

FFAR Final Progress Report

As part of closing out a FFAR grant, grantees must complete a Final Progress Report. Please use the template below to complete the programmatic report. The report must be submitted to FFAR within 90 days after the expiration or termination of a FFAR funded research grant. All questions about this form should be directed to grants@foundationfar.org.

The Final Progress Report communicates the cumulative results and major accomplishments of the funded grant research, including accomplishment for each aim and whether all research aims were fully completed. FFAR uses the content of the Final Progress Report to inform Congress, the Advisory Board, and other stakeholders on the successes, impacts and value of funding unique partnerships to support innovative science addressing today's food and agriculture challenges. If a question is not applicable to the project, please type "Nothing to report."

Grant Information	
Grant ID	534655
Award Program	Seeding Solutions: Addressing Challenges in Food and Agriculture Funding Opportunity
Project Title	Coordinated Site Network for Studying the Impacts of 4R Nutrient Management
Grant Start Date	10/01/2017
Grant End Date	12/31/2021
Total Grant Budget	\$2,000,000
Total FFAR Budget	\$1,000,000
Matching Funder(s)	Foundation for Agronomic Research
Final Report Date	04/27/2022
Project Director/Principal Investigator Information	
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General Information

- 1.1. Please list the geographic location(s) – city, state, congressional district - where the work was conducted. If the work was conducted outside of the US, please list the city and country.

Ames, IA – IA 4
 Calumet, IA – IA 4
 West Lafayette, IN – IN 4
 Lamberton, MN – MN 7
 Arcola, IL – IL 15
 Pana, IL – IL 13
 Novelty, MO – MO 6
 Woodslee, ON, Canada

- 1.2. How many new jobs were created because of this grant funding?
 A part-time technician supported this project at the ISU site in Northwest Iowa.
 A full time technician was hired on May 29, 2018 to support the work at the Ames, IA ARS site.
 A full time technician was hired on May 29, 2018 to support the work at the Ames, IA ARS site.

- 1.3. How many jobs were maintained because of this grant funding?
 Have helped to support professional staff, graduate students, and undergraduate students to assist with data collection, summary, and analysis. At least 15 in total.

- 1.4. Have there been any changes to your organization’s IRS 501(c)(3) non-profit status since you were awarded the grant? If yes, please explain.

No

- 1.5. Has your organization undergone a recent name change? If so, please provide the new name of your organization.

No

2. Scientific Report

- 2.1. Public Abstract (up to 500 words): The abstract should be 'stand-alone' and is intended for a general audience. It should be a concise overview/summary of the importance of the project, the issues that the project addressed, and the key findings of the project. The abstract should also clearly state how the results of the project help to address important needs in U.S. food and agriculture systems.

Launched in October 2017 (with funding from FFAR and FAR), the 4R NutriNet project linked eight agricultural field research site teams to study the impacts of 4R (Right source; Right rate; Right Time; Right place) nutrient management practices and other advanced soil and crop management practices on crop productivity and nutrient losses in corn-based systems. Researchers across the North American Corn Belt – from five universities, two government research units, and a non-profit organization – compared agronomic and environmental performance of current “farmer practice” to advanced systems, aiming to minimize environmental losses and maintain or enhance soil health and yield. A key objective of this project was to make the agronomic and environmental data FAIR (Findable, Accessible/Accessible, Interoperable, Re-usable) so as to permit synthesis of results across managements and agro-ecozones (soils and temperature and precipitation regimes), and to facilitate data re-use for calibration and verification of crop and hydrological models. This work leverages past investments in replicated subsurface drainage systems for water quality monitoring and has documented crop production, nutrient leaching, and greenhouse gas (GHG) emissions at all or a subset of the sites for GHG emissions. Three years of study have shown that 4R and other advanced practices can provide environmental benefits with no production decline, even though year-to-year weather differences impact absolute yield. Data from this project can be used to evaluate the models and tools currently under consideration for use in estimating climate change mitigation following implementation of “climate smart” practices.

- 2.2. Provide a description or interpretation of how the key findings of the project can be used by the agriculture community. It is important the PI identifies how these findings have been, or may be, adopted or adapted in U.S. agriculture and food systems. If the findings cannot yet be applied, this section should address how they can be used to guide future planning or decision-making (up to 1,000-word limit).

Field studies performed across eight locations in the Corn Belt supported the value of practicing the 4Rs of nutrient management (Right source; Right rate; Right Time; Right place) for balancing agronomic production and environmental outcomes. Three years of data across the sites showed these practices provide environmental benefits with no production decline. The studies were uniquely able to assess agronomic/environmental tradeoffs often not studied in tile drainage studies such as multiple N loss pathways (like nitrous oxide gas in addition to nitrate leaching) and phosphorus losses. Practices most likely to reduce nitrate leaching included

enhanced-efficiency fertilizers and cover crops. However, the variability across the study locations, which was a strength of this project, highlighted that site-specific practices may be necessary to balance agronomic and environmental goals even within this region.

2.3. Research Outcomes/Impact (up to 1,500-word limit). The primary goal here is to answer questions such as “How did this project lead to improvements in U.S. agriculture and food systems?” or “How can the findings of this study guide or make improvement in future investigations and research?” Outcomes should be explained and classified in one of the following ways:

- a) potential outcomes, i.e., findings, results, or recommendations that could impact U.S. agriculture and food systems, if used;
- b) b. intermediate outcomes, i.e., how the findings, results, or recommendations have been used by others to influence practices, legislation, research/product design, training and so forth; and
- c) c. end outcomes, i.e., how findings, results, or recommendations have contributed to documented reductions in work-related morbidity, mortality, and/or exposure.

Achievements:

- Measured crop and environmental outcomes (8 sites, 4–6 treatments ea, 3 yrs, total of 132 observations¹), 77% with 2+ forms of N loss. This provides a new opportunity to assess tradeoffs and synergies since most research to date has not attempted to simultaneously characterize more than one N loss pathway (e.g., Eagle et al. 2017 found only 1 site with 15 observations with both N₂O emissions and NO₃ leaching).
- Established standardized data collection, reporting and storage system, enhancing data quality and long-term value for modeling and synthesis.
- Educated undergraduate and graduate students and post-doctoral associates (7+ paid by project, plus others)

All field sites are tile drained – a typical practice across the Corn Belt where early-season rainfall delays planting and other field operations, or can cause flooding injury and death to planted, flood-sensitive crops like corn. Tile drains at these sites have been instrumented to monitor NO₃-N losses and other nutrients in drainage water. Crop yield, nutrient uptake, soil characteristics and N losses to the air were measured utilizing standard protocols for 2018–2020. This project has filled previous key research gaps by co-monitoring multiple production and environmental outcomes at each site and with close coordination among teams to generate standardized fully documented results. This facilitates the rigorous assessment of weather/ climate, soil, and management impacts across sites and years, as well as tradeoff and synergy evaluation between outcomes beyond what was available before. NutriNet has also helped coalesce teams and research questions for at least two other recently funded projects; one rescuing and interpreting historical agronomic and environmental data from tile-drained field research sites (PI

Brouder, USDA NIFA Award No. 2019-67019-29471), and another examining environmental outcomes and potential for N-rate reductions with advanced 4R practices (PI Drury).

Across the network of field research sites, the improved nutrient management practices maintained crop yield, increased nutrient use efficiency, decreased nitrogen balance, and reduced losses of nutrients to the air and water. Overall, 4R (one "R" change) and 4R-Advanced (two "R" changes or one change plus cover crops) had no significant effect on either corn or soybean yield over all three years, across sites. Average corn grain yield over the three years (2018–20) ranged from 174 bushels per acre (10.9 Mg/ha) at the SUBSURF site in Minnesota to 213 bushels per acre (13.4 Mg/ha) at the NWRP in Iowa. With the exception of extreme weather causing yield decline at MUDS2 (Missouri) in 2018 and at WQFS (Indiana) in 2019, there were no significant year-over-year yield differences. Soybean grain yield ranged from 46 bushels per acre (3.1 Mg/ha) at the MUDS2 site to 69 bushels per acre (4.6 Mg/ha) at the DOUGLAS site in Illinois. The average soybean yield across all sites and years was 61 bushels per acre. On average, soybean that followed unfertilized corn (zero N fertilizer) out-produced other treatments by 7 bushels per acre, and 2018 soybean yields were 9 bu/acre greater than that for 2019 and 2020.

