Grants and Education to Advance Innovations in Sustainable Agriculture

Final report for GNC14-197

Linking Nutrient Transport to Soil Physical Processes During Freeze/Thaw Events to Promote Wintertime Manure Management, Nutrient Use Efficiency, and Surface Water Quality

GNC14-197 (project overview)

Project Type: Graduate Student

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Grant Recipient: University of Wisconsin - Madison

Region: North Central

State: Wisconsin

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Project Information

Summary:

The application of dairy manure to the landscape during winter is a longstanding practice for farms in the Midwestern United States and other temperate regions. Practical motivations behind winter spreading include affordability, availability of time, and the reduced risk of compaction from farm equipment on frozen soils. Wintertime manure applications, however, coincide with environmental conditions that are prone to runoff and accelerate nutrient losses from agricultural fields. Understanding the nutrient dynamics in response to winter-applied manure is especially important to Wisconsin, a leading state in

dairy production, where up to 75% of annual runoff volumes occur on frozen and thawing soils. The high potential for winter runoff, hence nutrient transport, has prompted revisions to winter manure regulations, yet little conclusive data exist to guide these changing standards.

Effective year-round management of dairy agroecosystems necessitates a mechanistic field evaluation of runoff generation and nutrient loading on land with winter-applied manure. Previous research investigated these systems, however, was historically confounded by observational study designs that could not account for the variability in winter weather patterns or the complexity of frozen soils. Moreover, field- and watershed-based manure management models have a limited capacity to simulate nutrient transport during winter because of the poor understanding of frozen agricultural conditions and the lack of empirical data to build appropriate routines. To expand the utility of frozen soil research to agriculture, however, advancements are needed to develop suitable instrumentation and field methodology. From this, the goals of this study are twofold. First, while measuring runoff nutrient losses from wintertime manure applications, practical management techniques are simultaneously evaluated to identify practices that minimize winter runoff. Specifically, the use of conventional fall tillage versus no-tillage is compared with the timing of winter manure applications: unmanured controls, early December applications to frozen ground (prior to snowfall), and late January applications to frozen, snow-covered soil. Second, to account for variability in weather, aid outreach, and improve the feasibility of applied agricultural research on frozen soils, a coupled water-energy balance is incorporated into the field design. Using intense field methods, this approach quantifies the underlying physical processes that drive runoff on frozen, agricultural soils, such as the rate of snowmelt and infiltration potential of frozen soils.

This field study is established in south-central Wisconsin at the University of Wisconsin Arlington Agricultural Research Station. A set of 18 plots (5 x 15 m each) are installed in a complete factorial arrangement (2 landscape tillage treatments x 3 manure timing treatments), in triplicate, and will be monitored for three winter seasons (2015-2016, 2016-2017, 2017-2018). The field contains a complete weather station, each plot is equipped with a runoff collection system, and a total of 125 automated sensors and 90 passive instruments have been installed to capture the water-energy balance. Data from the Winters of 2015 – 2016 and 2016-2017 have accounted for variability in weather patterns and are providing informative data on the effect of tillage, the timing of the manure applications, and the rate at which manure may be applied to a frozen soil. These findings will be supplemented with several smaller-scale laboratory collaborations that isolate the interactions between nutrient release from manure exposed to snowpack and the infiltration limits of variably-saturated frozen soils.

Project Objectives:

The overall goal of this study is to quantify nutrient losses in runoff from winter-applied liquid dairy manure and identify management practices that will optimize on-farm nutrient retention during winter. To accomplish this goal, hence overcome the previous and current challenges of agricultural field research during winter (i.e. variability in weather and complex frozen soil dynamics), the study design incorporates a coupled water-energy balance. Quantifying the drivers of winter runoff – the rate of snowmelt and infiltration potential of frozen soils – relative to manure and land management practices, both the variability in weather conditions and frozen soils properties may be integrated with runoff and nutrient load evaluations. This intense mechanistic field approach provides key insight into environmental processes during winter as well as establishes appropriate methodology for future research in frozen agricultural systems.

Within these goals, we define our performance targets as:

1) Establish a field site with 5-6% slope, characterize relevant properties of the site, and conduct a pilot study during the first winter season (winter 2014-2015) to test the proposed site design and instrumentation configurations. This pilot year is necessary because of the historic challenge in conducting agricultural field research during winter, the need to bridge theoretical knowledge of frozen soils with applied agriculture, and the importance of establishing effective methodology for frozen soil research.

