



NEWTRIENT EVALUATION SUMMARY

CONSERVATION INNOVATION GRANT (CIG):

# Adaptive Irrigation Technology

Dairy Manure Treatment Innovations – Enhancing Water Quality and Sustainability

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**MARCH 2025**

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## BACKGROUND

Effective management of manure nutrients is critical for maximizing the fertilizer value of manure while minimizing environmental losses. Traditional manure application methods in the non-growing season often result in nutrient losses due to prolonged exposure to environmental factors before crops can utilize them. This delay increases the likelihood of nutrient runoff, leaching, and gaseous losses, reducing the overall value of manure as a fertilizer and potentially contributing to environmental concerns such as water quality degradation.

In-season manure application has emerged as a promising strategy to improve nutrient use efficiency by aligning nutrient availability with crop demand. Delivering manure nutrients during key crop growth stages can increase nutrient uptake, reduce nutrient losses, and improve overall crop productivity. However, the system and accuracy of in-season manure application methods, particularly those utilizing automated or autonomous systems, require further evaluation to determine their effectiveness and potential environmental impacts.

360 RAIN is an adaptive irrigation machine that autonomously delivers water, nutrients, manure, byproducts, and other resources, banded or broadcast, across the entire field during the growing season – even in irregular shaped fields. However, there is limited data assessing the accuracy of manure nutrient application and potential nutrient losses associated with this system. Understanding how closely the intended nutrient application matches the actual nutrients delivered, as well as the system's impact on nitrogen (N) leaching, is critical for determining its value in improving manure nutrient management.

## INTRODUCTION

This study aimed to evaluate the performance of an in-season, adaptive irrigation machine, the 360 RAIN, to better understand its effectiveness in delivering manure nutrients to crops and its potential impact on nutrient leaching. Specifically, the study focused on comparing the intended versus actual nutrient application rates and measuring nitrogen leaching beneath the crop root zone. Assessing these factors is essential to determine if in-season manure

application can improve nutrient use efficiency and reduce environmental losses compared to traditional manure application practices.

The 360 RAIN system presents an opportunity to apply manure during periods of high crop nutrient demand, potentially reducing the time nutrients remain exposed to loss pathways such as leaching and runoff. However, variability in nutrient concentrations, flow rates, and field conditions can influence the accuracy of applied nutrients and their subsequent environmental fate. This research sought to quantify these variables by comparing the intended nutrient application rates of manure with

measured field results and monitoring nitrogen leaching to understand potential environmental impacts.

By examining the effectiveness of in-season manure application using the 360 RAIN system, this research contributes to a broader understanding of how autonomous systems can optimize nutrient management. Ultimately, the findings from this study will help inform future nutrient management strategies, improve nutrient use efficiency, and reduce potential environmental losses associated with manure applications. Further data collection and long-term evaluations will be necessary to establish best management practices for in-season manure application systems.

## The Process

The 360 RAIN system (Figure 1) is an adaptive irrigation system designed to autonomously deliver nutrients directly to crops during the growing season. It operates using a long hose connected to a central source called a Field Riser. A vertical reel on the machine lays out and retrieves the hose as the machine moves, allowing it to cover large field areas without the need for any frequent repositioning. Equipped with a boom and multiple drops, the machine travels along crop rows, applying liquid nutrients with desired rates controlled via an app. Liquid applications are at or near the soil surface reducing particulate drift and nitrogen volatilization (Figure 2).

One of the key features of the 360 RAIN system is its ability to blend and apply liquid from multiple input sources. These sources can include water, manure effluent from dairy cows or hogs, collected runoff, silage leachate, fertilizer, and digestate depending on availability and management goals. By adjusting the source and ratio of inputs, the system allows for tailored nutrient application throughout the growing season. This flexibility enables producers to optimize nutrient delivery, potentially increasing nutrient uptake by crops, improving yield as well as enhancing crop and soil health, while reducing the risk of nutrient losses to the environment.

The speed of the machine is adjusted according to the desired application rate, ensuring even distribution of nutrients across the field. The system's capacity to apply nutrients directly to growing crops minimizes the time nutrients remain vulnerable to runoff or leaching, promoting improved nutrient use efficiency. Additionally, its ability to operate from a centralized location with an extended hose length allows for efficient coverage of both large-sized and abnormally shaped field areas. This innovative approach to nutrient application has the potential to enhance crop performance while reducing environmental impact.