Nitrous oxide emissions from corn and soybean managed as farmer normal treatments ranged from 1.6 lbs N₂O-N/acre at the MUDS2 site to 6.0 lbs N₂O-N/acre at the DUDLEY (Illinois). Emissions increased with higher N fertilizer application rates and were higher in 2018 compared to the other two years of the study. Improved N management practices reduced average N₂O emissions by about 25%. Average nitrate losses also looked quite different between sites, with relatively low losses of 4.7 and 5.3 lbs NO₃-N/acre at the MUDS2 and WQFS sites, respectively, and much higher average losses of 31 lbs NO₃-N/acre at the SUBSURF site. Nitrate leaching losses were also highest in 2018, an average of 10 lbs NO₃-N/acre more than in 2019 and 2020. On average, the 4R improved management reduced nitrate leaching losses in the soybean but not the corn phase of the rotation. However, as a subset of these improved practices, cover crops consistently reduced nitrate losses by more than 4 lbs NO₃-N/acre.

Higher N balance in corn generated more nitrate losses across sites and the tested 4R practices improved nutrient use efficiency. Therefore, researchers hypothesize that better environmental outcomes could be achieved by reducing N rates along with the 4R and 4R-Advanced practices. Future research that prioritizes rate reductions would provide more insight.

- 2.4. What were the goals/specific aims of the project? If the approved application lists milestones/target dates for important activities or phases for this reporting period, identify these milestones and dates, as well as show actual completion dates or the percentage of completion of milestone targets. (up to 1,500-word limit)

Our **objective** was to: *Quantify the impact of 4R Nutrient Stewardship on crop yield, soil health, nutrient use efficiencies, nutrient losses with leaching, and gaseous nitrogen losses across a network of coordinated studies in the major corn producing area of North America.* The eight sites included in this study span a broad geographic scope, but generally cover the heavily tile-drained North American Corn Belt. The sites are unique in that they are all instrumented to capture leaching losses of nutrients by monitoring losses in subsurface pipes (tiles) draining each plot. Although the focus will be on N management, the consistent comparison across all sites will include, at a minimum, partial nutrient balances for N, P, and K including losses in drainage for locally relevant, current nutrient management practices of farmers as compared to a more advanced 4R management system. In addition, most sites will investigate specific 4R variations including timing of nitrogen application and use of sidedress application. The novelty of this networked approach is that existing investment in agronomic/drainage research sites across the Corn Belt was leveraged to answer additional questions about 4R practice effectiveness that are not well addressed when only single location studies are considered. This work expands the inference space beyond individual sites to answer key questions about impacts of nutrient management of corn-based cropping systems on water quality in the Mississippi river basin and eutrophication in the Gulf of Mexico. It is only by synthesizing information across collective sites that large-scale agro-environmental questions can be addressed in a practical way.

3. Project Methods

- 3.1. Have any of the major goals/specific aims or milestones for the project changed since the award? If so, please list the goal(s) that have changed and provide justification for the change from the approved goals. (up to 500-word limit)

No

- 3.2. What was accomplished under the goals/specific aims or milestones for the project? Please describe in detail, 1) major activities; 2) specific objectives; 3) significant results, including major findings, developments, or conclusions (both positive and negative); and 4) key outcomes or other achievements. Include discussion of stated goals not met. The emphasis in reporting in this section should focus on accomplishments. In the response, emphasize the significance of the findings to the scientific field. This section can be as technical as the PI would like. (up to 5,000-word limit)

The project began in October 2017 with project sampling activities beginning in November 2017. All project treatments were implemented in the fall of 2017 or the spring of 2018. The project team met in person in November 2017 and have continued monthly video calls to discuss and finalize sampling plans and protocols and develop data dictionaries for the project database. Major accomplishments include the collection of

baseline soil samples from seven of our eight sites in the fall of 2017. The Canada site had unusually early freezing conditions but was sampled in the spring of 2018. We began detailed measurements on all sites in 2018. The project team functioned well in discussing protocols for sampling that align with needs for data synthesis and analysis. The data team developed all data architecture that describes the research sites treatments, data, and site history in a standardized format across all sites. The data team visited all US research sites and met with faculty, staff, and students who managed the site and data. Photographs and site maps were collected at each site. The data team completed the build of the internal website and spreadsheets using the Google platform. The platform went live to the team on Sept 1, 2018 and has been embraced by all with minimal adjustments needed after launch. Team members have used this website for all data entry and QC which is highly successful compared to a workflow where files are emailed back and forth. The centralized web platform ensures limited versioning occurs and maximizes transparency across all members. The website was constructed based on site visits and interactions with team members to ensure each site was represented correctly in terms of structure, treatments, and data collected so that customized entry interfaces could be developed

Research at all sites was carried out in 2018, 2019, and 2020. Team members uploaded research data from 2018, 2019, and 2020. This plot-level data represents 120 different variables (agronomic, soil, water, GHG). The data team then reviewed all uploaded data and itemized edits needed at each site to ensure standardization and QC were consistently applied.

Some specific results for the various sites are noted below. Synthesis results across all sites are noted in Section 2.3.

Missouri

- Nitrogen management systems for corn interacted with drainage treatments and affected N, P, and K removal. In general, N management systems with free drainage increased nutrient removal and yield (fall applied anhydrous ammonia + N-serve in a high yielding year) compared to the absence of drainage.
- In the presence of subsurface drainage, there were few differences among N management systems. However, in the absence of drainage, rotational crop (soybean) yields were 11 to 20 bu/acre higher with the N management systems used for corn production compared to the absence of N fertilizer in corn.
- Water management is a major factor affecting the success of 4R N management systems to reduce environmental loss.

Canada

The yield and N₂O results are 3-year averages (2018-2020) whereas the ammonia volatilization losses are 2 year averages (2019-2020).

- Ammonia volatilization losses were reduced by 72% when SuperU (urea with a combined urease and nitrification inhibitor) was used compared to broadcast urea.
- Injecting UAN into the soil reduced ammonia volatilization losses by 23.4% using a single slot injection system and by 65% when a newly developed double slot injection system (2 injection slots between corn rows) was used.

- Combining two 4R practices (N Source using a urease and nitrification inhibitor and placement using injection) reduced ammonia volatilization losses by 84-97% compared to broadcast urea.
- A single slot injection system increased corn grain yields by 6.2 % whereas a double slot injection system (2 injection slots between rows) increased corn grain yields by 13.1%.
- A combined urease and nitrification inhibitor (SuperU) was able to reduce N₂O emissions from soils by 2.6%. When Agrotain plus (combined urease and nitrification inhibitor) was added to liquid UAN, N₂O emissions were reduced by 18.6% when a single slot injection system was used whereas N₂O emissions were reduced by 44.4% when the new double slot injection system was used.
- Reducing ammonia losses by using a single slot or a double slot injection system kept more inorganic N in the soil which unfortunately increased N₂O emissions as the N rates were not adjusted to account for the reduced ammonia losses. However, using a combined urease and nitrification inhibitor helped to reduce N₂O emissions especially with a double slot injection system.

Minnesota

- The advance practice pre-plant polymer-coated urea reduced nitrogen losses, especially in wetter than normal springs, and produced greater corn grain yield and net economic return compared to the traditional practice of spring pre-plant urea.
- The advance practice of split application of nitrogen increased yield and net economic return, but did not reduce nitrogen losses (nitrate leaching and nitrous oxide and ammonia emissions) relative to the traditional practice of spring pre-plant urea.

