NRCS NR202D37XXXXG003 Final Report

Mid Atlantic 4R Nutrient Stewardship Association

Utilizing Nitrogen Modeling to Determine Soil Health Contributions to Nitrogen Fertility

Executive Summary

This study looked at site specific implementation of nutrient management plans on farms implementing soil health practices (continuous no-till, cover crops, green planting). The goal of the project was to demonstrate that nitrogen modeling tools should be considered within CSP activity enhancement E590B as a Precision Agriculture Technology that can be used to reduce risks of nutrient loss to surface water.

- Comparison of the Granular Agronomy Nitrogen Service model (the crop model) to the current mass balance nitrogen calculation approach used by advisers and regulatory agencies in Pennsylvania resulted in a 10% improvement of nitrogen use efficiency on acres utilizing the crop model vs acres utilizing a mass balance calculation (See Part A of this report)

- The crop model has the ability to quantify soil nitrogen contributions from soil sources, manure applications, and fertilizer applications. It also has the ability to track nitrogen loss through leaching, immobilization, volatilization and denitrification based on soil characteristics and user inputs. This provided an opportunity to talk with farmers about reducing nitrogen loss caused by specific loss pathways active in their fields through 4R Nutrient Stewardship Source, Place and Timing practices as well as cover cropping.

- Soil Health contributions to nitrogen fertility were looked at in two ways. First, pre-season soil nitrate samples were obtained in fields to determine the size of the soil nitrogen "pool." Second, 20 locations with cover crop were simulated using the crop model to project average site-specific nitrogen mineralization rates from the above ground portion of a cover crop based on soil type, cover crop characteristics, and weather. See Part B of this report for in-depth discussion on cover crop nitrogen contributions.

- Both currently accepted mass balance calculations and nitrogen modeling platforms have limits on their ability to improve water quality by reducing nitrogen loss. Soil conditions, drought, excessive rainfall, and other unplanned incidents will always exist to reduce nitrogen use efficiency and increase the risk of nitrogen loss. Advisors, trained in both state nutrient management regulations and nitrogen modeling platforms, are necessary to achieve the highest benefit to water quality.

Multiple nitrogen modeling services provide similar platforms in this space. During the conceptualization of the project, Granular was the platform that had the ability and interest to become a project cooperator and provide match for this project. Their match, in the form of reduced product cost and staff time contributions, was an important aspect of this project. It allowed the intimate use of their product, in-depth conversations into the working of the model with product developers, and for the cover crop analysis. Other nitrogen services offered in the marketplace may provide a similar level of modeling. This report does not constitute an endorsement of the Granular Agronomy Nitrogen Service above other services.

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Introduction

This project, titled *Utilizing Nitrogen Modeling to Determine Soil Health Contributions to Nitrogen Fertility*, is a project funded through a PA NRCS Conservation Innovations Grant (CIG). The PA4R Alliance is the project lead, with Alliance partners Granular and Rosetree Consulting providing not only match for project implementation, but also technical support and analysis.

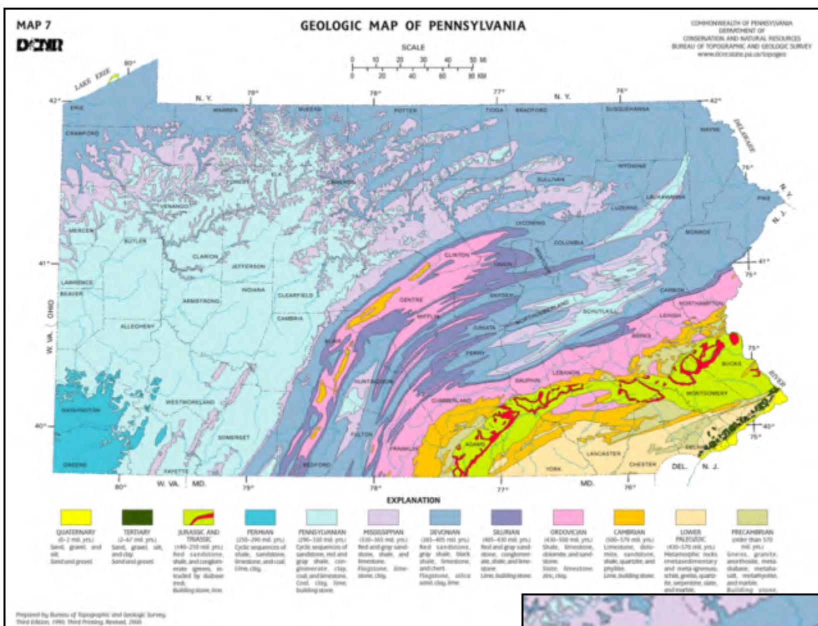
The objective of this project was to demonstrate that nitrogen modeling can be considered within CSP activity enhancement E590B as a precision agriculture technology that can be used to reduce risks of nutrient loss to surface water at the same level of confidence that current nutrient management tools provide. To achieve this objective, the project focused on the following items:

1. Farms currently implementing a nutrient management plan meeting either the PA Act 38 of 2005 program or NRCS 590 practice standard. Both nutrient management plans are based on a mass balance nitrogen calculation, allowing a direct comparison in the supplemental fertilizer recommendations produced by the crop model. All participants needed to have a fully implemented nutrient management plan.
2. Farms implementing soil health practices like continuous no-till, cover crops, and/or planting green. These practices are influential in producing nitrogen, scavenging nitrogen, and cycling nitrogen. There are no tools within the current mass balance regulatory frameworks (Act 38 & NRCS 590) to quantify the nitrogen contributions from soil health. All participating farms needed to have at least one soil health practice (continuous no-till, cover crops, planting green) implemented.
3. Farms willing to split-apply supplemental nitrogen fertilizer. Split application, a recognized 4R nutrient stewardship BMP, is used to reduce nitrogen loss, reduce excess application, maximize yield, and improve overall nitrogen use efficiency through focusing applications at the Right Time for maximum uptake and minimal loss, at the Right Place for easy uptake into plants, and at the Right Rate to meet realistic yield goals. Participating farms needed to have the ability and willingness to delay all or a portion of their supplemental nitrogen fertilizer to around the V8 growth stage.

General Methodology:

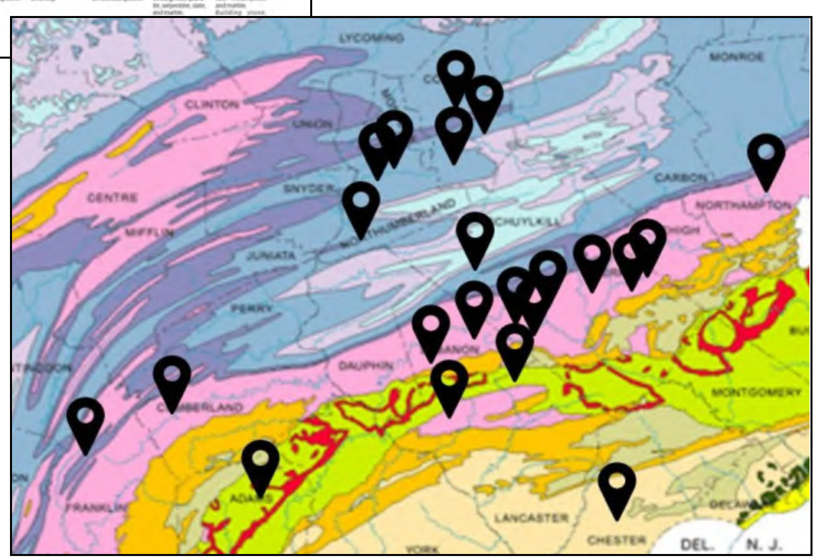
This project utilized a Nitrogen Modeling program (Granular Agronomy Nitrogen Service) on 22 operations / 83 fields (totalling ~4,000 corn acres) in order to compare this site-specific method of nitrogen management to the operations' Nutrient Management plan's mass balance calculation. A deep dive of the data on 13 geographically diverse and data representative fields is included in this report. All 22 cooperating farms utilized nitrogen modeling on half of the corn acres enrolled in the project, making nitrogen applications based on model outcomes. The remaining half of their enrolled corn acres were managed to align with the supplemental fertilizer rates calculated in their Nutrient Management Plans (Act 38 or NRCS 590).

Evaluating data across a diverse geography was an important part of this project. This project focused on ensuring a "fair trial" by including many of the state's predominant agricultural soils as well as enough geographic diversity to capture weather variations that can influence model outputs. The following maps show the locations of participating farms and the geological diversity those farms represent.



(Left) ***Soils Map of Pennsylvania***

(Below) ***Locations of participants in the project. 22 operations (83 fields) participated, representing the predominant agricultural soil types within the state.***



Overview of the Granular Agronomy Nitrogen (Modeling) Service:
The Granular Agronomy Nitrogen Service, delivered through trained advisors, utilizes a corn growth model to estimate crop nitrogen availability and uptake during a growing season. The Granular Crop Model (GCM) is a daily time-step deterministic crop growth model that takes inputs of soil, weather, management, and crop genetics in as inputs and simulates both below and above ground dynamics, including nitrification, leaching, mineralization, germination, root development, crop N uptake, and grain yield. This model is based upon many years of research and development, trained and validated from hundreds of field trials, and backed up with sources through literature reviews and other scientific efforts.

