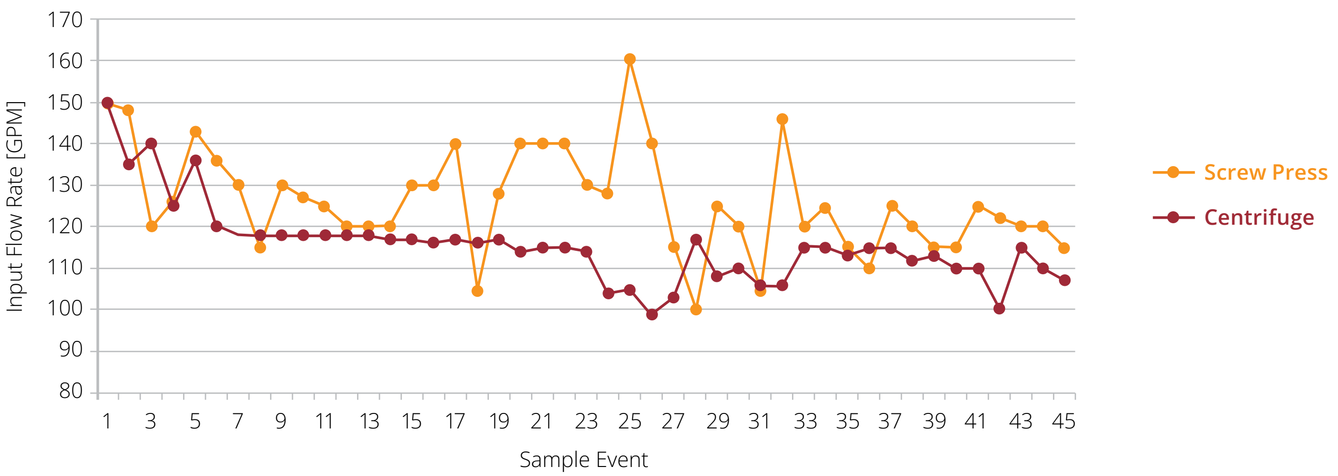


TABLE 1: PRIMARY MANURE CHARACTERISTICS BY SAMPLING LOCATION (NON-DETECTS WERE GIVEN A VALUE OF ZERO).

Sample	Statistics	Moisture [%]	Solids [%]	Volatile Solids [%]	Total Nitrogen [%]	Ammonium Nitrogen as N [%]	Phosphorus as P_2O_5 [%]	Potassium as K_2O [%]
Manure	Average	88.23	11.7	8.69	0.41	0.17	0.07	0.29
	Max	90.13	15.11	9.98	0.48	0.19	0.8	0.33
	Min	84.89	9.87	8.02	0.35	0.16	0.06	0.26
	Std. Dev.	1.56	1.56	0.69	0.04	0.01	0.01	0.02
Digestate	Average	93.56	6.44	4.76	0.38	0.23	0.06	0.29
	Max	94.42	6.91	5.21	0.41	0.25	0.07	0.36
	Min	93.09	5.58	3.75	0.33	0.18	0.05	0.25
	Std. Dev.	0.31	0.31	0.28	0.02	0.02	0.00	0.02
Screw Press Separated Solids	Average	73.95	26.05	22.17	0.57	0.26	0.16	0.29
	Max	76.69	29.24	25.57	0.80	0.39	0.42	0.40
	Min	70.76	23.31	12.25	0.48	0.19	0.11	0.27
	Std. Dev.	1.63	1.63	2.28	0.07	0.05	0.05	0.02
Screw Press Separated Liquids	Average	95.48	4.52	2.96	0.36	0.22	0.05	0.28
	Max	96.34	7.98	5.57	0.41	0.25	0.09	0.32
	Min	92.02	3.66	2.31	0.31	0.18	0.04	0.23
	Std. Dev.	0.77	0.77	0.59	0.03	0.02	0.01	0.02
Centrifuge Separated Solids	Average	71.72	28.28	18.35	0.78	0.37	0.46	0.30
	Max	73.87	29.76	22.67	0.88	0.43	0.56	0.33
	Min	70.24	26.13	16.32	0.60	0.25	0.15	0.21
	Std. Dev.	0.79	0.79	0.90	0.06	0.03	0.07	0.02
Centrifuge Separated Liquids	Average	97.37	2.63	1.38	0.29	0.18	0.03	0.24
	Max	99.28	3.06	1.77	0.44	0.22	0.03	0.29
	Min	96.94	0.72	0.38	0.09	0.06	0.01	0.09
	Std. Dev.	0.38	0.38	0.26	0.05	0.03	0.00	0.04
Ultrafiltration Concentrate	Average	95.99	4.01	2.73	0.37	0.18	0.05	0.22
	Max	99.27	5.61	4.08	0.83	0.22	0.07	0.30
	Min	94.39	0.73	0.37	0.09	0.05	0.00	0.06
	Std. Dev.	0.86	0.86	0.65	0.10	0.03	0.01	0.05
Ultrafiltration Permeate	Average	98.94	1.06	0.27	0.19	0.17	0.00	0.17
	Max	99.72	2.14	0.50	0.37	0.34	0.13	0.54
	Min	97.86	0.28	0.05	0.06	0.05	0.00	0.04
	Std. Dev.	0.32	0.32	0.09	0.05	0.05	0.02	0.09
Reverse Osmosis Concentrate	Average	98.26	1.74	0.42	0.30	0.27	0.00	0.23
	Max	99.52	2.48	0.75	0.63	0.34	0.00	0.42
	Min	97.52	0.48	0.12	0.09	0.08	0.00	0.08
	Std. Dev.	0.46	0.46	0.12	0.08	0.06	0.00	0.10