**FIGURE 1: PHOTO OF 360 RAIN.**



**FIGURE 2: PHOTO OF 360 RAIN BANDED DROP APPLYING MANURE TO GROWING CORN.**



## METHODOLOGY

**Farm Details:** The 360 RAIN system was evaluated on a farm located in east-central Wisconsin, focusing on two adjacent fields. The first field, a 100-acre corn silage field, was selected for the study, while the second field, a 75-acre hay field, was also utilizing the 360 RAIN system but was not part of the evaluation. The farm milks approximately 1,500 dairy cattle housed in freestall barns bedded with composted dairy manure fiber. Manure is collected from the freestall barns, passed through screw press separators to remove fiber, and then stored in a holding pond until it is ready for land application.

The system drew from three primary input sources: post-separated manure liquid from the storage pond, silage leachate and farmstead runoff from a leachate pond, and well water.

**Sample Collection and Monitoring:** To assess the effectiveness of the customized 360 RAIN system, liquid samples were collected from the three input sources—manure storage, leachate storage pond, and well water. These samples were analyzed by A&L Great Lakes Laboratories for 21 parameters, including moisture, total solids, total Kjeldahl nitrogen (TKN), phosphorus (P),

potassium (K), sulfur, calcium, magnesium, sodium, iron, aluminum, manganese, copper, zinc, organic carbon, and ammonium-nitrogen ( $\text{NH}_4\text{-N}$ ), among others.

The 360 RAIN system was deployed on the 100-acre corn field seven times during the growing season. Each deployment took approximately five days to cover the entire field (20 acres per day). To collect data on the applied liquid, five sampling events were conducted throughout the season. During each event, stainless steel collection pans were placed randomly within the application path of the 360 RAIN machine. After the application, the pans were weighed, and composite samples were collected for further analysis.

One of the five sampling events was specifically dedicated to the collection of well water, and all samples were shipped to A&L Great Lakes Laboratories within one week of sampling for analysis using the M7 Manure Analysis Package plus pH.

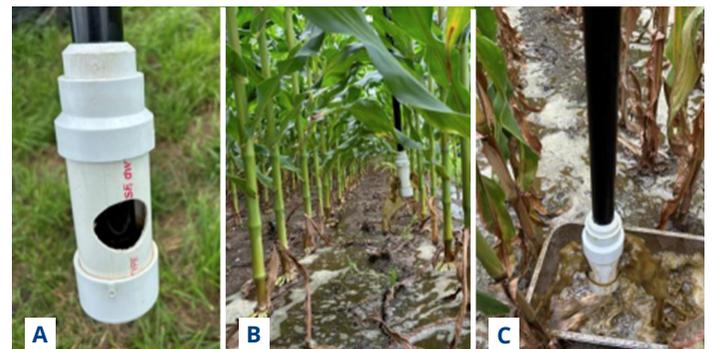
Additionally, resin cartridges were deployed to measure nitrogen cycling and leaching. These cartridges were placed in both the 100-acre cornfield receiving 360 RAIN applications and an adjacent 20-acre cornfield that received a one-time manure application using traditional methods for comparison. The resin cartridges were buried in undisturbed soil at depths of 0-5 cm, 5-6 cm, and 6-10 cm to capture inorganic nitrogen concentrations over the course of 106 days.

**NOTE:** This farm purchased a 2022 model of the 360 RAIN system and custom built their own boom extensions (Figure 3). 360 Yield Center does not endorse the custom boom. The drops are also not factory-available (Figure 4).

**FIGURE 3: CUSTOM BOOM SIZE AND DROPS USED FOR STUDY – NOT ADVISED BY 360 YIELD CENTER.**



**FIGURE 4: DROP STYLE NOT FACTORY-AVAILABLE WITH 360 RAIN SYSTEMS.**



**A)** Close up of drop. **B)** Application occurring between corn rows. **C)** Drop passing over collection pan during application.