Positioned in the Granular Agronomy Nitrogen Service, both current and historical weather (20 prior years) are inputted into the GCM to simulate the effects of weather that has already occurred in the growing season and the potential weather based on prior years. A median estimation of soil nitrogen levels across those multiple years is used for guidance of nitrogen to be applied. Users can also add site specific soil nitrate sample results to the model. The GCM can model both organic and inorganic sources of nitrogen, including common commercial fertilizers as well as organic residues from previous crops and manure.

At the time of these simulations the Granular Agronomy Nitrogen Service did not have an input for cover crops. However, new efforts for the 2022-23 growing season will enable the simulation of cover crops including plant development, water and N uptake, available N at termination and the effects they have on subsequent corn crops in that season. The cover crop data collected through this project is being used for this update and will help the model better quantify soil health contributions to nitrogen fertility.

The comparative differences between a regulatory mass-balance calculation to a crop growth model like the Granular Crop Model for estimating target nitrogen rates for corn are:

- **Dynamic to weather -** Each year's weather is different, so having the ability to make adjustments of nitrogen rates in-season is important. While a crop model cannot predict the weather, utilizing 20 prior years of weather history is useful to understand what could occur. Connecting this with the weather that has already occurred, a crop model can develop a simulation of what has occurred and what could likely happen. A mass-balance calculation used for regulatory nutrient management planning does not have the ability to adjust to current or future potential weather.
- **Flexible with management -** Because a crop model simulates the growth of a corn plant, management of the growing of that plant are necessary inputs. This includes planting date, seeding density, crop maturity rating, as well as key nitrogen information, such as rates, dates, forms of nitrogen and methods of application. A crop model simulates nitrogen uptake by the corn plant based on seeding parameters and adjusts potential N uptake based on maturity and seeding density. A crop model also simulates the conversion and movement of both commercial fertilizer and organic sources that are based on soil moisture and temperature estimations from weather. A mass-balance calculation used for regulatory nutrient management planning doesn't consider these dynamic effects due to management.

- **Simulations of difficult-to-measure outputs** - A crop model simulates many sub-processes that may be difficult to measure and quantify in most situations. These processes include the nitrogen loss pathways of nitrification, denitrification, leaching, mineralization, volatilization, and immobilization. Crop model simulations are based on controlled lab measurements and modeling and are leveraged across individual field environments. These simulated outputs can be useful for quantifying the amount of nitrogen losses that may take place under various management programs and environments, helping farmers, planners, researchers and policy makers provide proper guidance to farmers to ensure that the environment is considered while still helping the farmer produce the best to their abilities.
- **Fostering conversation, learning and changes to on-farm nitrogen management** - A crop model provides growers and their trained advisors with data around the most prevalent loss pathways in a field. While the data provided may not always be able to be used facilitate changes during the current growing season, it does provide a platform for trained advisors and farmers to have a conversation around on-farm management strategies and to modify 4R (source, rate, time and place) nitrogen decisions for the future growing season that will benefit NUE, yield and profitability and reduce impacts to water quality.

Part A: Selected Field Results

2021 Field Result Analysis

Project enrollment: 24 participants / 83 fields / ~4,000 corn acres

For the purposes of this deep-dive / analysis, 13 fields were selected for comparison. These 13 fields provide geographic & soil type diversity, as well as the adoption of varying soil health practices to enable a representative, deep-dive comparison between mass balance calculations and nitrogen modeling.

Nitrogen Use Efficiency Analysis

Operation/Farm/Field	Mass Balance NUE	Granular Model NUE
Adams County Site 1	1.24	1.17
Adams County Site 2	1.27	1.33
Adams County Site 3	1.02	1.1
Berks County Site 1	0.76*	1.1*
Berks County Site 2	0.77*	0.95*
Chester County Site 1	0.99	0.93
Chester County Site 2	1.08	1.08
Cumberland County Site 1	1.34	0.76
Cumberland County Site 2	1.78	0.94
Columbia County Site 1	1.09	1.05
Northumberland County Site 1	1.29	1.45
Lancaster County Site 1	1.08	0.68
Berks County Site 3	1.28	1.22
MEAN NUE Values		

NUE, or Nitrogen Use Efficiency, is calculated by dividing estimated yield by total nitrogen contributions, and represents the pounds of nitrogen needed to produce a bushel of corn. Lower NUE numbers represent a greater use efficiency – less nitrogen to produce a bushel of corn. While the NUE for modeled acres is 10% lower, indicating better use efficiency, the difference may not be a statistical one.

Interpreting Results from Selected Sites

Utilizing any crop modeling platform starts with establishing field boundaries. Once boundaries are complete, the system automatically creates a SSURGO soils data layer. The soils map is included in each of the comparisons in this report. Soils data like texture and depth are used to calculate nitrogen contributions, loss and availability. Users have the option to combine this SURGO layer with other layers (LiDar, yield maps, etc.) to create sub-field zones for variable rate applications and for discerning differences in N loss within a field. This project did not look at subfield management of nitrogen, but rather whole field management consistent with current regulatory nutrient management frameworks.

Once boundaries are established users can begin entering manure, fertilizer, planting and other information into the model. It is imperative that users accurately enter the site-specific and farm specific data like manure analysis, pre-season soil nitrate levels, and rotation/cover crop history. Application dates are also critical for the success of the model. Farms should work with a trained professional to ensure background information is accurately entered into the model.

Once all applications are entered into a crop model, the model will calculate “real-time” nitrogen levels and alert the user if nitrogen is needed. Additionally, the Granular Crop model specifically creates 2 graphs - a “Season Events & Nitrogen Availability Chart” and “In-Season Nitrogen Losses Chart.” It is important to note that each field within the project should have different graphs based on soil type, farm management and environmental interactions.

- The Events & Availability Chart presents available nitrogen as influenced by precipitation, crop uptake and management choices. All entered events are identified on this graph. The Season Events Chart also provides a target for the amount of soil nitrogen that should be present at tassel for users to reach their chosen yield goal.
- The Nitrogen Losses vs Contributions vs Uptake Chart quantifies nitrogen loss from the major nitrogen loss pathways (denitrification, leaching, volatilization, immobilization) and graphs it against mineralization and crop uptake. This graph is a visual key for users to see what loss pathways are most active in their fields. From there, users can develop BMPs to address nitrogen loss pathways.

Users have the ability, throughout the season, to change parameters (application rate, application source, application time, application placement, use of nitrogen stabilizer, etc.) and re-run the model to compare uptake & loss outcomes.

In-depth discussion is provided for site 1 to allow readers to interpret results for the remaining sites.

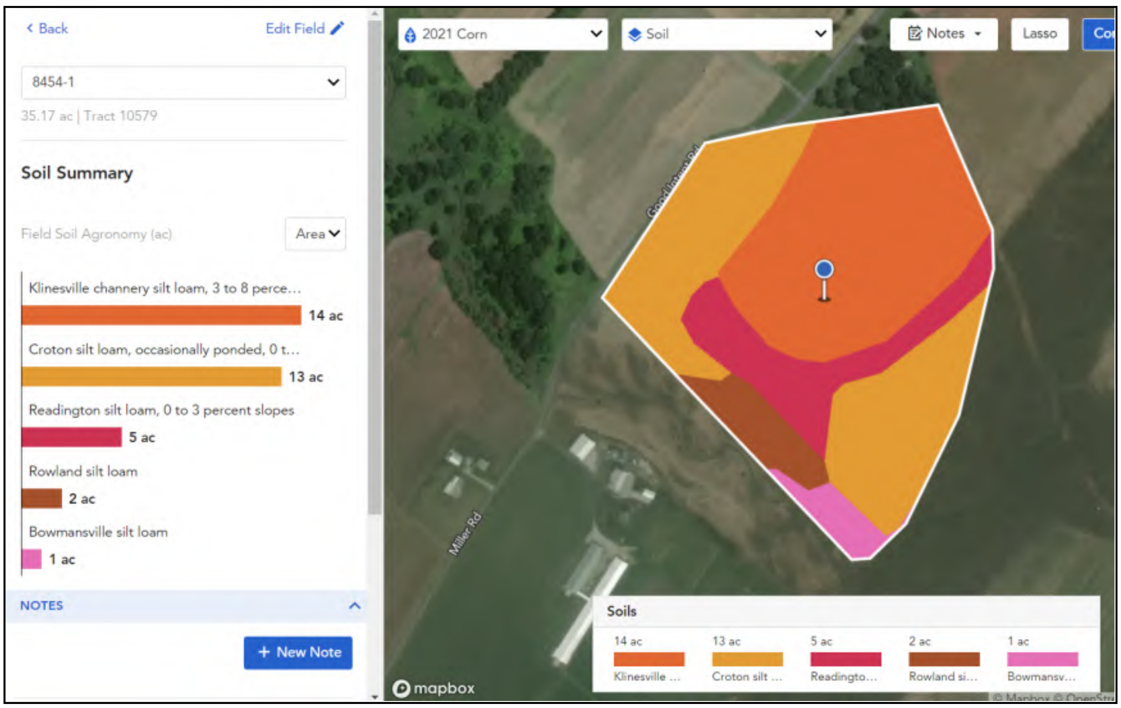
Adams County Site 1 - 35.17 Acres

Dominant Soil Types: Klinesville channery silt loam, 3 to 8 percent slopes
Croton silt loam, occasionally ponded, 0 to 3 percent slopes

Soil Health Practices In Place:
Continuous No-Till, Unharvested Cover Crops, Planting Green