Consistent Production of Treated Water Suitable for Reuse or Discharge: The manure processing system produces treated clean water that consistently meets discharge quality standards, generating approximately 28% of the influent manure volume as treated water suitable for reuse or discharge (Figure 3). Over the study period, the RO unit produced clean water with an average TDS of 62.7 mg/L, well below the Environmental Protection Agency secondary standard of 500 mg/L, and NH_4-N averaged 12.1 mg/L, indicating substantial N partitioning (Table 2, Figure 4). Additionally, P concentrations exceeded detection in only 11% of samples and remained far below the typical 1 mg/L discharge threshold. Assuming full system functionality with 80% uptime, the UF unit could process approximately 42 million gallons annually, significantly enhancing water reuse capabilities on-farm and reducing pressure on land application areas.

FIGURE 3: VOLUME OF MANURE THROUGH THE TREATMENT SYSTEM.

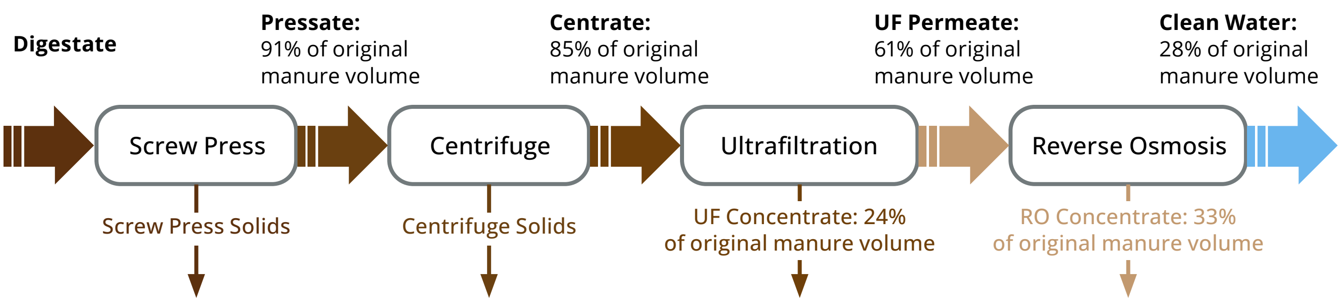
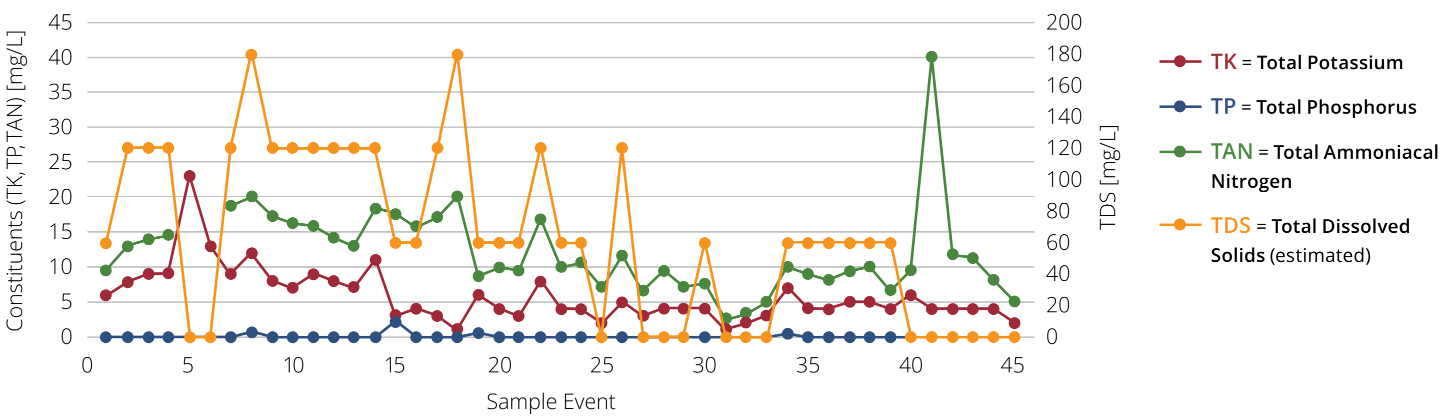