During 2021 Dr. Fernandez, who developed and organized the Annual Nitrogen: Minnesota's Grand Challenge and Compelling Opportunity Conference, conducted an in-depth evaluation of the impact of this research project in Minnesota by surveying the behavior/agronomic practice change of the audience. The conference influences N management practices in 5.4M acres (approx. 2.2M hectares) annually. The results of this project have been shared in this conference for a number of years as a "work in progress" and the final results were highlighted in 2021.

The results of this project in Minnesota showed that split-applying N improves N management. The conference survey showed that 38% of the attendees have already adjusted their practices or are considering doing it based on the results presented from this project. This represents substantial impact. Through this research project, it has been shown that a split application using a blend of urea and a polymer-coated urea (ESN) vs a single application of urea done before planting increased the economic return by \$63/acre (\$155/ha). Based on the number of acres influenced by this program, and 38% of attendees using or planning to use this guidelines, an annual increase in economic returns of \$129M was estimated.

The survey also showed that 58% of attendees are following or interested in following the new guidance emerging from this research project showing improvements in grain

yield and reductions in environmental losses. Dr. Fernandez determined that for a single pre-plant application of N, using ESN instead of urea can reduce ammonia (NH₃-N) emissions by 81% (1.2 lb NH₃-N/ac, 1.3 kg NH₃-N/ha) and nitrous oxide emissions by 55% (2.0 lb N₂O-N/ac, 2.2 kg N₂O-N/ha). The environmental impact is substantial. Based on the number of acres influenced by this program, and 58% of attendees using or planning to use this guidelines, Fernandez estimated a reductions of 1.83US tons (1.66 metric tons) in NH₃-N and 2.81US tons (3.09 metric tons) in N₂O-N emissions.

Illinois - Douglas

- Averaged across both phases of the rotation and over the past 5 years, we find that fall N plots lost 24 lbs/A while a 50:50 split N application of spring and side-dress with cover crops lost only 14 lbs/A (1 lb/A less then adding only 75% of the full N rate). Based on our long-term Embarras River dataset at Camargo, IL (initiated in 1993), the average river nitrate load is 27 lbs/A/yr, similar to the 100 Fall treatment. Therefore, the 5-yr average nitrate loss for the 50:50 split with cover crops represents nearly a 50% reduction in nitrate load compared to the river nitrate load.
- Cumulative tile nitrate loads over the past five years ranged from a high of 121 lbs/A (24 lbs/A/yr) with the full rate of fertilizer N in the fall (100 F) to a low of 71 lbs/A (14 lbs/A/yr) with the split pre-plant and side-dress plus cover crops (0-50-50 C).
- Overall, these data suggest that there can be greater net soil N mineralization following soybean than corn; and that a significant portion of annual tile load (and therefore river load) is likely derived from mineralization of soil organic matter following soybean production.
- Although N deficiency has limited corn yields in the 75% N treatment; nitrate continued to leach from these plots during the non-growing season. These data indicate that tile nitrate loads are not simply a matter of excessive N fertilization, suggesting that the leaching of mineralized N during the non-growing season is also an important source of tile nitrate.
- With 5 years of data, we can state with confidence that fall N is leakier and produces more tile nitrate than spring and side-dress N application in tile drained fields at this latitude. Averaged across the corn phase of the rotation, we found the 100% fall N treatment loses approximately 12 lbs/A more tile nitrate than 100% spring N application. This amount of loss only represents 7% of the total amount of fertilizer N applied; however, this same amount of loss represents more than 35% of the tile nitrate load. These data explain why fall N application rarely leads to yield loss; yet greatly increases tile nitrate load.
- This study has greatly added to our understanding of when and how nitrate is lost via tile drainage in corn and soybean rotations. This research documents the complexities of nitrate leaching and shows that tile nitrate loads are not simply a matter of excessive N fertilization, but rather the interaction of weather patterns

(temperature and precipitation), timing and rate of fertilizer N application, and previous crop.

Illinois - Dudley

Over the 3-y study period, pairing in-season split N application with a cereal rye cover crop reduced NO₃-N losses by 37% compared to pre-season N application alone, but soil N₂O emissions also increased by 27%. Corn yields were not significantly affected by the in-field management practices, indicating no agronomic tradeoffs. There was no tradeoff in dissolved reactive phosphorus losses due to the cereal rye cover crop during an intensive monitoring period during freeze/thaw cycles or when comparing annual losses.

Indiana

Several treatments at the Indiana location focused on co-production of food/feed and fuel by harvesting winter cover (cereal rye) or mulch (kura clover) crops as biofuels. Key findings of these novel systems were:

- Inclusion of rye into corn and soy cropping systems did not alter grain yields even though harvesting of rye at heading to achieve high biomass yields (~4000 kg/ha) delayed corn planting by as much as two weeks.
- Addition of rye to corn-soy rotations tended to reduce nitrate concentrations and load in drainflow in the first half of the calendar year but results were highly variable and more site-years of observation are needed to confirm direction and magnitude of system impacts on water quality.
- Nitrous oxide emissions were reduced in continuous corn systems by inclusion of either rye or kura clover. However, corn yields were N limited with the kura mulch. Introduction of rye into corn-soy rotations resulted in numerically lower N₂O emissions; as with nitrate load losses to tile drains, more site-years of data are needed to confirm system impacts on net greenhouse gas emissions.

Data from these novel systems were used to create a rye cover crop module for the Soil Water Assessment Tool. Evaluation of this new module found it could accurately predict leaf area development of rye but it underestimated the biomass accumulation. SWAT calibration work is ongoing.

At the Indiana location, work with legacy water quality data and an extensive comparison of laborious environmental assays with commercially available soil tests documented that (i) commercial/agronomic soil phosphorus test results can be used for environmental risk assessment of soluble phosphorus and (ii) existing recommendations promote applications that are agro-economically unnecessary and environmentally risky.

Iowa – Iowa State University

The objective of this replicated plot study in Northwest Iowa, 2015-2020, was to investigate the influence of N fertilizer timing on crop production and NO₃ load in subsurface (tile) drainage discharge. Four treatments applied to corn included fall anhydrous ammonia with a nitrification inhibitor (F), spring anhydrous ammonia (S), split-banded urea at planting and mid-vegetative growth (SS), and no N fertilizer (0N). Across crops and years, NO₃-N concentration in subsurface drainage discharge was the same 11.7 mg L⁻¹ for F and S applied anhydrous ammonia (AA). Concentration was

statistically lower with SS urea (10 mg L^{-1}) than F and S, and 0N was lower than SS at 8.3 mg L^{-1} . Average annual $\text{NO}_3\text{-N}$ loads were not different between any treatments due to plot variability in drainage discharge. Corn responded to N application, with overall mean yield the same for F, S, and SS. There were no agronomic or water quality benefits for applying AA in the spring compared to fall, where the F included a nitrification inhibitor and was applied to cold soils. Split-applied urea had a small positive water quality impact but no crop yield enhancement. This study shows that there were improvements to $\text{NO}_3\text{-N}$ concentration in subsurface drainage discharge, but more nutrient reduction practices are needed than fertilizer N management alone to reach nitrate reduction goals.

Iowa – ARS

The experiment at the central Iowa site near Ames focused on standard crop management and advanced management systems, including no-tillage and use of cover crops to sustain or increase crop production while minimizing negative environmental outcomes. Specifically, we compared current “business as usual” management of N fertilizer utilizing anhydrous ammonia with advanced 4R N management that included UAN starter and LSNT-based in-season N applications in a corn-soybean production system with and without a winter cover crop. An advanced relay cropping system of a corn - camelina (*Camelina sativa* L.) - soybean rotation was included in the study to determine both the effect on nutrient losses and the economic viability. Camelina is an oil seed/bioenergy crop that can be grown as a cash-generating winter cover crop. Two N loss pathways, subsurface drainage nitrate loads and nitrous oxide emissions, were concurrently evaluated.