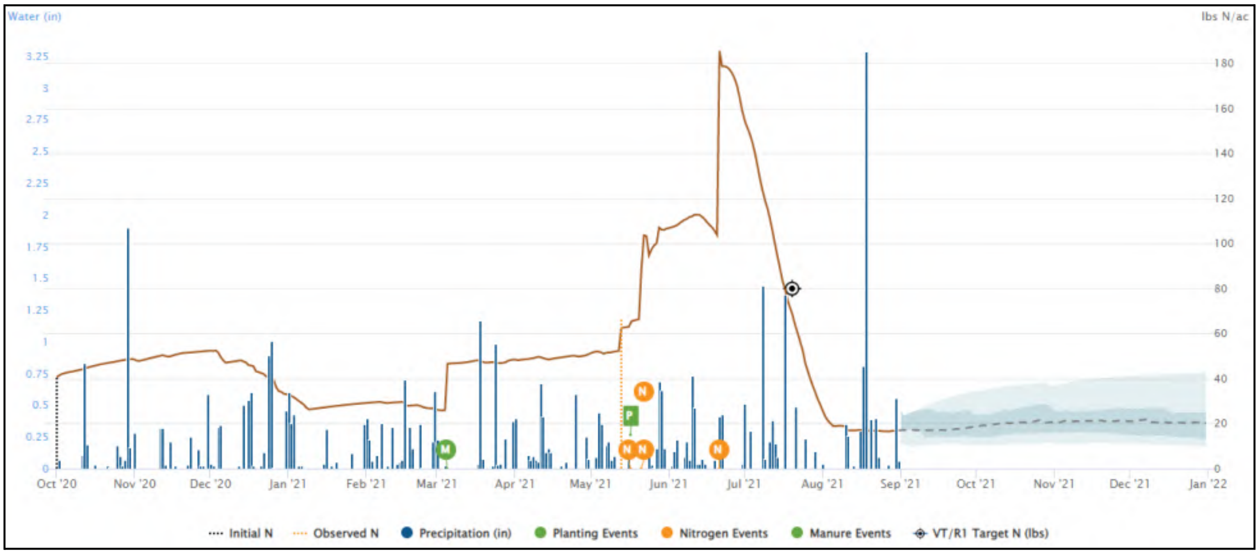
Adams County Sites 1, 2 & 3 are the same operation. Each field has a different dominant soil type. It is a family poultry operation that implements a 2-3 year rotation. Poultry manure is focused on corn acres. The farm has a long history of cover crops.

Soils Map: Adams County Site 1



SURGO soils data layer established after creating field boundaries. A user developing a soils map through NRCS's Web Soil Survey would create an identical map. Additional layers like LiDar and yield maps can be added to create “Decision Zones" within a field. Decision Zones can be treated like individual fields within a field for the purposes of creating variable rate nitrogen prescriptions. This project did not use Decision Zones or VR technology, although some cooperators had enough data to create them and had the equipment to implement them.

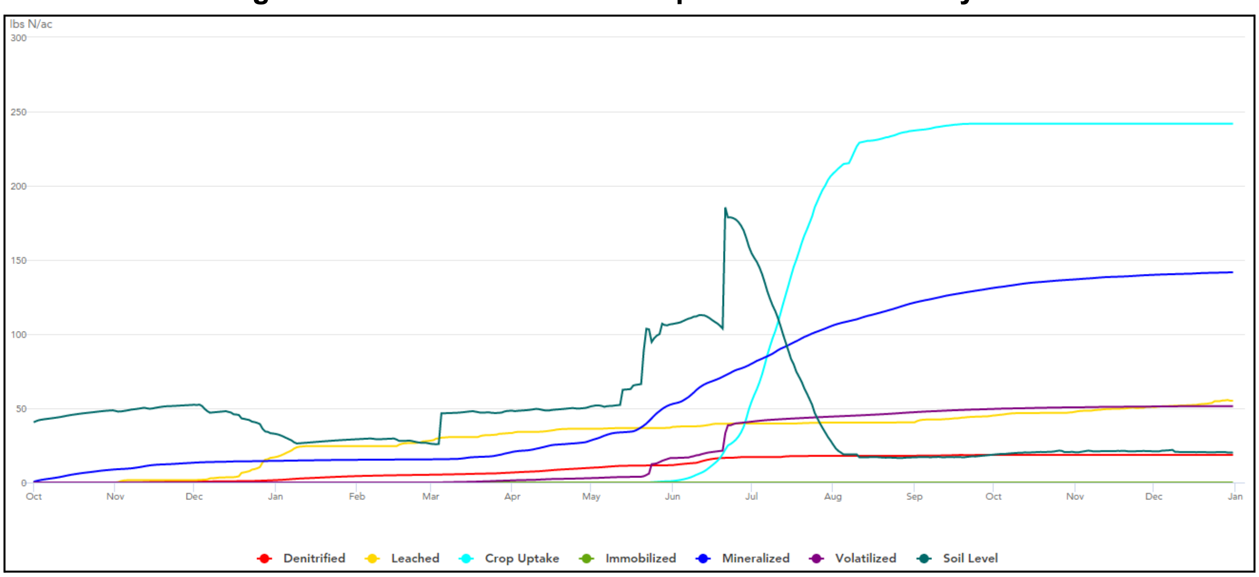
Events & Nitrogen Availability: Adams County Site 1



With a quick glance at both graphs readers can see the soil nitrogen line is the same. Also, notice the model begins calculating nitrogen loss on October 1. Farms that would have applied manure for the 2021 crop year prior to October 1, 2020 use a default date of October 1, 2020.

Initial N on October 1 is calculated by the model, based on user inputs and model assumptions. *Observed N* is the incorporation by the model of the pre-season nitrate sample, taken on May 12 for this site. The model will recalibrate based on a user-entered soil nitrate sample result. All manure applications, nitrogen fertilizer events, and planting events are shown on the graph, as is the target soil nitrogen level needed at tassel to achieve the set yield goal. The screenshot of this graph was taken in early September 2021 - events prior to that date show calculated nitrogen levels while time after that date is modeled as a range of outcomes.

Nitrogen Loss vs Contribution vs Uptake: Adams County Site 1



The four major nitrogen loss pathways are quantified in this chart, based on soil characteristics, precipitation and farm management activities. Readers can see that overall nitrogen losses in this field were around 25 lbs – around 5 lbs from denitrification and 10 lbs each from volatilization and leaching. Low losses can, in part, be attributed to farm management practices. Manure was applied in the spring to a growing cover crop and nitrogen fertilizer applications were split to reduce loss. Notice the "steps" in the volatilization line - they match application events where no nitrogen stabilizer effective on reducing volatilization was used.

The mineralized nitrogen line estimates nitrogen mineralized from various sources like soil organic matter, legumes, cover crops and organic manure nitrogen. Total mineralized nitrogen for this site is calculated at 140 lbs/acre.

Another interesting line is the total nitrogen uptake line. Notice the 240 lb uptake projection does not match the 172 bu/A yield goal. There is not enough information in the model to assess this difference, but it could be partially related to plant density, % of plants contributing to yield and inherent variety differences.

Readers will be able to identify nitrogen loss concerns on participating farms through these graphs, and be able to formulate possible alternatives for reducing that loss through 4R BMPs that focus on manure and fertilizer use efficiency.

Mass Balance vs. the Model: Adams County Site 1

	Mass Balance	**Granular Nitrogen Model**
Pre Season Nitrate Soil Test	NA	62 lbs N/ac
Yield Goal	185 bu/ac	185 bu/ac
Manure Application	2 tons turkey manure spring	2 tons turkey manure 3/5/21
Available N from manure	81 lbs N/ac	(54) lbs N/ac
Residual Manure N	20 lbs N/ac	0 lbs N/ac
Residual Legume N	0 lbs N/ac	0 lbs N/ac
At Planting Fertilizer Nr	15 lbs N/ac	15 lbs N/ac 5/15/21
Pop up/in-furrow Fertilizer N	2 lbs N/ac	2 lbs N/ac 5/15/21
Pre-Emerge Fertilizer N	30 lbs N/ac	33 lbs N/ac 5/17/21
Side-dress Fertilizer N	33 lbs N/ac	90 lbs N/ac 6/20/21
Total Applied N	183 lbs N/ac	202 lbs N/ac
Pre-Harvest Field Measured Yield	147 bu	172 bu
Calculated Nitrogen Use Efficiency	1.24 lbs N/bu	1.17 lbs N/bu
Precipitation 10/1/2020 - 10/1/2021		46 inches
Precipitation Planting - 10/1/2021		21 inches

The green highlighted cell shows the calculation with the best nitrogen use efficiency.

The chart above shows the different factors each tool, mass balance calculation and Granular Nitrogen, account for when calculating nitrogen fertilizer needs.

Pre-Season Nitrate Test: A crop model typically allows for users to take a nitrate soil test around the time of planting, before commercial nitrogen fertilizer is applied, to calibrate the model to historic field conditions like previous manure, legume nitrate, mineralized nitrogen from organic matter, etc. There are significant differences between participating sites in the amount of mineralized nitrogen present at planting. The timing of the Pre-Season Nitrate Test will influence what sources can be additionally credited. For instance, Adams County Site 1 had manure applied in March, and the soil nitrate sample was taken in May. A portion of the soil nitrate measured in May is the manure nitrogen applied in March. As such, source contributions will need to be modified based on the pre-season nitrate sample date. It is unclear how the model modifies manure & residual contributions based on timing of the sample.