**Calculations:** Nitrogen leaching was assessed by analyzing the resin cartridges, following the methods described by Bischoff (2007) and Grahmann et al. (2018). After the cartridges were retrieved, they were divided into three layers, and nitrogen concentrations were measured. The nitrogen leaching flux was calculated by subtracting the internal blank layer (5-6 cm) nitrogen concentrations from the first layer (0-5 cm), which captured the accumulated nitrogen leached from the soil.

To measure nitrogen concentrations, a 10-gram subsample from each of the first two layers was extracted using 2 M potassium chloride (KCl) and agitated for 60 minutes. The samples were filtered and stored at -10°C for later analysis of ammonium-nitrogen (NH<sub>4</sub><sup>+</sup>-N) and nitrate-nitrogen (NO<sub>3</sub><sup>-</sup>-N) concentrations. Moisture content was also determined for each layer to correct the nitrogen concentrations.

The cumulative nitrogen leaching flux was estimated using the equation from Wey et al. (2022), which allowed for quantification of nitrogen loss over the 106-day sampling period.

## DISCUSSION OF RESULTS

The results from the evaluation of the 360 RAIN system provide valuable insights into its effectiveness as a nutrient management tool for in-season application. The data collected from both the application events and resin

cartridge sampling offer a comprehensive understanding of the system’s performance in managing nutrients under real-world conditions. In this section, we will analyze the impact of the 360 RAIN system on nutrient distribution, crop health, and environmental sustainability, comparing it with traditional nutrient management methods to assess potential benefits and areas for improvement.

### Key Benefits of Adaptive Irrigation

**Effective Nutrient Delivery:** The system’s nutrient application is precisely targeted, offering a controlled method for delivering nutrients across the field. By applying nutrients consistently and precisely over time, the 360 RAIN system supports not just the growth of healthy crops, but also the long-term health of the soil. Consistent nutrient application helps maintain an optimal nutrient balance in the soil, promoting soil microbial activity and preventing nutrient deficiencies or toxicities that can occur from uneven or excessive fertilizer applications. Over the course of seven application events, 67,388 gal/acre were applied, with 14.4% manure holding pond liquid, 54.1% well water, and 31.5% leachate pond liquid, which contributes to the nutrient load. The use of multiple sources allowed for a more balanced nutrient distribution (Table 1), helping to the sustain healthy crop growth while optimizing nutrient use efficiency. A starter nitrogen fertilizer was also used on the 360 RAIN field.

**TABLE 1: APPLICATION RATES USING THE 360 RAIN ACROSS THE 2024 CROPPING SEASON.**

Sample Events			A & B	C		D		Annual Total
360 RAIN Application	1	2	3	4	5	6	7	
	gal/acre							
Manure Lagoon	1,000	1,000	1,000	2,500	2,500	1,700	0	9,700
Leachate Pond	0	4,397	4,276	12,543	0	0	0	21,216
Well Water	3,839	0	0	0	10,313	11,615	10,705	36,472
<b>Event Total</b>	<b>4,839</b>	<b>5,397</b>	<b>5,276</b>	<b>15,043</b>	<b>12,813</b>	<b>13,315</b>	<b>10,705</b>	<b>67,388</b>

**Improved Nutrient Distribution:** The 360 RAIN system enhances the efficiency of nutrient delivery by directly applying nutrients to the root zone, ensuring that crops receive the right amount of nutrients at the right time. This targeted application method minimizes nutrient loss due to runoff or volatilization and allows for more precise management of manure, leachate, and well water. The nutrient application data from the 360 RAIN system (Table 2) demonstrates consistent delivery of N (TKN and  $\text{NH}_4\text{-N}$ ), P, and K across different sample events, with  $\text{NH}_4\text{-N}$  application rates ranging from 13.2 to 70.7 lbs/acre and total N from 23.7 to 103.8 lbs/acre. P and K were applied at rates from 8.4 to 25.9 lbs/acre and 24.3 to 83.9 lbs/acre, respectively. This controlled delivery helps minimize both over-application and under-application of nutrients, leading to improved crop health, higher yields, and reduced reliance on synthetic fertilizers.