Legacy data (2012-2015) from the site indicated that both N loss pathways responded to precipitation amount and timing, highlighting the importance of identifying strategies to mitigate losses and adapt to changing precipitation and temperature regimes in the region. While neither N loss pathway consistently responded to tillage, a cereal rye cover crop in a no-till system reduced overall nitrate losses in subsurface drainage water. Nitrous oxide emissions responded only to in-season fertilizer management, where a treatment with no N fertilizer applied was significantly lower than all other treatments. While the mechanisms behind these N loss pathways do not appear to be linked, these findings still indicate that stacking multiple conservation strategies, such as cover cropping and no-till, can provide environmental quality benefits without tradeoffs in crop production.

In the current field study (2016-2021), a basic corn-soybean rotation was compared with a corn-winter camelina-soybean relay cropping system to evaluate nitrate losses in tile drainage, nitrous oxide emissions from soil, postharvest soil inorganic N content and crop yields. Main crop corn and soybean yields were decreased in the relay cropping system by 9.8% and 23.3%, respectively, as a result of management changes to the system and interspecific competition. However, grain yields were maintained in the soybean phase when the yield of the camelina oilseed crop was considered. Despite providing a winter cover, nitrate loads in tile drainage were not reduced in the camelina relay cropping system. Fertilizer additions to support the camelina crop also increased nitrous oxide emissions in two of the three soybean years by 2.05 and 2.38 $\text{kg N}_2\text{O-N ha}^{-1} \text{ yr}^{-1}$. Most

of the increased emissions in the camelina system were associated with peak emissions events following tillage and fall starter N fertilizer application and during the spring thaw, which may point to risks of exacerbating greenhouse gas emissions during fall management in this system. These results highlight the need for careful evaluation of sustainable intensification strategies to ensure environmental performance.

An ongoing study of P balance in these corn-soybean cropping systems indicated that P losses in surface runoff or subsurface drainage were small relative to the amount of P exported in grain. When P application rates were based on soil test results, subsurface TP losses were approximately 0.3 kg P ha⁻¹ yr⁻¹. A lack of P loss in surface runoff was strictly site dependent, but nearly flat tile-drained land with little runoff is not uncommon. There was a trend in P losses in drainage to be greater in years when corn was grown.

3.3. Discuss efforts taken to ensure the approach is scientifically rigorous.

Include approaches taken to ensure robust and unbiased results.

Significant time was spent early in the project to develop standardized processes and protocols for sample collection across the entire team. Terms and units were detailed in elaborate data dictionaries and the protocols were made easily available on the team website (e.g., agronomic, soil, water, and GHG sampling protocols). In the database, each observation is clearly linked to specific protocol to ensure reproducibility of analyses and interpretations. Data entries were reviewed and any irregularities in the data were reported to the PI and addressed (explanation was provided or data was re-analyzed and re-entered). Cross site and year comparisons were also conducted.

3.4. List key stakeholders that could be served by results of this project.

Stakeholders include Certified Crop Advisors, drainage contractors (e.g., Land Improvement Contractors of America associations), and conservation professionals like SWCD and NRCS staff. Many of the outreach presentations listed below are to these types of stakeholders.

3.5. How have the results of this reporting period been disseminated to communities of interest? Describe how the results have been disseminated to communities of interest. Include any outreach activities that have been undertaken to reach members of communities who are not usually aware of such activities, to enhance public understanding and increase interest in learning and careers in science, technology, and the humanities. Reporting the routine dissemination of information (e.g., websites, press releases) is not required. For awards not designed to disseminate information to the public or conduct similar outreach activities, a response is not required; the grantee should write "nothing to report." A detailed response is only required for awards or award components

that are designed to disseminate information to the public or conduct similar outreach activities. Note that scientific publications and sharing research sources will be reported under Information Products. (up to 1,000-word limit)

Numerous presentations have been given to disseminate project information.

1. Helmers, M. 2017. Impacts of 4R Nitrogen Management on Drainage Water Quality. Presentation at the South Dakota Agronomy Conference (200 attendees)
2. Preza Fontes, G., L. Christianson and C. Pittelkow. 2017. Within-field drainage flow and nitrogen loading variability following tile drainage installation. ASA, CSSA, & SSSA International Annual Meetings. Tampa, Florida. 22-25 October 2017. Abstract #106641.
 - a. **4th place in national Graduate Student Poster Competition**
3. Helmers, M. 2018. Coordinated Site Network for Studying the Impacts of 4R Nutrient Management on Crop Production and Nutrient Loss. Presentation at Agricultural Drainage Management Systems Task Force and NCERA 217 meeting in Raleigh, NC (65 attendees)
4. Helmers, M. 2018. Impacts of 4R Nitrogen Management on Drainage Water Quality. Presentation at the Fourth Annual Nitrogen: Minnesota's Grant Challenge and Compelling Opportunity Conference (100 attendees)
5. Peterson, H. 2018. Nutri-Net project looks to quantify impact of 4R nutrient stewardship practices. Better Crops Vol. 102 No. 1.
6. Gentry, L. Webinar (Partnership for Ag Resource Management) on August 9, 2018
7. Gentry, L. Webinar (Illinois Soybean Association) on August 2, 2018
8. Gentry, L. IL 4R Field Day on October 23, 2018
9. Gentry, L. American Society of Agronomy annual meeting on November 6, 2018
10. Gentry, L. IL NLRs workshop on November 13, 2018
11. Gentry, L. IL Certified Crop Advisor conference on December 12, 2018
12. Sawyer, J. 2018. Evaluation of measurement methods as surrogates for tile-flow nitrate-N concentrations. Northwest Research Farm field day, Sutherland.
13. Sawyer, J. 2018. Evaluation of measurement methods as surrogates for tile-flow nitrate-N concentrations. INREC Board meeting, Des Moines.
14. Sawyer, J. 2018. Corn nitrogen fertilization: production and environment aspects. Integrated Crop Manag. Conf., Iowa State Univ., Ames.
15. Pittelkow, C., G. Preza Fontes, H. Dougherty, and L. Christianson. Water and cropping nutrient balance updates. Oral presentation. Dudley Smith Farm Summer Field Day. Pana, Illinois. 21 June 2018. ≈30 in attendance.
16. Helmers, M. Iowa Nutrient Reduction Strategy: Challenges and Opportunities at Farm News Ag Show in Fort Dodge, IA, December 5, 2018 (25 attendees)
17. Helmers, M. Impacts of 4R nitrogen management on nitrate-N loss in subsurface drainage at Integrated Crop Management Conference in Ames, IA, November 28, 2018 (310 attendees)
18. Preza Fontes, G., L. Christianson, and C. Pittelkow. Dudley Smith Farm Winter Field Day. 2018. DSF Water Quality and Nutrient Management Project Update. 15 February 2018. ≈25 in attendance