Yield Goal: Same for both products

Manure Application: Both tools account for a 2-ton application. Granular accounts for the application date because the model will begin calculating loss and mineralization on March 5. The version of Granular used for this project did not account for the influence of existing cover crops present at the time of application. The goal of future models is to allow users to enter cover crop data.

Availability of manure nitrogen can be different for a manure application, depending on how a user enters the data into the model. Users can create farm specific manure analysis and enter availability factors. Even with those options, users may need to adjust the application rate to make available nitrogen match a nutrient management plan. For instance, fall applied dairy manure on a rye forage cover crop at 6,000 gal/A would have a limited nitrogen contribution to the corn planted following rye harvest. The current mass balance calculation used in PA provides an availability factor for this situation. The model does not. Instead, users would need to reduce the application rate to around 2,400 gal/A to have the model calculate the equivalent contribution.

One issue we faced in this project centered around manure nitrogen availability. Both Rosetree Consulting's certified nutrient management plan writers and Granular's Pro-Services staff (individuals certified to assist farms with modeling and yield data management) worked to enter data on the 83 fields. The Pro-Services staff was not familiar with PA regulations and availability factors which led to calculated nitrogen contributions not matching PA nutrient management plans. This error was not caught in time to correct the model. It highlights the need for local professionals familiar with regulatory policies to provide oversight to farms that are using the model in cost share programs or regulatory programs.

Residual Legume and Manure N: This is a major difference between a mass balance calculation and the version of the Granular model used in this project. Mass balance calculations provide a specific nitrate contribution for residual manure and legumes. The crop model did not directly account for nitrate contributions from legume or past manure applications, but rather, partially accounted for these contributions in the pre-season soil nitrate sample. The 2023 version of Granular Agronomy Nitrogen Service will allow users to select these sources for higher visibility of the residual source.

Fertilizer Applications: A crop model will account for the Time, Source, and Placement of fertilizer materials to calculate availability and loss. Accurate entry of application dates & methods are very important for this “real-time” calculation. For instance, 150 lbs of nitrogen called for in a nutrient plan is applied with burndown herbicides. The field receives a 1 inch rain 24-hours after application and a total of 4 inches of rain before the corn is waist high. The model can account for the movement of this nitrogen through loss pathways, while the mass balance calculation cannot. If the farmer split applies his 150 lbs, applying 50 at planting and 100 lbs as a sidedress, the mass balance calculation does not give credit to split applied nitrogen, a 4R Timing practice recognized for improving nitrogen use efficiency. The model takes this into account when calculating available nitrogen and contributions to yield.

Precipitation: Precipitation is the driver not only for nitrogen loss pathways, but also for mineralization of soil sources. In the previous example, 5 inches of precipitation can lead to significant leaching and runoff losses, leaving the crop potentially deficient in nitrogen & unable to maximize yield. Another impact of precipitation is to mineralization rates. Soil moisture in the top layer of the soil is critical for microbial degradation of organic materials. Too little soil moisture in the top layer can reduce mineralization rates of the soil, resulting in less contributions from sources like legumes, cover crops, and organic manure fractions. Mass balance calculations are static, unable to adapt to in season changes in conditions. Nitrogen models can account for some of these interactions when calculating available nitrogen.

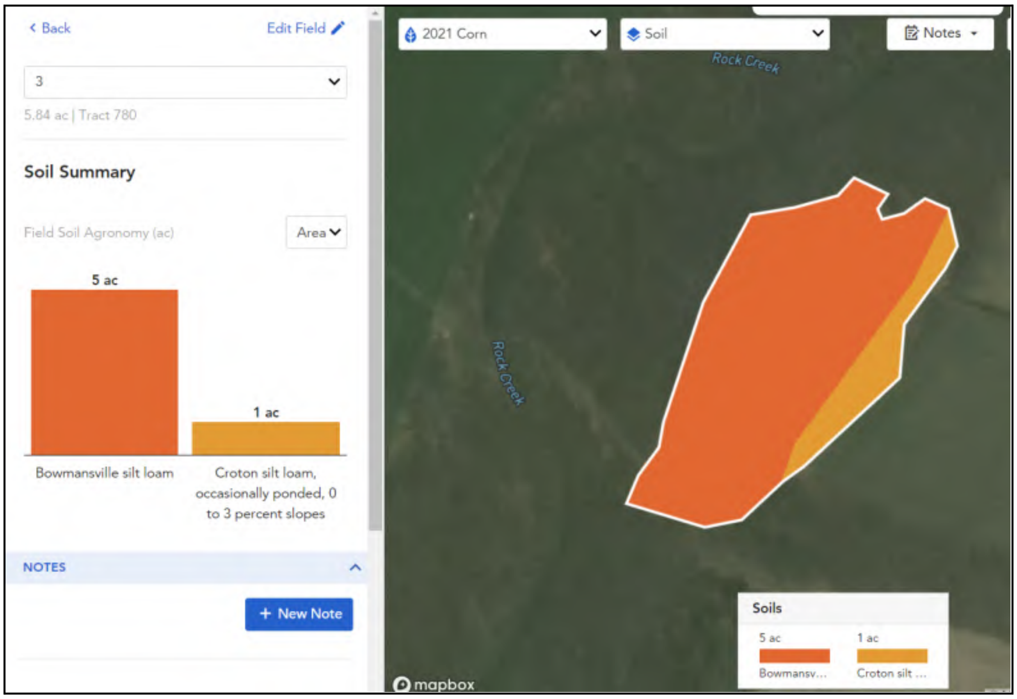
Calculated Nitrogen Use Efficiency: This is the estimated yield divided by the total amount of nitrogen accounted for. It was not the goal of this project to provide a statistical analysis of the results to identify what constitutes a statistical difference. Rather, it was the goal to compare commercially available modeling tools with trusted mass balance calculations to determine if they can provide the same level of confidence to a grower and a water quality regulating agency for site specific management of nitrogen.

Adams County Site 2 - 5.84 Acres

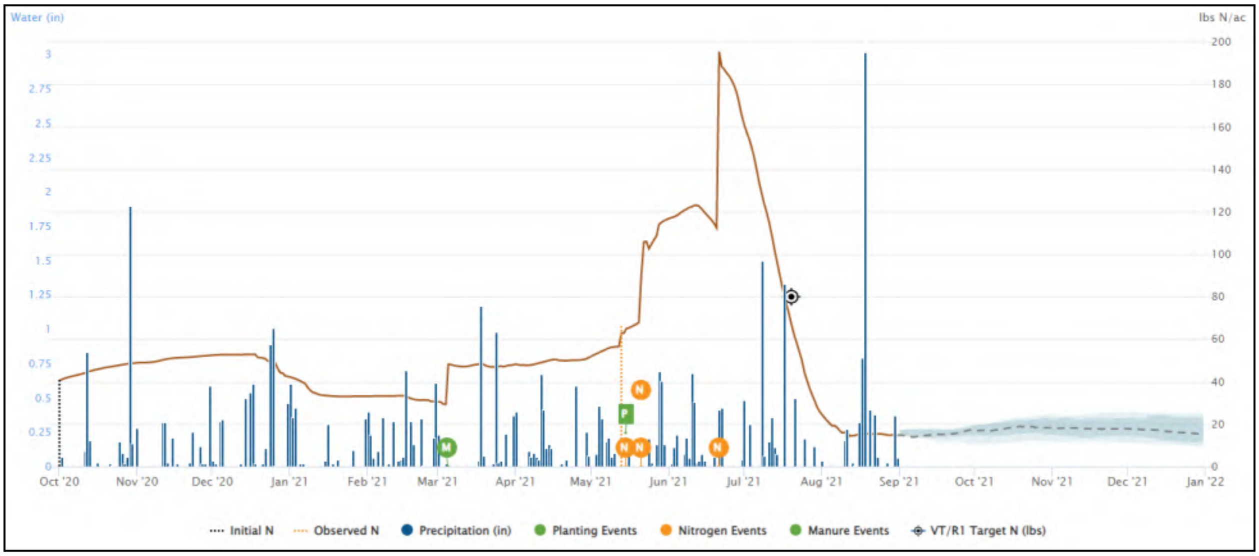
Dominant Soil Type: Bowmansville silt loam
Soil Health Practices In Place: Continuous No-Till, Cover Crops, Planting Green

Adams County Sites 1, 2 & 3 are the same operation. Each field has a different dominant soil type. It is a family poultry operation that implements a 2-3 year rotation. Poultry manure is focused on corn acres. The farm has a long history of cover crops.