2) After verifying the field design through a pilot season, install 18 large-scale plots (each 5 x 15 m) during the summer – fall 2015 (SARE Project Report 2016). These plots are planted with continuous corn for silage and assigned to conventional or no-tillage as well as one of three manure timing treatments: unmanured controls, early December applications to frozen ground (prior to snowfall), and late January applications to frozen, snow-covered soil.

3) Following the establishment of 18 field plots, equip each plot with individual runoff collection systems, soil temperature and moisture sensors, and instrumentation for soil frost and snow depth measurements. One plot per treatment (i.e. six plots) are equipped with additional instrumentation that bolster the water-energy balance: ground heat flux plates, infrared radiometers, and matric potential sensors. In addition to the comprehensive monitoring of the plots, establish a complete weather station to capture net radiation, wind speed, vapor pressure, air temperature, rain and snow-water equivalents, and snow depth. In total, this study design requires 125 automated sensors, and 90 passive instruments to be built, calibrated, and installed during summer – fall 2015.

4) Conduct the full-scale plot study for three winter seasons (2015-2016, 2016-2017, 2017-2018). During each of these three seasons, runoff and nutrient losses will be analyzed along with the water-energy balance parameters to partition nutrient losses from manure and tillage treatments as well as gain a process-level understanding of frozen soil and snow dynamics in response to manure applications. Outreach events will be hosted on the site for farmers, researchers, programmers, and government stake holders.

5) Analyze field data and build winter routines for manure management and biophysical models with collaborators. As data are combined with supplementary laboratory research, disseminate findings via peer-reviewed manuscripts, public outreach events, and local to national conferences.

Cooperators

Dr. Francisco Arriaga
Dr. K.G. Karthikeyan
Dr. Peter Vadas
Dr. Laura Ward Good

Educational & Outreach Activities

3 Consultations
1 Curricula, factsheets or educational tools
6 On-farm demonstrations
2 Published press articles, newsletters
6 Tours
9 Webinars / talks / presentations
1 Workshop field days

Participation Summary

50 Farmers

75 Ag professionals participated

Education/outreach description:

We developed our field site into an outreach-friendly location that was a frequent destination to diverse field tours at the research station. Our groups ranged from the Nuffield Farm Tour (international farmers); to Monsanto Co. representatives; to the UW Crop Science Club; local & regional farmers, consultants, county agents, and custom manure applicators; out-of-state USDA-ARS scientists, visiting professors in soil and water management, and government stakeholders responsible for manure management regulations.

We tailored the outreach events according to each group's interests and size. Our approach was typically a combination of formal and informal communication. For large groups, I developed a number of "slides" that could be displayed on an easel as I spoke, to reach both audio and visual learners. The slides were summarized with handouts. I often included instrumentation demos for equipment that was buried in the ground/not visible to help explain how we collected the data. After about 15-20 minutes of presentation, I opened the floor to questions until all were answered (~10 minutes). I found it was really important to include an informal setting as well with each event (~15-30 minutes). For example, after answering questions to the group, I asked the participants to please walk around the field site, look in our runoff collection boxes, open things up, touch the instruments, and to ask questions. This was a great way to facilitate conversation and create a comfortable environment for individuals to open up.

Our most publicized event was being showcased at the North American Manure Expo in August 2017. We continue to have smaller outreach opportunities at the field site and will be presenting the results at the Soil Science and Agronomy Society of America conference in late October. I have been awarded three speaking awards for reporting on this project.

Because of the ambitious undertaking in establishing this project, intense field seasons that ended in May 2017, detailed laboratory investigations that support the field data (to be completed in Oct 2017), and frequent outreach events, we are now actively working on peer-reviewed publications. Our first will be submitted in Oct 2017 and we anticipate nine more after that. Here is a list of the anticipated publications (i.e. currently in-progress), for which I will be the first author:

Stock, M.N., F.J. Arriaga, and P.A. Vadas. 201X. Increasing snow surface energy from winter applications of
liquid dairy manure. Water Resour. Res.

Stock, M.N., F.J. Arriaga, P.A. Vadas, L.W. Good, and K.G. Karthikeyan. 201X. Snowpack and runoff dynamics
during freeze-thaw events on agricultural soils with winter-applied, liquid dairy manure applications. Soil Sci. Soc. Am. J.