19. Pittelkow, C., G. Preza Fontes, H. Dougherty, and L. Christianson. 2018. Dudley Smith Farm Summer Field Day. Water and cropping nutrient balance updates. Pana, Illinois. 21 June 2018. ≈30 in attendance.
20. Preza Fontes, G., C. Pittelkow, and L. Christianson. 2018. Dudley Smith Farm Winter Field Day. DSF Water Quality and Nutrient Management Project Update. 15 February 2018. ≈25 in attendance.
21. Fernández, F.G. 2018. Nitrogen management in challenging growing seasons. United AgTech Post Harvest Meeting, Trimont, MN. 27 November 2018. (110 attendees).
22. Burnett, S., and K. Nelson. 2018. Impacts of 4R nutrient management on crop production and nutrient loss in Missouri. Presentation 7 Aug. Novelty, MO. Attendees: 300.
23. Burnett, S., and K. Nelson. 2018. Coordinated site network for the impacts of 4R nutrient management on crop production and nutrient loss: Missouri site. University of Missouri Greenley Memorial Research Center Field Day Report. pp. 19-22.
24. Ghazanfarpour, N., S.M. Brouder, and J.J. Volenec. 2018. Prediction of Tile Drainage and Crop Yield from Long-Term Corn Rotations Using DSSAT Model in the Midwestern United States. 2018 Joint ASA, CSSA and Canadian Society of Agronomy Mtg. Baltimore, MD. Nov. 4-7.
(<https://scisoc.confex.com/scisoc/2018am/meetingapp.cgi/Paper/112825>)
25. Welikhhe, P. and S.M. Brouder. 2018. Development and Evaluation of Phosphorus Sorption Capacity-Based Environmental Indices. 2018 Joint ASA, CSSA and Canadian Society of Agronomy Mtg. Baltimore, MD. Nov. 4-7.
(<https://scisoc.confex.com/scisoc/2018am/meetingapp.cgi/Paper/111504>)
26. Burnett, S., and K. Nelson. 2019. Coordinated site network for the impacts of 4R nutrient management on crop production and nutrient loss: Missouri site Presentation. 6 Aug. Novelty, MO. Attendees: 250
27. Eagle, A.J. 2019. 4R NutriNet: The 1st Year. Coordinated Site Network...4R Nutrient Management...Crop Production, Nutrient Loss, and Soil Health. At: 4R Nutrient Stewardship Summit, 10 June, Cleveland, OH. Attendees: ≈75
28. Jaynes, D. 2019. Poster presentation comparing yields and nitrate losses of winter camelina, winter rye, and no cover crop treatments to the Long-Term Agroecosystem Research (LTAR) Network, June 4-6, Lincoln, N.E
29. Helmers, M. 2019. Impacts of 4R Nitrogen Management on Drainage Water Quality. Presented at the South Dakota Agronomy Conference (180 attendees) [Invited]
30. Sawyer, J. Impacts of 4R nitrogen management on nitrate-N loss in subsurface drainage. Integrated Crop Manag. Conf., Iowa State Univ., Ames.
31. Sawyer, J. Nitrogen management in variable environments, Iowa State Univ. Extension Crop Advantage Series statewide meeting series.
32. Sawyer, J. Evaluation of measurement methods as surrogates for tile-flow nitrate-N concentrations. INREC Board meeting, Des Moines.
33. Sawyer, J. Nitrogen management and aerial applications – Field Extension Education Laboratory (FEEL), Crop Management Clinic, Ames.
34. Christianson, L., H. Dougherty, G. Preza Fontes, and C. Pittelkow. 2019. A baffled bioreactor: Sounds confusing, but it's good science! Oral presentation. Dudley Smith Farm Winter Field Day. Taylorville, Illinois. 06 February 2019. ≈40 in attendance.
35. Christianson, L. The Christianson IDROP Lab: Clean water, strong farms. Oral presentation. UIUC ACES Faculty Meeting 3rd year faculty presentations. 05 April 2019.

36. Preza-Fontes, G., C. Pittelkow, and L. Christianson. 2019. Balancing water quality, nitrogen management, and corn production goals in Illinois. Poster presentation. NCERA-217 multi-state meeting/Ag Drainage Management Taskforce meeting. Moorhead, Minnesota. 05-06 June 2019. ≈80 in attendance.
37. Christianson, L. 2019. State update: Drainage research in Illinois. Oral presentation. NCERA-217 multi-state meeting/Ag Drainage Management Taskforce meeting. Moorhead, Minnesota. 05-06 June 2019. ≈80 in attendance.
38. Preza-Fontes, G., K. Greer, C. Pittelkow, and L. Christianson. 2019. Dudley Smith water quality and nutrient management project update. Oral presentation. Dudley Smith Farm Summer Field Day. Pana, Illinois. 19 June 2019. ≈30 in attendance.
39. Gentry, L. Risk Management Conference hosted by the Illinois Sustainable Ag Partnership on June 19, 2018
40. Gentry, L. Illinois Fertilizer and Chemical Association Annual Conference in Peoria on January 29, 2019
41. Gentry, L. Ohio Agribusiness Association in Columbus on Feb. 1, 2019
42. Gentry, L. U of I Crop Management Conference in Mt. Vernon, Springfield, Champaign, and Malta on Jan. 22, Jan. 30, Feb. 6, and Feb. 20, 2019
43. Gentry, L. Midwest Cover Crop Council meeting in Springfield on Feb. 21, 2019
44. Gentry, L. Soil fertility webinar (U of I Extension) on Feb. 28, 2019
45. Gentry, L. Central States Water Environment Association 2019 Government Affairs Seminar on March 27, 2019
46. Gentry, L. Annual meeting of the Illinois Association of SWCD on July 15, 2019
47. Gentry, L. Nitrogen Management Workshop for American Farmland Trust on July 23, 2019
48. Helmers, M. Iowa Nutrient Reduction Strategy: Local and Regional Water Quality Benefits at Iowa Rural Water Conference in Des Moines, IA, February 20, 2019 (65 attendees)
49. Helmers, M. Iowa Nutrient Reduction Strategy: Challenges and Opportunities at Crooked Creek Watershed meeting in Fairfield, IA, February 7, 2019 (25 attendees)
50. Helmers, M. Drainage research update at Crop Advantage Series Meeting in Iowa City, IA, January 29, 2019 (55 attendees)
51. Helmers, M. Drainage research update at Crop Advantage Series Meeting in Storm Lake, IA, January 8, 2019 (20 attendees)
52. Helmers, M. Iowa Nutrient Reduction Strategy: Challenges and Opportunities at Winfield Solutions meeting in Ames, IA, February 21, 2019 (125 attendees)
53. Helmers, M. Iowa Nutrient Reduction Strategy: Challenges and Opportunities at Hawkeye Farm Show in Cedar Falls, IA, February 27, 2019 (17 attendees)
54. Helmers, M. Challenges and Opportunities for Nitrate Reduction at University of Kansas Environmental Engineering Conferences in Lawrence, KS, April 17, 2019 (125 attendees)
55. Helmers, M. Challenges and Opportunities for Nitrate Reduction in Iowa at Global Water for Food Conference, Lincoln, NE, May 1, 2019 (75 attendees)
56. Menegaz, S.T., and F.G. Fernández. 2019. Nitrate in tile-drain water relative to time and source of nitrogen application. In: Annual Meetings Abstracts. ASA, CSSA, and SSSA, Madison, WI.

57. Fernández, F.G., and S. Menegaz. 2019. Nitrate leaching reduction with controlled release urea and time of application. In: XXII Latin American Congress of Soil Science. Montevideo, Uruguay. 7-11 October 2019.
58. Menegaz, S.T., and F.G. Fernández. 2019. Nitrogen leaching and corn yield as affected by nitrogen application timing and source. 17th Annual International Nitrogen Use Efficiency Conference. Columbia, MO. 5-7 August 2019.
59. Fernández, F.G. 2019. Enhanced efficiency fertilizers for corn production and environmental protection. Argus Added Value Fertilizers US. Atlanta, GA. 3-5 June 2019.
60. Fernández, F.G., and D.E. Kaiser. 2019. What this spring's wet conditions mean for nitrogen loss. In: Minnesota Crop News. Posted on 28 May 2019.
61. Kaiser, D.E., J. Vetsch, L. Pease, B Carlson, and F.G. Fernández. 2019. How does drainage impact crop production and water quality? University of Minnesota Extension Nutrient Management Podcast, St Paul, MN. 15 May 2019.
62. Two articles based on data from the Gentry Illinois site were published in Prairie Farmer in June 2019.
63. Preza-Fontes, G., L. E. Christianson, and C. M. Pittelkow. 2021. Evaluating tradeoffs between N leaching losses and N₂O emissions with environmental damage costs. 2021 ASA-CSSA-SSSA International Annual Meeting. Salt Lake City, Utah. 07-10 November 2021.
64. Preza-Fontes, G., C. Pittelkow, and L. Christianson. Subsurface drainage nitrate losses in continuous corn as affected by 4R practices and cover cropping. 2020 ASA-CSSA-SSSA International Annual Meeting. Virtual meeting. 09-13 November 2020. Abstract #127982.
65. Preza Fontes, G., L. Christianson, and C. Pittelkow. 2019. Soil N₂O emissions in continuous corn as affected by 4R and cover crops. Tri-Societies Annual Meeting. San Antonio, Texas. 10-13 November 2019. Abstract #258-3.
66. Preza-Fontes, G., L. Christianson, and C. Pittelkow. 2019. Soil N₂O emissions in continuous corn as affected by 4R and cover crops. North Central Extension-Industry Soil Fertility Conference. Des Moines, Iowa. 05-06 November 2019. Abstract #6406.
67. Preza-Fontes, G., C. Pittelkow, and L. Christianson. 2019. Balancing water quality, nitrogen management, and corn production goals in Illinois. NCERA-217 multi-state meeting/Ag Drainage Management Taskforce meeting. Moorhead, Minnesota. 05-06 June 2019. ~80 in attendance.
68. Christianson, L. 2019. Soil Science Society of America Invited Session: Coupling and feedback of phosphorus and nitrogen in soil and ecosystem. Nitrogen, phosphorus, and tile drainage, oh my! A case for edge-of-field practices. Tri-Societies Annual Meeting. San Antonio, Texas. 10-13 November 2019. Abstract # 206-1.
69. Agomoh, I., Drury, C.F., Reynolds, W.D., Phillips, L.A., and X.M. Yang. 2019. Nitrogen fertilizer practices to improve nitrogen availability under corn production. Canadian Society of Soil Science, Saskatoon, Saskatchewan. July 2019. Attendees: 75.
70. Drury, C.F., Reynolds, W.D., Yang, X.M., Phillips, L.A. and A. Woodley. 2019. Can we effectively mitigate NH₃ and N₂O emissions from agricultural soils. Soil Sci. Soc. of Am. San Antonio, Texas. Attendees: 100.
71. Gentry, L.E. 2019. Nitrogen mineralization following soybean production is a major source of tile nitrate. International meeting of American Society of Agronomy. San Antonio, TX Nov.11 Attendees: 50.