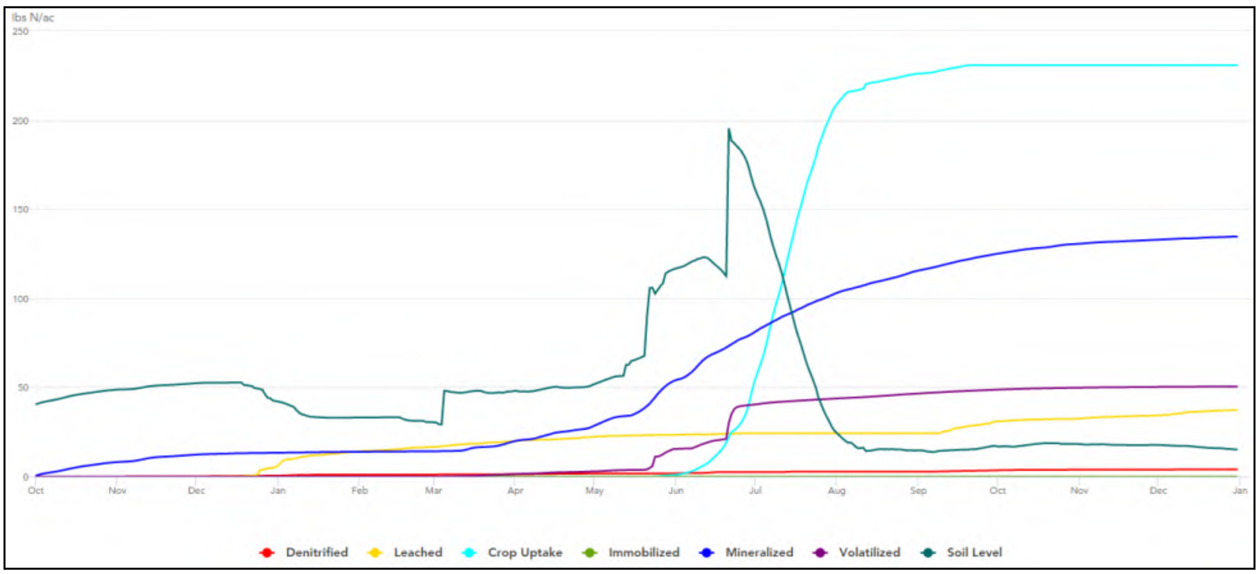
Soils Map: Adams County Site 2



Events & Nitrogen Availability: Adams County Site 2



Nitrogen Loss vs Contribution vs Uptake: Adams County Site 2



Volatilization losses from fertilizer applications are noticeable in the graph. The version of the Granular model used for this project did not identify any immobilization losses due to presence of a high biomass cover crop. The Adams County farm used for sites 1, 2, & 3 is the “Small Grain Headed” cover crop scenario presented in Part B of this report. The site was modeled to show site specific nitrogen contributions from the cover crop. A picture of the cover crop is below.

Mass Balance vs. the Model: Adams County Site 2

	Mass Balance	Granular Nitrogen Model
Pre Season Nitrate Soil Test	NA	62 lbs N/ac 5/12/21
Yield Goal	185 bu/ac	185 bu/ac
Manure Application	2 tons turkey manure	2 tons turkey manure 3/5/21
Available N from manure	81 lbs N/ac	(54) lbs N/ac
Residual Manure N	20 lbs N/ac	0 lbs N/ac
Residual Legume N	0 lbs N/ac	0 lbs N/ac
At Planting	15 lbs N/ac	15 lbs N/ac 5/16/21
Pop up/in-furrow	2 lbs N/ac	2 lbs N/ac 5/16/21
Pre-Emerge	30 lbs N/ac	33 lbs N/ac 5/18/21
Side-dress	33 lbs N/ac	90 lbs N/ac 6/20/21
Total Applied N	181 lbs N/ac	202 lbs N/ac
Pre-Harvest Field Measured Yield	142 bu	152 bu
Calculated Nitrogen Use Efficiency	1.27 lbs N/bu	1.33 lbs N/bu
Precip 10/1/2020 - 10/1/2021		46 inches
Precip Planting - 10/1/2021		20 inches

The Granular model calculated lower nitrogen availability from the manure application due to PA availability factors given to manure applied on a growing cover crop. The model may have captured some of this difference in the soil nitrate sample taken on 5/12/21.

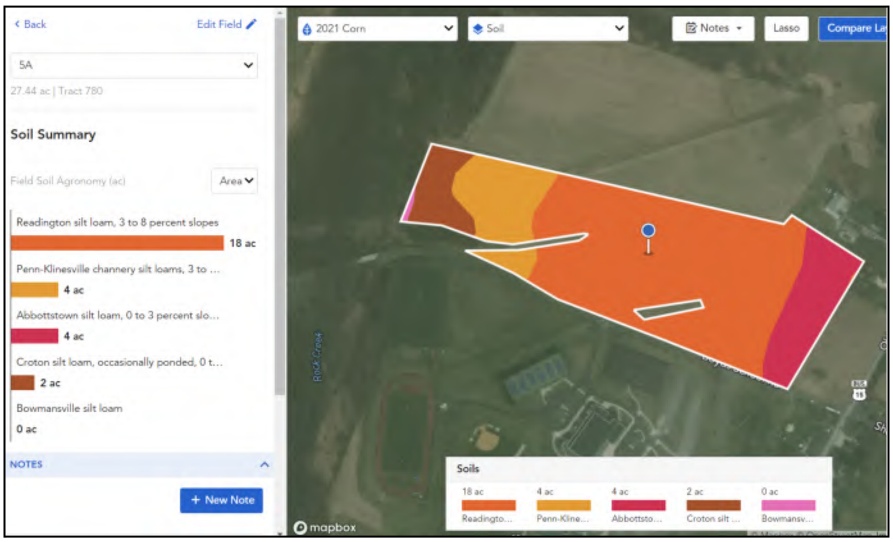
Note that the 62 lbs of measured nitrate is not included in the total applied N calculation. This 62 lbs includes nitrogen available from the manure source + any legume residual + soil sources. To include this 62 lbs in the total applied N calculation would be “double dipping.” It is interesting to note that this soil was supplying 62 lbs of nitrate when the rye cover crop was in full head and rye was near its highest demand for nitrogen. Overall nitrogen rates are higher for the modeled acres, but higher yield results in a better NUE. The increased yield of 10 bu/A also results in increased phosphorus removal of 4 lbs/A.

Adams County Site 3 - 27.44 Acres

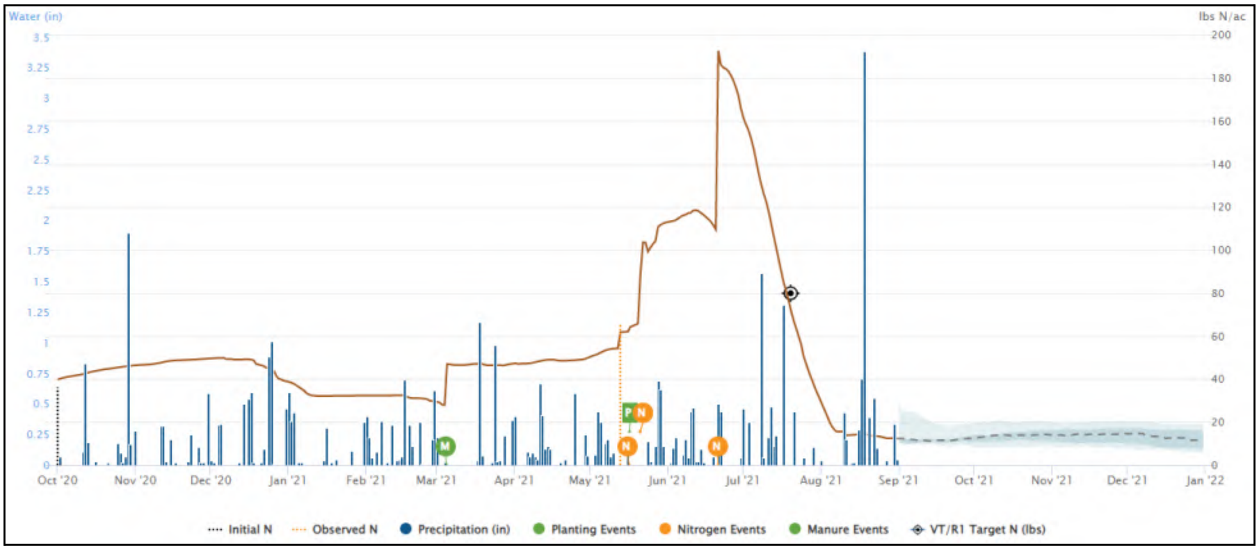
Dominant Soil Type: Readington silt loam, 3 to 8 percent slopes
Soil Health Practices In Place: Continuous No-Till, Cover Crops, Planting Green

Adams County Sites 1, 2 & 3 are the same operation. Each field has a different dominant soil type. It is a family poultry operation that implements a 2-3 year rotation. Poultry manure is focused on corn acres. The farm has a long history of cover crops.