Stock, M.N., F.J. Arriaga, P.A. Vadas, L.W. Good, and K.G. Karthikeyan. 201X. Reducing nutrient losses from
winter-applied manure in dairy agroecosystems through tillage and manure application timing. J. Environ. Qual.

Stock, M.N., F.J. Arriaga, and P.A. Vadas. 201X. Influence of soil hydraulic conductivity and subsurface fluxes as
a function of tillage: implications for infiltration on frozen soils. Soil Sci. Soc. Am. J.

Stock, M.N., F.J. Arriaga, P.A. Vadas, L.W. Good, and K.G. Karthikeyan. 201X. Modeling frozen soil and snowmelt hydrology in dairy agroecosystems. Soil Sci. Soc. Am. J.

Stock, M.N., F.J. Arriaga, P.A. Vadas, L.W. Good, and K.G. Karthikeyan. 201X. Predicting winter runoff events
from weather and snow patterns in dairy agroecosystems. J. Environ. Qual

Project Outcomes

30 Farmers reporting change in knowledge, attitudes, skills and/or awareness
4 Grants received that built upon this project
4 New working collaborations

Project outcomes:

Impacts

<u>Broad Impacts:</u>
We conducted this study at full scale from 2015-2017, with a pilot year to test instrumentation during 2014-2015. Our first finding was that the maximum manure application rate of 7000 gal ac-1 in Wisconsin is an overestimate on soils under no-tillage. In order to avoid immediate runoff, we reduced our application rate to 4000 gal ac-1.
Analysis of runoff across the winter seasons consistently indicated that the plots under no-tillage were twice as likely to produce runoff compared to the plots under conventional fall tillage and nutrient losses were significantly higher. The total seasonal phosphorus loss ranged from 0.0 – 0.4 lb/ac in the tilled plots and 0.1-1.6 lb/ac in the no-tillage plots. Similarly, total seasonal nitrogen losses ranged from 0.0 –

1.4 lb/ac in the tilled plots and 0.4 – 3.7 lb/ac in the no-tillage plots. Under no-tillage conditions, the soil surface is smooth. Therefore, as the soil was frozen and had a reduced infiltration potential, the melting snow simply ran off without any barrier to slow it down. On the other hand, the presence of fall tillage – implemented along the contour – created depressional storage on the soil surface. This series or ridges and furrows collected water, which increased the amount of time for the water to infiltrate into the frozen soil. We are currently conducting laboratory tests to directly measure any changes to hydraulic conductivity, or the rate at which water moves through the soil, to determine if infiltration was also faster under tillage during the winter.

The presence of tillage produced the dominant effect on reducing runoff and nutrient losses, but manure application timing also made a difference. In comparing an early (December) versus later (January) manure application timings, applying manure earlier in the freezing season improved nutrient retention. When manure was applied later in the freezing season, the soil had greater frost development, hence lower infiltration potential. Moreover, the manure applied later in the season, on top of snowpack, changed the snowmelt dynamics. We measured a significant difference in albedo (the amount of solar radiation that is reflected) that lasted for approximately three weeks after application. As a result, the plots with January manure applications continuously absorbed more solar radiation, which accelerated snowmelt. During thaw events, the snow in plots with January manure applications often melted 1-3 days earlier than unmanured control plots and plots with December applications. This creates a nutrient retention challenge: frozen soils have a reduced infiltration potential, thus require additional time to infiltrate melt water to avoid runoff. When applying manure later in the freezing season, snowmelt is accelerated, which exacerbates the runoff conditions.

<u>Year-by-Year:</u>
Pilot data from winter 2014-2015 (SARE Project Report 2016) indicated that as the soil profile freezes and collects snowpack, the surface becomes complex and the soil moisture and matric potential sensors produce an electronic signature. As soil temperature decreased below 0°C, the liquid water content of the soil froze, thus decreasing the liquid soil water content available for hydraulic processes, such as infiltration. Similarly, the soil matric potential became increasingly negative during frozen periods, thus providing field evidence that supports the physical theory of frozen soils. This decrease in matric potential may create an upward water flux to the freezing front, which increases soil frost development and also limits its infiltration potential. The additional sensors installed in 2015 aim to capture this upward hydraulic flux, which is important to nutrient distribution in the soil profile and losses in runoff. At the soil surface, we quantified the soil heat flux, a measure of the conductive energy within the soil that supplies energy for snowmelt processes and is likely influenced by wintertime manure applications. As expected, the ground heat flux remained near 0 W m-2 when snowpack was present. However, upon thaw, the ground heat flux approached 30% of the daily energy balance, which suggests the ground heat flux is typically underestimated during freeze/thaw conditions in biophysical models (i.e. these models assume that the ground heat flux is about 10% of the energy balance). This finding is significant to understand snowmelt dynamics, especially in response to manure, which likely further increase the energy available for melt processes.