72. Gentry, L.E. 2019. Lessons learned from cover crop research. IL Certified Crop Advisor Conference. Springfield, IL. December 5. Attendees: 80.
73. Gentry, L.E. 2019. The source and management of N and P losses. IL Fertilizer and Chemical Association (IFCA) 4R Indoor Field Day. Bloomington, IL December 12. Attendees: 100.
74. Fernández, F.G., and S. Menegaz. 2019. Nitrate leaching reduction with controlled release urea and time of application. In: XXII Latin American Congress of Soil Science. Montevideo, Uruguay. 7-11 October 2019.
75. Menegaz, S.T., and F.G. Fernández. 2019. Nitrate in tile-drain water relative to time and source of nitrogen application in southwestern Minnesota. Eastern South Dakota Water Conf. Brookings, SD. 16 October 2019.
76. Fernández, F.G., and S.T. Menegaz. 2019. Mitigating nitrate leaching from corn fields with management: Source and application time. 19th Annual Drainage Research Forum. Brookings, SD. 26 November 2019.
77. Deno, Brodrick, J.J. Volenec, and S.M. Brouder. 2019. Cover Cropping for Sustainable Co-Production of Bioenergy, Food, Feed (BFF) and Enhancement of Ecosystem Services (ES). ASA-CSSA-SSSA Annual Mtg., San Antonio, Tex. Nov. 10-13. <https://scisoc.confex.com/scisoc/2019am/meetingapp.cgi/Paper/118713>.
78. Welikhe, P., and S.M. Brouder. 2019. Using Artificial Neural Networks to Improve Phosphorus Indices. ASA-CSSA-SSSA Annual Mtg., San Antonio, Tex. Nov. 10-13. <https://scisoc.confex.com/scisoc/2019am/meetingapp.cgi/Paper/118298>
79. Brouder, S.M. 2019. Analyst Perspective & Outside-the-Box Research. The Next Big Idea. Ecosystem Service Valuation Workshop, Washington, D.C. April 23-24.
80. Brouder, S.M. 2019. Climate Smart Agriculture. Session 1, Breakout A (Food Supply). Ending Global Hunger Colloquium 2019, West Lafayette, IN April 10- 11.
81. Brouder, S.M. 2019. Synergies and Tradeoffs When Implementing Soil and Water Conservation Strategies. UNSA-Purdue Global Food Security Workshop. Arequipa, Peru. June 19-21.
82. Drury, C.F., Woodley, A.W., Reynolds, W.D., Yang, X.M. and L.A. Phillips. 2020. Impact of urease and nitrification inhibitors on N₂O emissions from agricultural soils. DNDC Modeling workshop (20 attendees) [invited]
83. Fernández, F.G. 2020. Is it possible to obtain a consistent outcome with nitrogen management? 2020 Crop & Pest Management Connect. Online. 8 December 2020. (145 attendees).
84. Gentry, L.E. 2020. New data on source and scope of nutrient loss in tile drained systems. IFCA Annual Convention Peoria, IL January 21. Attendees: 250.
85. Gentry, L.E. 2020. Tile nitrate loads are not simply a matter of excessive N fertilization. Nutrient Research and Education Council Investment Insights Live. Champaign, IL. February 13. Attendees: 60.
86. Brouder, S.M. 2020. The Plant "Food Plate" – What does it look like and why do we care. In Animal, Vegetable, Mineral: Multidisciplinary Perspectives in Food Systems Panel, Food and Nutrition Conference and Expo., Virtual Conference, Oct. 17-20.
87. Helmers, M. 2020. Long-term impacts of 4R N management practices & cover crops on nitrate-N loss. Presented as part of Iowa Learning Farms Webinars (99 live views)
88. Fernández, F.G. 2021. Nitrogen management research and the Minnesota Groundwater Protection Rule. Iowa State Univ. CropsTV Series. Online. 6 January 2021.

89. Fernández, F.G. 2021. Nutrient management and environmental stewardship given current conditions. 2020 Crop Management Input Seminar, Central and East-Central MN. Online. 26 February 2021. (57 attendees).
90. Fernández, F.G. 2021. ESN: Is it a viable nitrogen source for Minnesota? South Central Crops and Marketing Seminar. Online. 4 March 2021. (25 attendees).
91. Fernández, F.G. 2021. Nitrogen management on poorly drained soils. Univ. of Minnesota Southern Research and Outreach Center Agronomy Field Tour. Online. 22 June 2021. (68 attendees).
92. Carlson, B., F.G. Fernández, L. Pease, J. Vetsch, and J. Strock. 2021. What the latest research says about nutrient management in tile drainage systems. Univ. of Minnesota Extension Nutrient Management Podcast, St. Paul, MN. 24 February 2021.
93. Helmers, M. 2021. 4Rs of nitrogen management and cover crops for reducing nitrate-N losses. Presented at Integrated Crop Management Conference in Ames, IA (125 attendees)
94. Helmers, M. 2021. Exploring impacts of cover crops, tillage, and N-inhibitor on crop performance and water quality as part of Iowa Learning Farms Virtual Field Days (74 live views)
95. Helmers, M. 2021. Water quality monitoring and research. Presented as part of Iowa State University Farms Virtual Field Day Series (250 live views)
96. Helmers, M. 2021. Drainage design and 4Rs of nitrogen management to optimize corn yield and minimize nitrate loss. Presented at the South Dakota Agronomy Conference (85 attendees) [Invited]
97. Helmers, M. 2021. Challenges and opportunities for nitrate reduction. Presented at the University of Minnesota Crop Pest Management Short Course (90 attendees) [Invited]
98. Helmers, M. 2021. Impacts of N management and cover crops on nitrate leaching. Presented at Indigo Ag virtual field day (85 attendees)
99. Brouder, S.M., and J.J. Volenec. 2021. Initiatives for Advancing Evidence-Based Nutrient Management in US Midwest Agroecosystems. In Advances in Agricultural Evidence Webinar and Panel. Centre for Environmental Evidence Webinar Series, April 13.
100. Brouder, S.M. 2021. Agroecology and regenerative agriculture. Healthy Menus R&D Collaborative Mtg (Hybrid), Culinary Institute of America, Aug. 25
101. Brouder, S.M. 2021. Plant Nutrition in a changing climate and perspectives on agriculture's role in mitigation and adaptation. Keynote/Plenary Address. Biostimulants World Congress, Nov. 30th, 2021, Hollywood, FL.
102. Christianson, L., G. Preza Fontes, and K. Greer. 2021. Dudley Smith Farm Winter Field Day. The first three years of tile drainage research at the Dudley Smith Farm... and many more to come! 09 February 2021. ~39 in attendance.
103. Abendroth, L. 2021. Presented NutriNet data entry and tools to newly funded grant leadership (n=4) of DRIVES. This was requested to provide best practices and approach as they begin their efforts. USDA NIFA Funded Project "Diverse Rotations Improve Valuable Ecosystem Services" (DRIVES).
104. Drury, C.F. 2021. Mitigation practices to reduce NH₃ volatilization and N₂O emissions from agricultural soils. Soil C and GHG Emissions Mitigation Modeling Workshop (110 attendees) [invited]
105. O'Brien PL, Emmett BD, Kovar JL, Malone RW, Cambardella CA, Jaynes DB, Kaspar TC, Kohler K, Moorman TB, and Parkin TB. 2021. Crop production response to