TABLE 2: PRIMARY TREATED CLEAR WATER CHARACTERISTICS BY SAMPLING LOCATION (NON-DETECTS WERE GIVEN A VALUE OF ZERO).

Sample	Statistics	pH	Conductivity [mmho/cm]	Total Dissolved Solids (estimated) [mg/L]	Ammonium Nitrogen [mg NH_4-N/L]	Phosphorus [mg P/L]	Potassium [mg/L]	Chloride [mg/L]	Manganese [mg/L]
Treated Water	Average	6.8	0.14	62.7	12.10	0.094	5.78	5.11	0.058
	Max	9.5	0.50	180.0	40.00	2.260	23.00	91.00	0.420
	Min	4.4	0.00	0.0	2.40	0.000	1.00	0.00	0.000
	Std. Dev.	0.7	0.11	53.6	6.20	0.360	3.80	13.40	0.093

FIGURE 4: TREATED CLEAN WATER SAMPLE CONCENTRATION OVER ALL SAMPLING EVENTS (NON-DETECTS WERE GIVEN A VALUE OF ZERO).



Evaluation Key Challenges and Issues

Operational Downtime and Mechanical Reliability Significantly Impact Throughput: Despite the system's design capacity, actual throughput was limited by mechanical issues. Notably, UF Unit A was offline for the majority of the sampling period, and pump failures (on 7/26/2023, 11/17/2023, and early 2024) led to periods of zero flow (Methods). Sediment clogging and freeze issues in the underground pipe between buildings further disrupted operation. These interruptions reduced the effective capacity of the system from its designed 115,000 gallons per day to a functional reality of 45 GPM inflow during much of the sampling period. Without consistent uptime, the full potential for nutrient separation and clean water production could not be realized. The reliance on complex mechanical systems, such as inline pumps and membrane filters, introduces maintenance burdens that must be addressed for consistent system performance.

High Variability in Nutrient Concentrations and Removal Reduces Management Predictability: While the system achieved strong average nutrient separation, day-to-day performance showed high variability. For example, TAN removal efficiency from screw press and UF stages showed the highest coefficients of variation (Figure 5), indicating inconsistency in how ammonium was handled. Nutrient concentrations in liquid phases varied widely—e.g., NH_4-N in RO concentrate ranged from 0.08% to 0.34%, and TP in screw press solids ranged from 0.11% to 0.42% (Table 1). Moreover, separation indices for N and K remained consistently below high-efficiency thresholds (Figure 6), suggesting these nutrients were poorly captured in solids. This variability complicates nutrient budgeting and land application planning, potentially limiting the benefits of precise nutrient recovery unless supported by frequent monitoring and adaptive management strategies.

FIGURE 5: COEFFICIENT OF VARIATION (CV) FOR THE REMOVAL EFFICIENCY FOR TOTAL SOLIDS (TS), VOLATILE SOLIDS (VS), TOTAL NITROGEN (TN), TOTAL AMMONIACAL NITROGEN (TAN), TOTAL PHOSPHORUS (TP), AND TOTAL POTASSIUM (TK).