**Comparable Nitrogen Leaching Despite Increased Water Application:** Nitrogen leaching was evaluated using resin cartridges. The 360 RAIN field received 110 lbs N/acre of N per acre via Urea Ammonium Nitrate (UAN) before data collection began and 8,700 gallons of in-season liquid manure (equivalent to 63 lbs N/acre), for a total of 173 lbs N/acre. In comparison, the control field received 180 lbs N/acre. Resin cartridge data showed similar N leaching between the two fields, with an average leaching rate of 58 lbs/acre for the 360 RAIN field and 56 lbs/acre for the control field. This indicates that despite the additional water applied in the 360 RAIN field, which tends to increase leaching, nitrogen leaching rates

were comparable between the two fields. However, it should be noted that the resin cartridges were deployed after spring manure and commercial fertilizer was applied to the control field, which likely missed some nitrogen leaching that occurred earlier in the season.

## Evaluation Key Challenges and Issues

**Inconsistent Application Measurements:** One of the key challenges observed in this evaluation was inconsistency between the calculated application rates and measured application using pans (Figure 5). Nitrogen leaching and nutrient application showed considerable discrepancies in measurements, particularly for total nitrogen (45% difference) and ammonium (57% difference), indicating that current methods for measuring nutrient application may not be fully accurate or reliable. Future sampling methodologies should use larger sampling areas to reduce variability and improve accuracy.

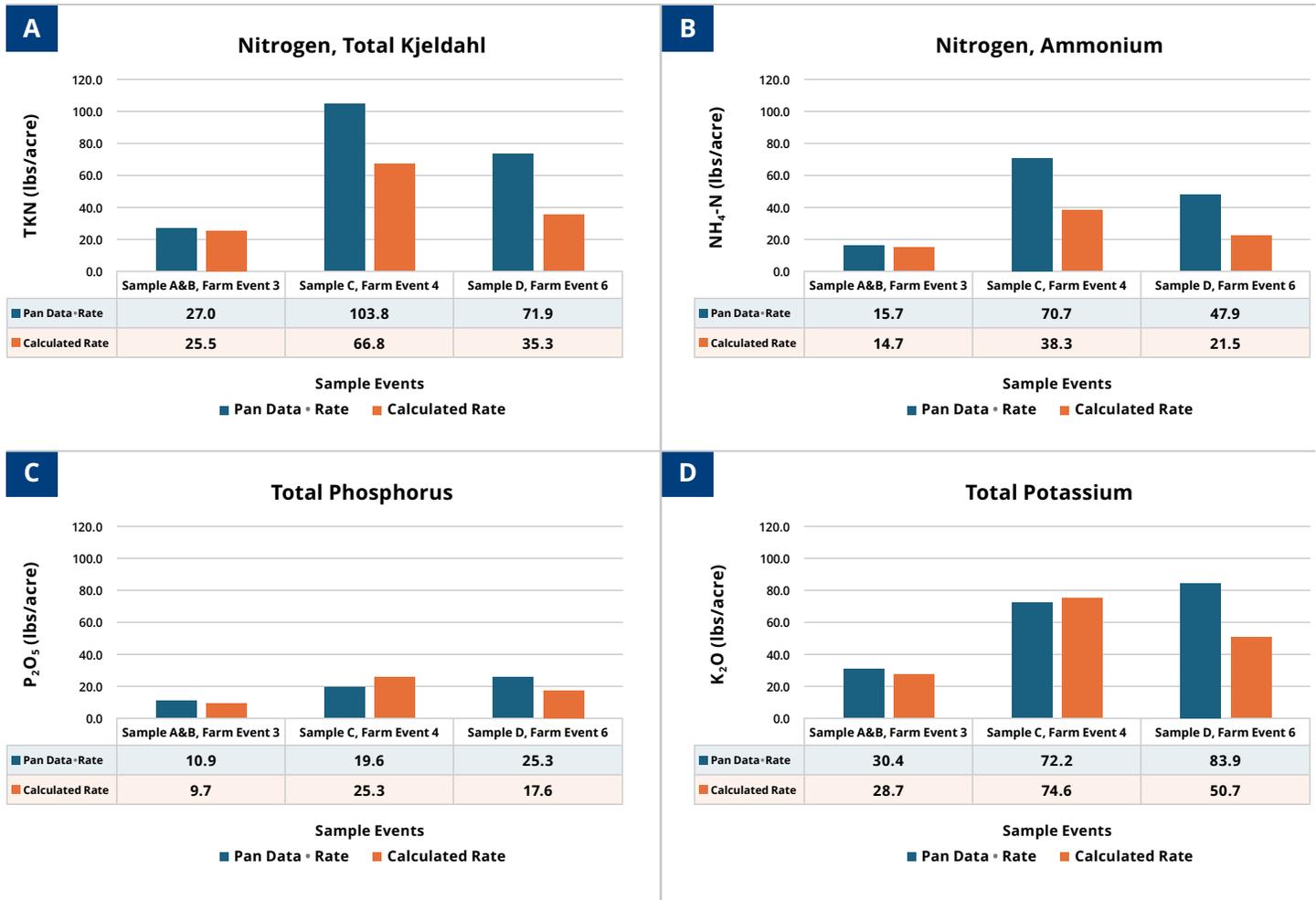
**Timing of Resin Cartridge Installation:** The timing of the resin cartridge installations, which occurred after the manure application on the control field, may have missed critical leaching events early in the season. This delay in data collection could have led to discrepancies in nitrogen leaching estimates between the two fields, especially in the early stages of nutrient application. Future studies should consider more precise timing of resin cartridge placement to capture a full picture of leaching patterns across different application methods.