Temperatures were above normal at the beginning of the winter 2015-2016 season. The soil did not begin to freeze until December 30, 2015, approximately one month later than usual, and the soil remained near saturation until it froze. We applied manure to our plots with a December manure-timing treatment on December 10, 2015 on unfrozen, bare ground that was near saturation. We applied manure to our plots with a January manure timing treatment on January 26, 2016, when the soil had 50 cm of frost, on average, and approximately 16 cm of snowpack. The dry matter of the liquid dairy manure was 2.1 % in December and 2.9 % in January. We intended to use a manure application rate equivalent to 7000 gallons per acre, as is the maximum amount allowed in Wisconsin. We observed immediate runoff, however, when greater than the 4000 gallons per acre equivalent was applied to the no-till plots. Therefore, beginning with our first manure application in December 2015, we reduced the application rate to 4000 gallons per acre for all the plots and we will remain using this lower rate for the remainder of the study.

We monitored nine runoff events between December 1, 2015 and April 1, 2016. During each of the nine thaw events, on average, 75% of the no-till plots produced runoff, whereas the tilled plots produced runoff during one of the nine events. We found the electrical conductivity of the runoff after the December manure application to be about three times higher than the runoff from the unmanured controls plots. The electrical conductivity was about 90 times higher from the plots with January manure applications, indicating that more dissolved ions and solids may transfer from the manure to the runoff when manure is applied on top of snowpack in late January. Phosphorus losses were significantly reduced through the use of tillage.

The 2016-2017 field season was marked with frequent freeze/thaw events, but 10 produced significant runoff. Manure applied during the 2016-2017 field season had a 6 % solids content. The total nitrogen and phosphorus losses were over three times greater in the plots with no-tillage compared to the plots with fall conventional tillage.

Analysis for the two seasons indicates the plots under no-tillage were twice as likely to produce runoff compared to the plots under conventional fall tillage. The total seasonal phosphorus loss ranged from 0.0 – 0.4 lb/ac in the tilled plots and 0.1-1.6 lb/ac in the no-tillage plots. Similarly, total seasonal nitrogen losses ranged from 0.0 – 1.4 lb/ac in the tilled plots and 0.4 – 3.7 lb/ac in the no-tillage plots. Fall tillage created depressional storage on the soil surface, which collected water and increased the amount of time for water to infiltrate into frozen soil. Manure application during January accelerated snowmelt by 1-3 days, which increased runoff and nutrient losses. Further analysis of winter hydrology and soil infiltration is underway. This field study provides additional understanding of winter runoff processes and evaluates soil nutrient retention to balance economic and environmental viability.

Accomplishments

Performance Target 1: Establish a field site with 6% slope, characterize relevant properties of the site, and conduct a pilot study during the first winter season (winter 2014-2015) to test the proposed site design and instrumentation configurations.
In summer 2014, we selected a field site with 5.9 % slope at Arlington Agricultural Research Station in south-central Wisconsin. We conducted a digital elevation survey with RTK GPS and designated the plots

across the slope. For our pilot study in winter 2014-2015, extensive instrumentation was built and calibrated in the laboratory and then installed in the two plots. To determine appropriate depths for instrumentation, ten years of county frost depth records were reviewed. Instrumentation for the 2014-2015 pilot season included:

- 32 thermocouples (Type T), built and installed to measure soil temperature profiles. Each plot contained two thermocouples at 0, 5, 10, 20, 30, 50, 75, and 100 cm depths.
- 24 matric potential sensors (model MPS-2, Decagon Devices Inc., Pullman, WA), installed to measure the direction and magnitude of water movement in the soil. Each plot contained two matric potential sensors at 10, 25, 40, 55, 70, and 85 cm depths.
- 10 water content sensors (model CS616, Campbell Scientific Inc. Logan, UT), installed in each plot to measure the volume of water stored in the soil at given depths. Each plot contained one water content sensor at 25, 40, 55, 70, and 85 cm depths.
- 4 load cells (model FC22, Measurement Specialties Inc., Freemont, CA), installed to measure the length and volume of each runoff event and the rate at which runoff flowed from each plot. Two load cells were used per plot.
- 2 frost tubes, installed to measure the frost depth of each plot.
- A weather station was installed at the field site with all proposed instrumentation: an air temperature and vapor pressure sensor (model VP-3, Decagon Devices Inc., Pullman, WA), a sonic anemometer to measure wind speed (model DS-2, Decagon Devices Inc., Pullman, WA), a net radiometer (model CNR1, Campbell Scientific Inc., Logan, UT), a snow-water equivalent/rain gauge (model CS705, Campbell Scientific Inc., Logan, UT), and an ultrasonic ranging sensor to measure the depth of snow accumulation (model SR50, Campbell Scientific Inc., Logan, UT).

In summer 2015, during the large-scale plot and instrument installation (see below), six soil pits were excavated to 1.3 m depths. We described the soil profiles of each pit to classify the soil series on the field site and used a handheld x-ray florescent analyzer (XRF) (model Delta Professional, Delta, Olympus Corporation, Waltham, MA) to measure a range of elements by soil horizon. Soil cores and other samples were collected from each horizon for supplementary laboratory studies that will quantify the soil water characteristic curves and hydraulic conductivities.

<u>Performance Target 2</u>: install 18 large-scale plots (each 5 x 15m) during the summer – fall 2015.

In Spring and Summer 2015, 18 plots in a 2 x 3 complete factorial design were installed. Treatments include two land management practices (conventional versus no-tillage) and three manure application timing treatments (applications at the onset of the freezing season, mid-winter applications on top of snow-covered frozen soils, and unmanured controls) in triplicate (SARE Project Report 2016).

<u>Performance Target 3</u>: equip each plot of the 18 plots with separate runoff collection systems, soil temperature and moisture sensors, and instrumentation for soil frost and snow depth measurements. Install additional instrumentation in one plot per treatment (i.e. six plots) to bolster the water-energy balance (SARE Project Report 2016).

In total, 125 automated sensors and 90 passive instruments are to be built, calibrated, and installed during summer – fall 2015. Runoff collection systems, flumes, and drainage pipe for all plots were built and installed to hydrologically isolate the plots from the surrounding field. We also selected one plot per treatment, for a total of six plots, to receive additional instrumentation to capture hydrologic and thermal fluxes within the subsurface soils. In these six plots, pits to a depth of 1.30 m were excavated for instrument installation. After instrumentation was installed and soil pits were filled, tillage treatments were applied as needed and corn was sowed. Engineering and construction of additional instrumentation and sensor mounts continued in the laboratory through fall 2015. After harvest and tillage, the final instrumentation installation was complete.

All 18 plots contain:

• One thermocouple (Type T) at 8, 16, 32 cm depths.

• One volumetric water content/electrical conductivity/temperature sensor (model CS655, Campbell Scientific, Logan, UT) at an 8 cm depth

• Three snow sticks for use in measuring snow depth

• One frost tube for use in measuring frost depth up to 1.3 m deep

6 of the 18 plots (one per treatment) contain additional instrumentation:

• One infrared radiometer (model SI-111, Campbell Scientific, Logan, UT) to measure the surface temperature, regardless if the winter surface changes from soil to manure or snow

• One additional thermocouple at a 0 cm depth in the soil – Additional volumetric water content/electrical conductivity/temperature sensors (model CS655, Campbell Scientific, Logan, UT) at 56 and 122 cm depths

• Four matric potential/temperature sensors (model MPS-2, Decagon Devices, Inc., Pullman, WA), at 48, 65, 114, 130 cm

• Two heat flux plates at 5 cm depths to measure surface energy fluxes within the soil

• Two load cells (model FC22, Measurement Specialties Inc., Freemont, CA) for runoff monitoring as in the pilot season

• The weather station includes a net radiometer to measure incoming and outgoing radiation and albedo (model CNR1, Campbell Scientific Inc., Logan, UT), a sonic anemometer to measure wind speed and direction (model DS-2, Decagon Devices, Inc., Pullman, WA), an air temperature and vapor pressure sensor (model VP-3, Decagon Devices Inc., Pullman, WA), a snow-water equivalent/rain gauge (model CS705, Campbell Scientific Inc., Logan, UT), and an ultrasonic ranging sensor to measure the depth of snow accumulation (model SR50, Campbell Scientific Inc., Logan, UT).