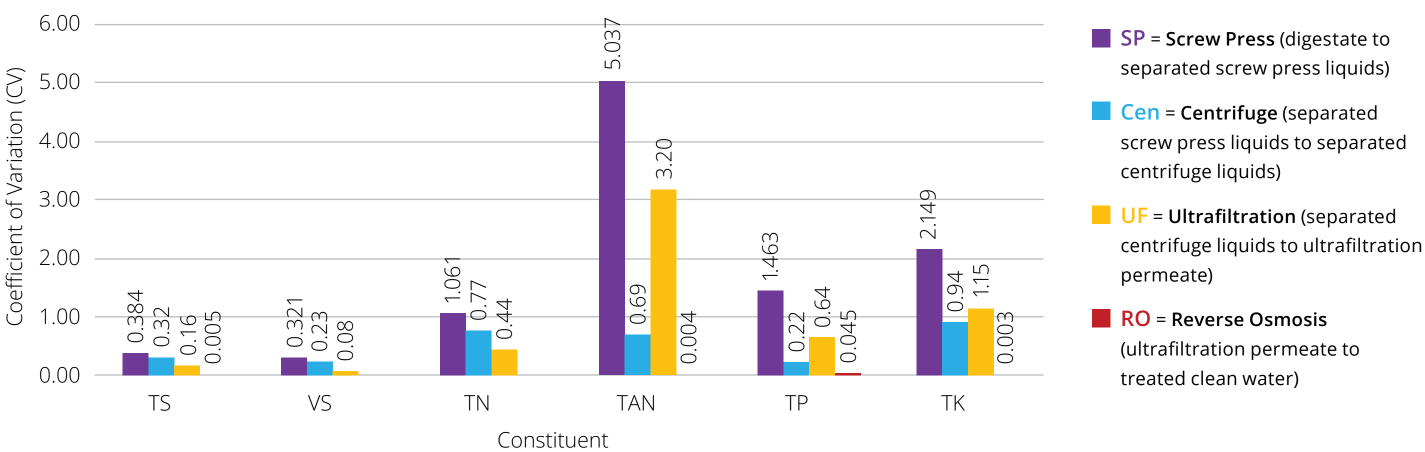
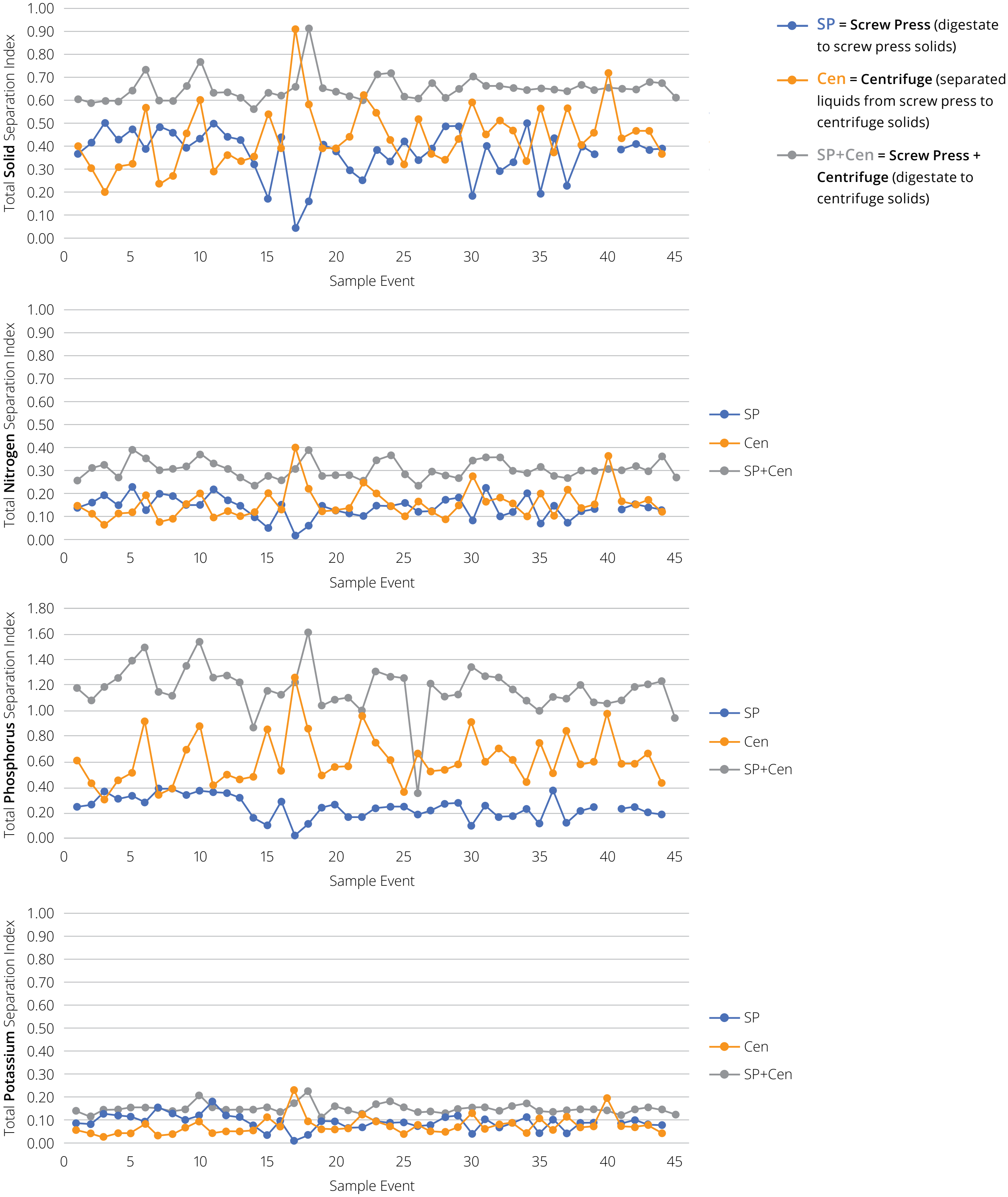