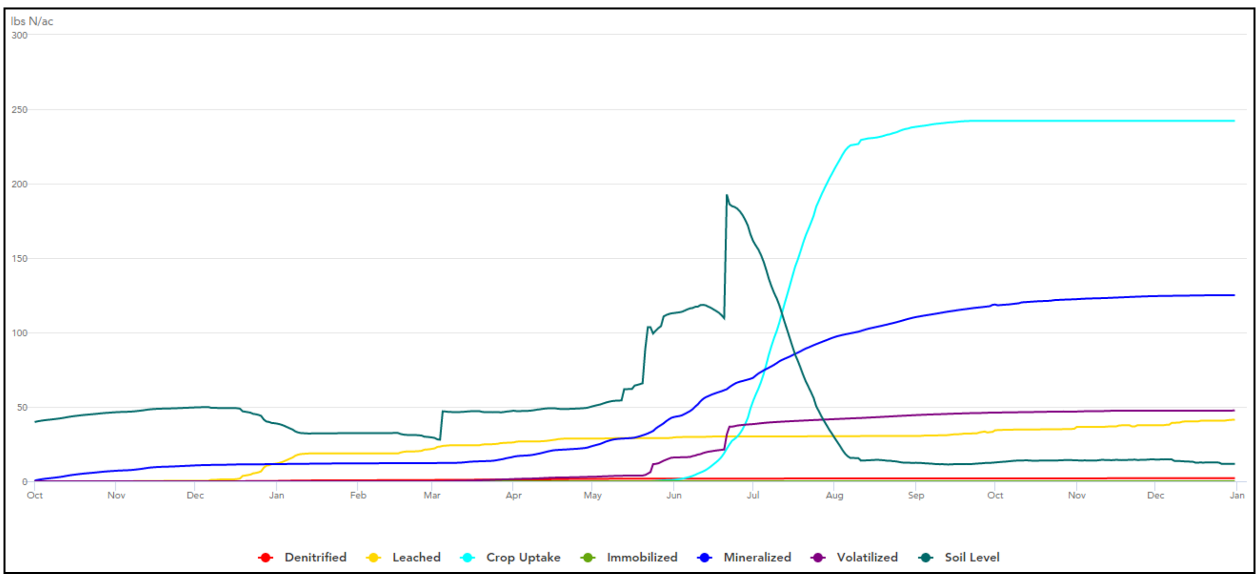
Soils Map: Adams County Site 3



Events & Nitrogen Availability: Adams County Site 3



Nitrogen Loss vs Contribution vs Uptake: Adams County Site 3



Volatilization losses from fertilizer applications are noticeable in the graph. The version of the Granular model used for this project did not identify any immobilization losses due to presence of a high biomass cover crop. The Adams County farm used for sites 1, 2, & 3 is the “Small Grain Headed” cover crop scenario presented in Part B of this report. The site was modeled to show site specific nitrogen contributions from the cover crop.

Mass Balance vs. the Model: Adams County Site 3

	Mass Balance	**Granular Nitrogen Model**
Pre Season Nitrate Soil Test	NA	62 lbs N/ac 5/12/21
Yield Goal	185 bu/ac	185 bu/ac
Manure Applications	2 tons turkey manure	2 tons turkey manure 3/5/21
Available N from manure	81 lbs N/ac	(54) lbs N/ac
Residual Manure N	20 lbs N/ac	0 lbs N/ac
Residual Legume N	0 lbs N/ac	0 lbs N/ac
At Planting	15 lbs N/ac	15 lbs N/ac 5/16/21
Pop up/in-furrow	2 lbs N/ac	2 lbs N/ac 5/16/21
Pre-Emerge	30 lbs N/ac	33 lbs N/ac 5/18/21
Side-dress	0 lbs N/ac	90 lbs N/ac 6/20/21
Total Applied N	148 lbs N/ac	202 lbs N/ac
Pre-Harvest Field Measured Yield	145 bu/a	184 bu/a
Calculated Nitrogen Use Efficiency	1.02 lb N/bu	1.1 lb N/bu
Precip 10/1/2020 - 10/1/2021		46 inches
Precip Planting - 10/1/2021		20 inches

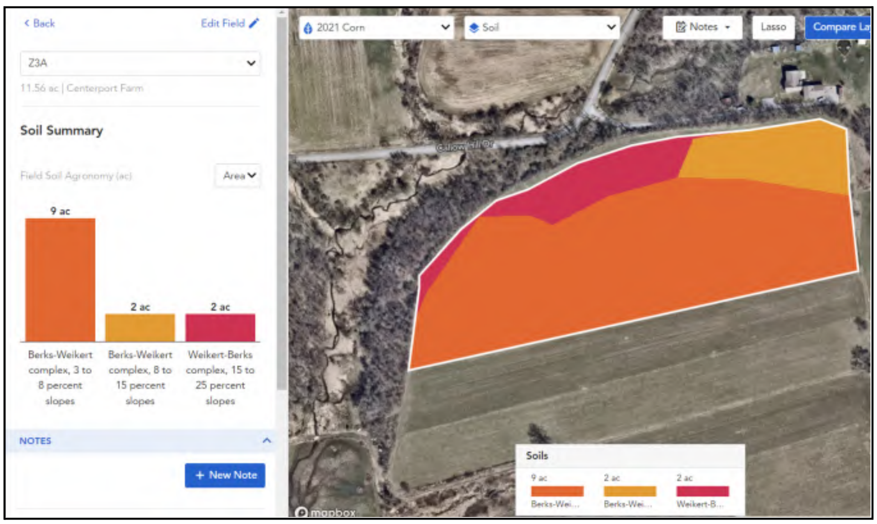
Much of the comments are the same for Adams County site 3 as were made for Adams County site 2 pertaining to residual nitrogen contributions. The higher sidedress rate for this field may be due to a different dominant soil type - Readington. Klinesville and Croton soils were the dominant soil types in sites 1 & 2, respectively.

Berks County Site 1 - 11.56 Acres

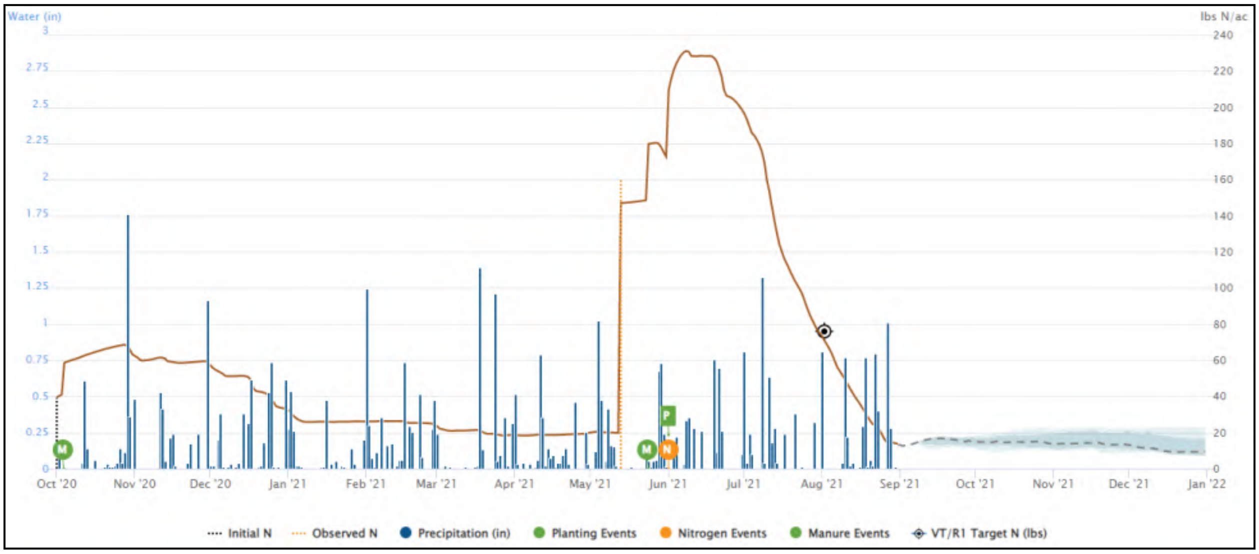
Dominant Soil Type: Berks-Weikert complex, 3 to 8 percent slopes
Soil Health Practices In Place: Continuous No till, Forage Cover Crop

Berks County Sites 1 & 2 are at the same dairy farm. The farm implements a 1-year corn silage / small grain silage rotation and has a long history of 2-3 manure applications annually and traditionally does not apply all the nitrogen called for in their nutrient management plan. Sites 1 & 2 are the same Berks Weikert soil, but site 1 is a northern field on a 3-8% slope, while site 2 is a southern facing field with a 8-15% slope.

Soils Map: Berks County Site 1

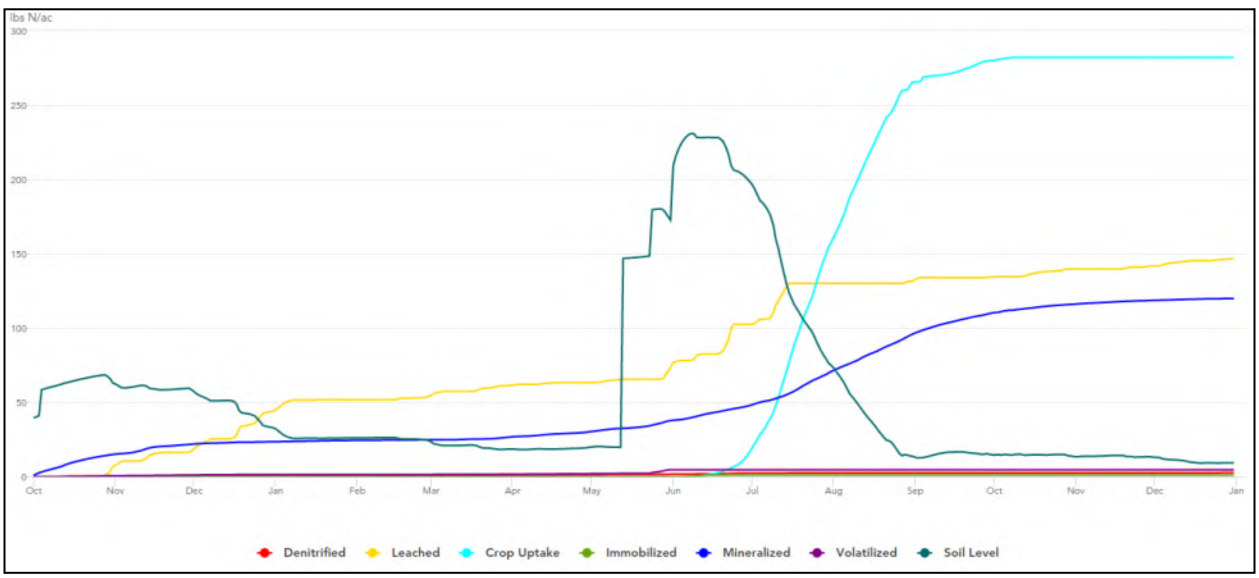


Events & Nitrogen Availability: Berks County Site 1



Note the Observed N date of 5/12 - 160 lbs of available nitrogen was present in the field *before* manure and at-planting nitrogen was applied.