A trail cam was installed in February 2016 to capture field images of the freeze/thaw process across all of the plots (SARE Project Report 2016). Our goal was to use imagery to help explain and present differences in treatments to dairy producers and other stakeholders. 1 x 1 m quadrats within each plot were also photographed with each field visit beginning in February 2016, which continued in the 2016-2017 winter season. These quadrats were used to build and validate a new multiple linear regression model that uses digital imagery, a simple calculation of time, and inexpensive, tangible, and generally accessible field data to estimate albedo. This is a significant impact because albedo is expensive to measure with traditional instrumentation, thus is less common in agricultural research. We used our albedo data to then conduct full energy balances of the manure management practices to understand the underlying drivers of runoff during winter.

Performance Target 4: Conduct the full-scale plot study (2015-2016, 2016-2017) and host outreach events at the field site.

Corn for silage was grown both seasons and yield was manually assessed in September 2015 and October 2016, with tissue subsamples for percent moisture and nutrient tissue content analysis. Soil samples (routine 1 inch and 6 inch cores) were also collected from each plot for routine nutrient analysis. After fall field operations were complete each year, surface instrumentation was reinstalled to monitor soil, hydrologic, and atmospheric conditions, which will help elucidate the underlying mechanisms that drive nutrient losses and runoff from winter-applied manure. During the 2015-2016 winter season, we applied manure to our plots with a December manure-timing treatment on December 10, on unfrozen, bare ground that was near saturation. We applied manure to our plots with a January manure timing treatment on January 26, 2016, when the soil had 50 cm of frost, on average, and approximately 16 cm of snowpack. During Winter 2016-2017, manure was applied on December 9 and January 27 for the manure timing treatments. We monitored nine runoff events between December 1, 2015 and April 1, 2016, and have monitored ten runoff events from December 1, 2016 – April 1, 2017. Unfiltered runoff samples were tested for total solids (TS), volatile solids (VS), total Kjeldahl nitrogen (TKN), total Kjeldahl phosphorus (TKP), and electrical conductivity. Filtered samples (0.45 μm) are being analyzed for DRP, TDP, NH4-N, and NO3-N.

Our first outreach event was held at Arlington Agricultural Research Station on February 23, 2016. We presented our study design, preliminary data, and hosted a site visit to the Soil Nutrient Application Planner (SnapPlus) committee, which included researchers, software developers, and government stakeholders who work toward developing nutrient management plans for producers. Additional outreach events included USDA-ARS employees from out-of-state labs in October 2016, and the UW Crop Science Club in November 2016, the Nuffield International Farmers in May 2017, Monsanto Co. in June 2017, the Soil and Water Management Society in July 2017, and the North American Manure Expo in August 2017.

Performance Target 5: Analyze field data and build winter routines for manure management and biophysical models with collaborators. As data are combined with supplementary laboratory research, disseminate findings via peer-reviewed manuscripts, public outreach events, and local to national conferences.

This project has been presented at the Soil Science Society of America in 2015 in 2016 (Minneapolis, MN, and Phoenix, AZ, respectively), the USDA-NIFA annual conference in 2016 (Washington DC), and the American Water Resources Association Conference in 2017. The project took second place in the Soil Physics and Hydrology student competition at the 2016 Soil Science Society of America and won the student oral competition at the American Water Resources conference in 2017. This work will also be presented at the Agronomy Society of America in October 2017. The design of our field site has also allowed for newly funded collaborations that expanded our winter field seasons into a year-round experimental site and new manure treatments are being added for the 2017-2018 winter season. A list of most outreach events is listed under Performance Target 4.

We are currently working on publications and implementing the field data into models.

Knowledge Gained:

We knew scientists and farmers alike were less familiar with nutrient management of frozen soils and we also realized much of our understanding of frozen soils was built around assumptions from the growing season (i.e. unfrozen soil). It was surprising and fascinating to learn that unfrozen soils require such different management practices to reduce nutrient losses. From this, we have learned to conceptualize frozen soils one way, unfrozen soils another, and then look at a farmer's land and business needs to weigh the seasons together to determine the best management practices. For example, we were surprised that conventional tillage significantly decreases runoff and nutrient transport during the winter, when it is known to increase losses during the growing season. We realized the importance of the winter season and that for sustainable management, the entire year needs to be considered.