**TABLE 2: LAND APPLIED N-P-K CALCULATED USING PAN FIELD DATA.**

Sample Event	Nitrogen, Total Kjeldahl (TKN)	Nitrogen, Ammonium ( $\text{NH}_4\text{-N}$ )	Total Phosphorus ( $\text{P}_2\text{O}_5$ )	Total Potassium ( $\text{K}_2\text{O}$ )
Units	lbs/acre			
A	24.8	13.2	8.4	25.9
B	23.7	14.8	10.0	24.3
C	103.8	70.7	19.6	72.2
D	71.9	47.9	25.3	83.9
<b>Total for A-D* (event 3, 4, &amp; 6)</b>	<b>202.7</b>	<b>134.3</b>	<b>55.7</b>	<b>186.5</b>

\*A and B are different samples from the same event so averaged A and B before totaling A-D.

**FIGURE 5: COMPARISON OF APPLICATION RATES FROM THE PAN DATA COMPARED TO CALCULATED RATES FOR A) TKN, B) NH<sub>4</sub>-N, C) P<sub>2</sub>O<sub>5</sub>, AND D) K<sub>2</sub>O.**



## IMPLICATIONS

The results of this study offer strong evidence that the 360 RAIN system can effectively apply in-season manure and water without compromising crop health or dramatically increasing nitrogen leaching. The ability to apply liquid manure, leachate pond water, and well water directly to growing crops presents a significant opportunity for improving nutrient utilization, reducing fertilizer dependency, and enhancing crop productivity. Additionally, the system's capacity to distribute manure applications throughout the season offers potential benefits for both environmental sustainability and farm profitability.

While the study identified some operational and measurement challenges, including higher-than-expected nutrient application rates and potential underestimation of early-season leaching, these challenges are addressable with further research and system optimization. The fact that nitrogen leaching rates remained comparable despite the 360 RAIN field receiving significantly more water is particularly promising, suggesting that in-season manure applications have the potential to better synchronize nutrient availability with crop demand.

As more farms continue to adopt the 360 RAIN system, additional research and field trials will be critical to further refine application strategies, optimize nutrient delivery,

and better understand long-term environmental impacts. While this study provides valuable insights into the potential of 360 RAIN for nutrient and water management, it also highlights opportunities for improved measurement techniques and more accurate assessments of early-season nutrient losses. With continued research and adaptation, the 360 RAIN system has the potential to significantly enhance sustainable manure management practices and further support farmers in maximizing the value of their manure nutrients.

For additional information on the vendor, environmental impacts, financial implications, and land application technology, visit the 360 RAIN Vendor Snapshot on the [Newtrient website](#).

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

This study was funded by the Natural Resources Conservation Service (NRCS) through a Conservation Innovation Grant (CIG). The views and findings presented in this publication are those of the author(s) and do not necessarily reflect the official views or policies of NRCS or the U.S. Department of Agriculture.

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