- conservation practices and sustainable intensification in a corn-soybean cropping system. ASA-CSSA-SSSA International Annual Meeting, Salt Lake City, UT [Virtual].
106. Emmett BD, O'Brien PL, Kovar JL, Malone RW, Cambardella CA, Jaynes DB, Kaspar TC, Kohler K, Moorman TB, and Parkin TB. 2021. Nitrogen losses in response to conservation practices and sustainable intensification of corn-soybean cropping systems in the Upper Midwest. Soil Water and Conservation Society Annual Meeting. Des Moines, IA.
 107. O'Brien, PL. 2021. Lessons learned from relay-cropping camelina with soybean in central Iowa. Iowa Learning Farms Conservation Webinar Series, September 22.
 108. Drury, C.F., Reynolds, W.D., Yang, X.M., Phillips, L.A., Woodley, A.L. and I. Agomoh. 2021. Redirecting N fertilizer to crops. Outdoor farm show (70 attendees) [invited]
 109. Gentry, L.E. 2021. Update of agricultural efforts to address the IL NLRs. Central States Water Environment Association: Illinois Government Affairs Seminar. Virtual. March 5. Attendees: 50.
 110. Gentry, L.E. 2021. Sources of tile nitrate. University of Illinois Agronomy Day. Urbana, IL July 22. Attendees: 80.
 111. Gentry, L.E. 2021. Agricultural systems that reduce nutrient loss and maintain profitability. IFCA Field Day at Precision Planting. Pontiac, IL. September 21. Attendees: 50.
 112. Gentry, L.E. 2021. Can we manage N immobilization to reduce tile nitrate? American Society of Agronomy Annual Meetings. Salt Lake City, UT. November 9. Attendees: 60.
 113. Gentry, L.E. 2021. Comparing yields, profitability, and nutrient loss of C-S-W vs. Conventional C-S. Indiana CCA Convention. Indianapolis, IN. December 15. Attendees:100
 114. Pease, L., F.G. Fernández, J. Strock, J. Vetsch, G. Sands, and J. Kjaersgaard. 2021. Minnesota statewide research update. 2021 Conservation Drainage Network Annual Meeting. Online. 7-8 April 2021.
 115. Gentry, L.E. 2022. Evaluating the 4Rs for Crop Yield and Tile Nutrient Loss. IFCA Convention, Peoria, IL. January 18. Attendees: 125
 116. Drury, C.F., Yang, X., Reynolds, W.D., Phillips, L., Woodley, A. and I. Agomoh. 2022. Nitrogen Knowledge: Selecting management practices to reduce nitrogen losses & increase yields. Ontario Agriculture Conference (178 attendees) [invited]
 117. Drury, C.F., Armstrong, S., Cowan, D., Legg, J., Bohner, H., Stevanus, A., and J. Munroe. 2022. TEC Talk Tuesdays. Fantastic Fertility Panel. Ontario Agricultural Conference (171 attendees) [invited]
 118. Drury, C.F., Lauzon, J., and M. Richards. 2022. 4 Tips to reach your most economical rate of nitrogen. Innovative Farmers of Ontario Conference (70 attendees) [invited].

3.6. Describe challenges or delays encountered during project and actions that were taken to resolve them. Only describe significant challenges that may have impeded the research and emphasize their resolution. (up to 500-word limit)

COVID challenges did close down some labs and delay some of the sample analysis but we were able to complete the project within the project extension.

- 3.7. What opportunities for training and professional development has the project provided during this reporting period? If the research is not intended to provide training and professional development during this period, state "Nothing to Report." For all projects reporting graduate student and/or post-doctoral participants, grantees are encouraged to describe how Individual Development Plans (IDPs) are used to help manage the training for those individuals. (up to 500-word limit)
- 3.8. Please indicate the number of undergraduate and graduate students, post-doctoral scholars, or other educational components involved during this reporting period. If other education components are involved, please describe them in detail. (up to 500-word limit)

One M.S. student was supported during this period in Missouri. Two undergraduate students have participated in the Iowa State project, and one graduate student (not funded on the project) participated in project activities. Illinois had a graduate student working on the project. USDA-ARS in Iowa trained one graduate student. Indiana had two M.S. students and one PhD student participating in project activities (all funded from other sources). Minnesota partially funded a graduate student. There were at least 15 undergraduates participating on the project across the sites each year. A postdoctoral fellow was working on the ON site.

4. Information Products

- 4.1. Please list the type(s) of information products (e.g., scholarly publications, reports or monographs, workshop summaries or conference proceedings, video, audio, images, models, software, curricula, instruments or equipment, intervention, etc.) produced during the project resulting directly from the FFAR award.

Scholarly publications

- 4.2. Please provide a list of citations for the information products produced during the project.
- 4.3. Are there publications or manuscripts accepted for publication in a journal or other publication (e.g., book, one-time publication and monograph) during the

project resulting directly from the FFAR award? If yes, please provide citation.

Woodley, A.L., Drury, C.F., Reynolds, W.D., Tan, C.S., Yang, X.M. and T.O. Oloya. 2018. Long-term cropping effects on partitioning of water flow and nitrate loss between surface runoff and tile drainage. *J. Environ. Qual.* 47:820-829.

Preza Fontes, G., R. Bhattarai, L. Christianson, and C. Pittelkow. 2019. Combining environmental monitoring and remote sensing technologies to evaluate cropping system nitrogen dynamics at the field-scale. *Frontiers in Sustainable Food Systems* 3(8) doi: 10.3389/fsufs.2019.00008.

Andino, L. F., Gentry, L.E., & Fraterrigo, J.M. 2020. Closed depressions and soil phosphorus influence subsurface phosphorus losses in a tile-drained field in Illinois. *Journal of Environmental Quality*, 49(5), 1273– 1285.

Preza-Fontes, G., C. Pittelkow, K. Greer, R. Bhattarai, and L. Christianson. 2021. Split-Nitrogen Application with Cover Cropping Reduces Subsurface Nitrate Losses while Maintaining Corn Yields. *Journal of Environmental Quality* 50(6):1408–1418. doi.org/10.1002/jeq2.20283

Drury, C.F., Reynolds, W.D., Yang, X., McLaughlin, N., Calder W. and Phillips, L.A. 2021. Diverse rotations impact microbial processes, seasonality and overall nitrous oxide emissions from soils. *Soil Sci. Soc. Am.* 85:1448-1464.

Kovar, J.L. 2021. Maize response to sulfur fertilizer in three Iowa soils. *Communications in Soil Science and Plant Analysis*. 52(8):905-915. <https://doi.org/10.1080/00103624.2020.1869773>.

Preza-Fontes, G., L.E. Christianson, K. Greer, R. Bhattarai, and C.M. Pittelkow. 2022. In-season split nitrogen application and cover cropping effects on nitrous oxide emissions in rainfed maize. *Agriculture, Ecosystems, and Environment* 326:107813. doi.org/10.1016/j.agee.2021.107813

Yang, X.M, Drury, C.D, Reynolds, W.D. and M.D. Reeb. 2022. Carbon loss in tile drainage and surface runoff from a clay loam soil after over a half century of continuous and rotational corn management. *Can. J. Soil Sci.* (in press).