Nitrogen Loss vs Contribution vs Uptake: Berks County Site 1



Leaching losses are higher than expected from a field with nitrogen fertilizer banded sub-surface at planting and no additional fertilizer applied. The steps in the leaching line match well with rainfall events, indicating that the soil type has a high propensity for leaching.

Mass Balance vs. the Model: Berks County Site 1

	Mass Balance	Granular Nitrogen Model
Pre Season Nitrate Soil Test	NA	160 lbs N/ac (Sample date: 5/12/21)
Yield Goal	175 bu/ac	175 bu/ac
Manure Applications	7k dairy early fall 7k dairy spring	7k dairy 10/1/20 7k dairy 5/24/21
Available N from manure	68 lbs N/ac	35 lbs N/ac
Residual Manure N	24 lbs N/ac	0 lbs N/ac
Residual Legume N	0 lbs N/ac	0 lbs N/ac
At Planting	60 lbs N/ac	60 lbs N/ac 5/27/21
Pop up/in-furrow	0 lbs N/ac	0 lbs N/ac
Pre-Emerge	0 lbs N/ac	0 lbs N/ac
Side-dress	(23) lbs N/ac	0 lbs N/ac
Total Applied N	175 lbs N/ac	255 lbs N/ac
Pre-Harvest Field Measured Yield	230 bu/A	230 bu/A
Calculated Nitrogen Use Efficiency	0.76 lbs N/bu*	1.1 lbs N/bu*
Precip 10/1/2020 - 10/1/2021		46 inches
Precip Planting - 10/1/2021		17 inches

*No sidedress was made to these fields, so no comparison of NUE can be made. The mass balance part of the field should have received an additional 23 lbs of nitrogen, while the model would not have called for additional fertilizer to be applied. The 23 lbs is presented as applied and calculated in the NUE number.

The amount of soil nitrate measured in this field, 160 lbs/A, explains the very low calculated nitrogen use efficiency for the mass balance calculation. The N Model's nitrate sample was taken prior to the spring manure application, so the fall manure contributions + residual manure + soil sources are captured in the nitrate sample. Spring manure applications were not. Total nitrogen applied for the model closely reflect expected overall NUE, indicating that the pre-season nitrate sample was effective at capturing soil contributions.

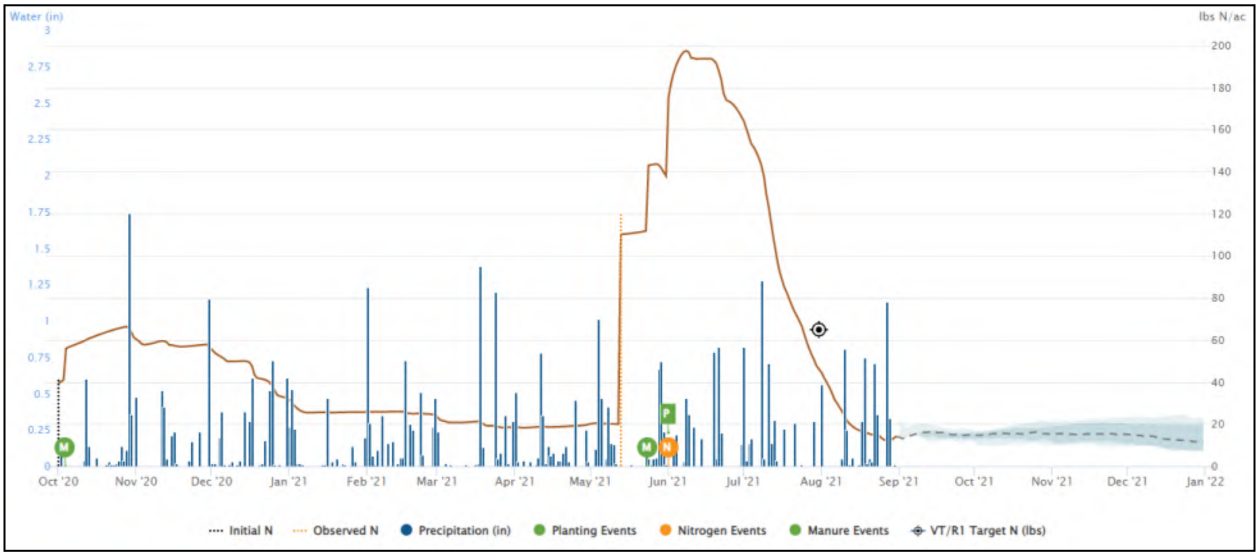
Berks County Site 2 - 7.36 Acres

Dominant Soil Type: Berks-Weikert complex, 8 to 15 percent slopes
Soil Health Practices In Place: Continuous No Till, Forage Cover Crop

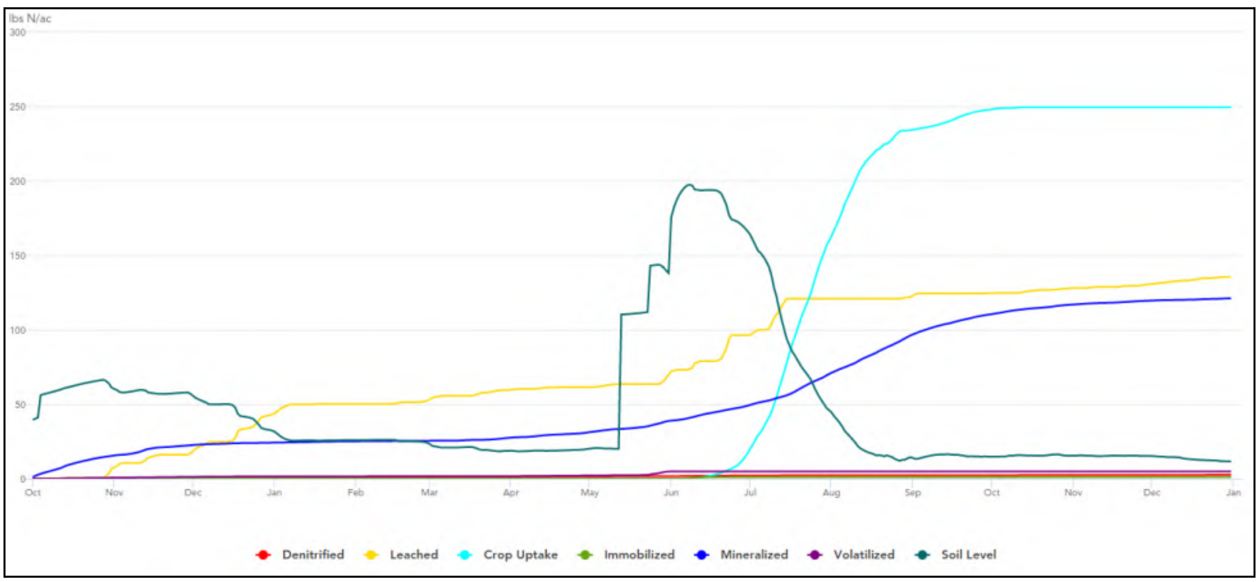
Berks County Sites 1 & 2 are at the same dairy farm. The farm implements a 1-year corn silage / small grain silage rotation and has a long history of 2-3 manure applications annually and traditionally does not apply all the nitrogen called for in their nutrient management plan. Sites 1 & 2 are the same Berks Weikert soil, but site 1 is a northern field on a 3-8% slope, while site 2 is a southern facing field with a 8-15% slope.

Soils Map: Berks County Site 2

Events & Nitrogen Availability: Berks County Site 2



Nitrogen Loss vs Contribution vs Uptake: Berks County Site 2



Leaching losses are higher than expected from a field with nitrogen fertilizer banded sub-surface at planting and no additional fertilizer applied. The steps in the leaching line match well with rainfall events, indicating that the soil type has a high propensity for leaching.

Mass Balance vs. the Model: Berks County Site 2

	Mass Balance	Granular Nitrogen Model
Pre Season Nitrate Soil Test	NA	120 lbs N/ac (Sampled on: 5/13/21)
Yield Goal	175 bu/ac	175 bu/ac
Manure Applications	7k dairy early fall 7k dairy spring	7k dairy 10/1/20 7k dairy 5/24/21
Available N from manure	68 lbs N/ac	35 lbs N/ac
Residual Manure N	24 lbs N/ac	0 lbs N/ac
Residual Legume N	0 lbs N/ac	0 lbs N/ac
At Planting	60 lbs N/ac	60 lbs N/ac 5/28/21
Pop up/in-furrow	0 lbs N/ac	0 lbs N/ac
Pre-Emerge	0 lbs N/ac	0 lbs N/ac
Side-dress	(23) lbs N/ac	0 lbs N/ac
Total Applied N	175 lbs N/ac	215 lbs N/ac
Pre-Harvest Field Measured Yield	227 bu/a	227 bu/a
Calculated Nitrogen Use efficiency	0.77 lbs N/bu*	0.95 lbs N/bu*
Precip 10/1/2020 - 10/1/2021		46 inches
Precip Planting - 10/1/2021		16 inches

*No sidedress was made to these fields, so no comparison of NUE can be made. The mass balance part of the field should have received an additional 23 lbs of nitrogen, while the model would not have called for additional fertilizer to be applied. The 23 lbs is presented as applied and calculated in the NUE number.