FIGURE 6: SEPARATION INDEX (SI) OVER TIME FOR TOTAL SOLIDS (TOP), TOTAL NITROGEN, TOTAL PHOSPHORUS, AND POTASSIUM (BOTTOM) FOR THE SCREW PRESS AND CENTRIFUGE.



IMPLICATIONS

This study demonstrates that membrane-based nutrient partitioning systems, when integrated into multi-stage manure treatment processes, offer significant potential for improving nutrient recovery, producing clean water suitable for reuse or discharge, and enhancing the agronomic value of separated manure fractions. The system evaluated achieved high removal efficiencies for VS and P, particularly after the UF and RO stages, while producing treated water that regularly met discharge thresholds for TDS, NH_4-N, and P. These outcomes point to a strong alignment between system outputs and both regulatory and agronomic goals.

The ability to partition nutrients into more manageable and targeted end products—such as P-rich concentrates and NH_4-N–dominant RO streams—presents a promising pathway for nutrient stewardship and land application optimization. However, the study also revealed considerable variability in system performance, particularly in NH_4-N and K partitioning, which may complicate nutrient budgeting and reduce confidence in precision application strategies. This highlights the importance of real-time monitoring, operator training, and adaptive management when deploying such advanced systems at scale.

Downtime and operational inconsistencies were also notable during the study period, affecting overall throughput and reliability. While these challenges are not uncommon in pilot or early-stage commercial systems, they underscore the need for robust system design, routine preventative maintenance protocols, and improved resilience of membrane components under farm-scale conditions.

With further refinement, membrane systems could offer dairy operations a scalable and environmentally sound solution for transforming raw manure into higher-value, lower-risk inputs for crop production. Future research should focus on reducing variability, improving uptime, and validating long-term system performance under a range of environmental and operational scenarios. If these challenges are addressed, membrane systems may play a critical role in helping farms meet emerging water quality standards and nutrient efficiency goals.

For additional information on the vendor, environmental impacts, financial implications, and ultrafiltration membrane-based nutrient partitioning technology, visit the Aqua Innovations Plus, LLC Vendor Snapshot on the **Newtrient website**.

Newtrient's mission is to reduce the environmental footprint of dairy while making it economically viable to do so.

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Newtrient, LLC
10255 W. Higgins Road
Suite 900
Rosemont, IL 60018
847-627-3855
info@newtrient.com

www.newtrient.com