Waring, E.R., J. Sawyer, C. Pederson, and M.J. Helmers. In review. Impact of fertilizer timing on nitrate loss and crop production in northwest Iowa. *Journal of Environmental Quality*.

Alves de Oliveira, L., A. Muñoz Ventura, G. Preza Fontes, K.D. Greer, C. Pittelkow, R. Bhattarai, R.D. Christianson, and L.E. Christianson. In review. Control points on subsurface drainage dissolved reactive phosphorus concentrations and losses in Illinois, USA. *Journal of Environmental Quality*.

O'Brien, P.L., Emmett, B.D., Malone, R.W., Nunes, M., Kovar, J.L., Kaspar, T.C., Moorman, T.B., Jaynes, D.B., & Parkin, T.B. 2022. Nitrate losses and nitrous oxide emissions under contrasting tillage and cover crop management. *Journal of Environmental Quality (in press)*.

Welikhe, P., Brouder, S.M., Volenec, J.J., Gitau, M., Turco, R.F. 2020. Development of Phosphorus Sorption Capacity – Based Environmental Indices for Tile-drained Systems. *J Environ. Qual.* DOI: 10.1002/jeq2.20044.

Welikhe, P., Brouder, S. M., Volenec, J. J., Gitau, M. W., Turco, R. F., De Armond, N. S. (2020). Tile discharge, dissolved reactive phosphorus concentrations and loads for the WQFS (Water year 2011 – 2013).. Purdue University Research Repository. doi:10.4231/BJHE-3239

Welikhe, P., S.M. Brouder, J.J. Volenec, M. Gitau, and R. Turco. 2021. Using artificial neural networks to improve phosphorus indices. *Journal of Soil Water Conservation*. 76 (6) 513-526 doi:10.2489/jswc.2021.00153

Welikhe, P., S.M. Brouder, J.J. Volenec, M. Gitau, and R. Turco. 2021. Dynamics of dissolved reactive phosphorus loss from phosphorus source and sink soils in tile-drained systems. *Journal of Soil Water Conservation*.

Brouder, S.M., and J.J. Volenec. In Press. Nutrition of Plants in a Changing Climate In: Z. Rengel, I. Cakmak, P. White (eds.) *Marschner's Mineral Nutrition of Higher Plants*, 4th Edition. Academic Press/Elsevier, Amsterdam, Netherlands

Dissertation and Theses:

Deno, Brodrick L. 2020. Cover cropping for sustainable co-production of bioenergy, food, feed, (BFF) and enhancement of ecosystem services (ES). MSc. Thesis. Purdue University Graduate School, <https://doi.org/10.25394/PGS.13411109.v1>

Welikhe, P.K., 2020. Evaluating the effects of legacy phosphorus on dissolved reactive phosphorus losses in tile-drained systems. Doctoral Dissertation, Purdue University Graduate School. <https://doi.org/10.25394/PGS.12253262.v1>

Waring, E. R. 2021 Investigating in-field practices to mitigate nitrate loss from subsurface drainage in Iowa in a Corn/Soybean rotation (Order No. 10271439). Available from Dissertations & Theses @ Iowa State University; ProQuest Dissertations & Theses Global. (2625295468). <https://www.proquest.com/dissertations-theses/investigating-field-practices-mitigate-nitrate/docview/2625295468/se-2?accountid=10906>

Preza Fontes, G. 2021. Balancing water quality, nitrogen management, and corn production goals in Illinois. Doctoral Dissertation. Department of Crop Sciences, University of Illinois, Urbana, Illinois.

Muñoz Ventura, A. 2021. Nutrient release from winter cover crops exposed to freeze-thaw events. MS Thesis. Department of Crop Sciences, University of Illinois, Urbana, Illinois.

Menegaz, S.T. 2021. Mitigation of nitrate, nitrous oxide, and ammonia loss with time and source of nitrogen application in corn. M.S. Thesis. University of Minnesota.

4.4. Website(s). List the URL for any internet site(s) that disseminates the research activities. A short description of each site should be provided. It is not necessary to include the publications already specified above.

4.5. Have inventions, patent applications, and/or licenses resulted from the project (U.S. and international)? If yes, indicate the invention, patent application(s), and/or license(s).

	# Filed (Enter Numeric Value)	# Approved (Enter Numeric Value)	Patent Numbers (Separated by commas)
Patents	#	#	
Copyrights	#	#	
Trademarks	#	#	
Inventions	#	#	

4.6. Are any of the information products produced during this grant that are confidential, proprietary, or subject to special license agreements? If so, please list them below and describe why they must remain confidential. Also, note if (and when) you plan to make these data publicly available in the future or if they must remain confidential indefinitely. (up to 500-word limit)

No

4.7. Beyond depositing information products in a repository, what other activities have you undertaken to ensure that others (e.g., researchers, decision makers, and the public) can easily discover and access the listed information products? What other activities have you undertaken to ensure that other can access and

re-use these data in the future?

The data team has been involved with numerous other projects relative to cloud-based infrastructure and data repositories and are making sure there will be straight forward public access after project completion. This includes meeting the FAIR standards and going beyond that to ensure the data are machine readable with extensive quality control steps performed iteratively along with descriptive metadata and files. Data will be published at the USDA National Agricultural Library Ag Data Commons in 2022 with a published doi. The team is also planning on submitting a manuscript describing the data for greater visibility and knowledge of the NutriNet data.

5. Data Management

5.1. Did the project generate any data? Data generation includes transformation of existing data sets and data from existing resources (e.g., maps and imageries). Please list the data generated for the award.

The project generated data spanning farm management, agronomic, soil, greenhouse gas, water quality and quantity, and weather data. Agronomic variables include: vegetative and grain biomass (cover crop, soybean, corn), N, P, and K content of veg. and grain biomass, plant population, stalk nitrate, and yield. Soil variables include: bulk density, organic carbon, texture, pH, total nitrogen, nitrate, and ammonium. Soil health measures include many of the same as well as wet aggregate stability, potential C and N mineralization, inorganic, organic, and total C, and microbial biomass C and N. Greenhouse gas measures include nitrous oxide emissions, soil temperature and moisture, and soil nitrate or ammonium at time of sampling. Water measures include subsurface drainage volume, and concentrations of nitrate-N, ammonium, ortho-phosphorus and potassium in the drainage water. Weather data include daily precipitation at each location as well as temperature, humidity, wind speed, and solar radiation. This set of measurements have allowed the team to calculate annual nutrient losses for nitrogen, phosphorus, and potassium.

In addition, photographs have been collected of all US sites with approximately 500 photographs total describing equipment, treatments, and overall landscape. For each research site, a portion of the site history and landscape metadata has been completed.

5.2. If you list multiple data sets, are these data sets related? If so, please provide a short description of how they are related.

All data sets are related to the impact of 4R Nutrient Stewardship on crop yield, soil health, nutrient use efficiencies, nutrient losses with leaching and gaseous losses. The 9 experimental sites implemented standard protocols and methods to ensure data could be

brought together at the end. All data sets are organized and coded to allow for machine readability and seamless linking across the relational database, with unique IDs for research sites and plots.

- 5.3. Please provide copies of relevant metadata records to support FFAR's mission of enhancing the discoverability of FFAR funded project data and information products. Include or attach copies of records and a simple file inventory, if necessary, in a compressed folder.



Certification

The undersigned hereby certifies that to the best of their knowledge and belief, the above report and all supporting documents are true, accurate and complete. I am aware there is a significant penalty for submitting false or misleading information.

If applicable, I agree that my electronic signature is legally binding, equivalent to, and has the same validity and meaning as my handwritten signature. I will not claim otherwise.

PI Full Name: __Matt Helmers__

PI Signature:  Date: __4/27/2022__

Authorized Signing Official (ASO) Name: __Catharine Perry__

ASO Signature: *Catharine Perry* Date: __4/27/2022__