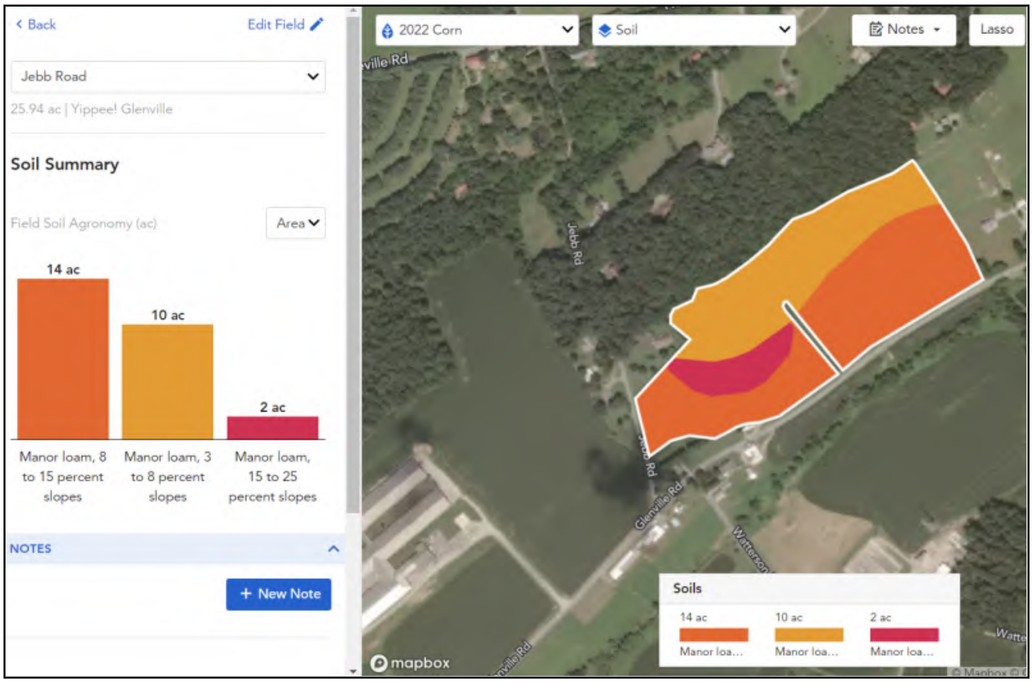
The amount of soil nitrate measured in this field, 120 lbs/A, explains the very low calculated nitrogen use efficiency for the mass balance calculation. The N Model's nitrate sample was taken prior to the spring manure application, so the fall manure contributions + residual manure + soil sources are captured in the nitrate sample. Spring manure applications were not. Total nitrogen applied for the model closely reflect expected overall NUE, indicating that the pre-season nitrate sample was effective at capturing soil contributions.

Chester County Site 1 - 25.94 Acres

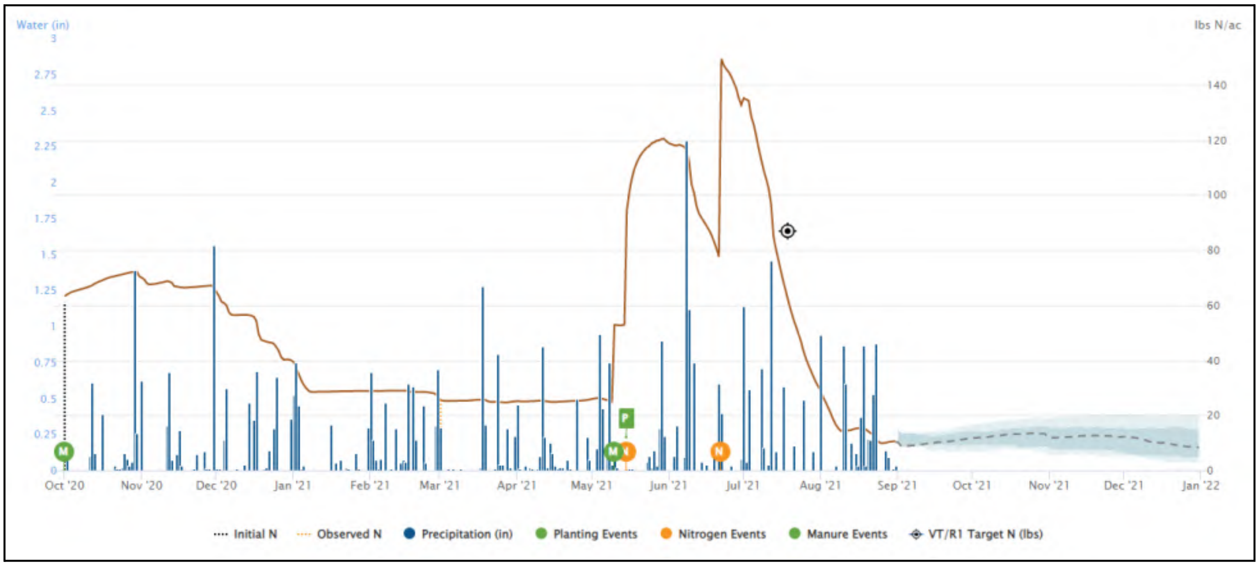
Dominant Soil Types: Manor Loam, 8 to 15 percent slopes & 3 to 8 percent slopes
Soil Health Practices In Place: Continuous No-till, Forage Cover Crop

Chester County Sites 1 & 2 are at the same dairy farm. The farm implements a 1-year corn silage / small grain silage rotation and has a long history of 3+ manure applications annually. Site 1 is a Manor soil type, while Site 2 is a Chester soil type.

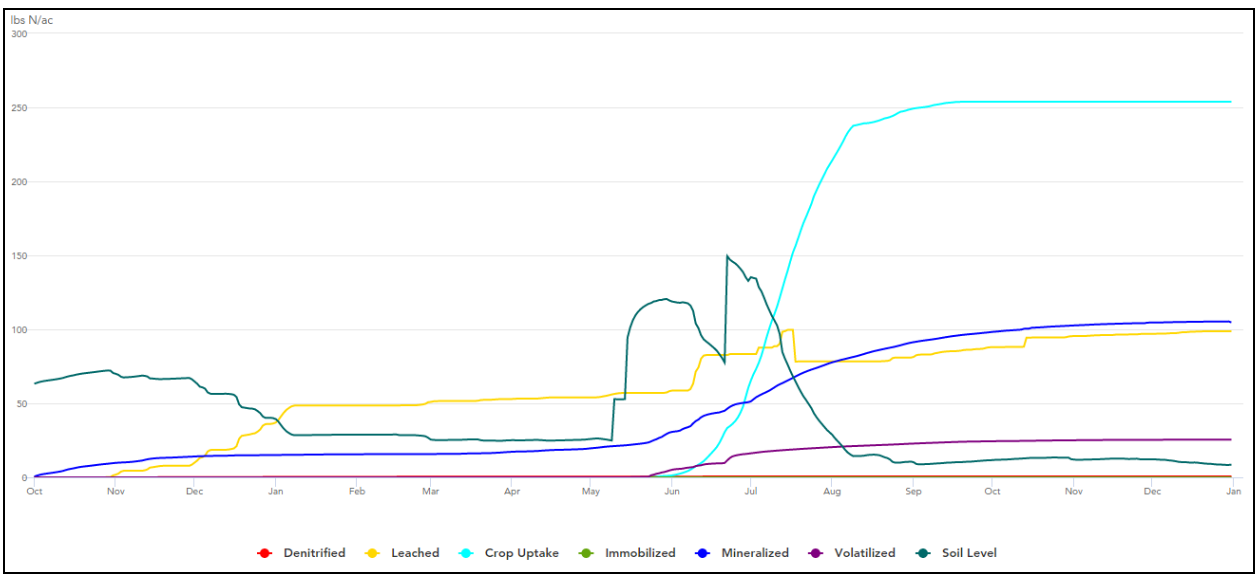
Soils Map: Chester County Site 1



Events & Nitrogen Availability: Chester County Site 1



Nitrogen Loss vs Contribution vs Uptake: Chester County Site 1



Note the leaching losses occurring in December & January. This may be an omission in the current Granular program for not recognizing the presence of a cover crop.

Notice the leaching losses that occurred in mid June following the single rain event. The model was able to capture this leaching loss and reflect it in a higher sidedress rate.

Mass Balance vs. the Model: Chester County Site 1

	Mass Balance	Granular Nitrogen Model
Pre Season Nitrate Soil Test	NA	26 lbs N/ac (Sampled on: 5/13/21)
Yield Goal	220 bu/ac	220 bu/ac
Manure App	12k dairy early fall 12k dairy spring	12k dairy 10/1/20 12k dairy 5/20/21
Available N from manure	76 lbs N/ac	61 lbs N/ac
Residual Manure N	24 lbs N/ac	0 lbs N/ac
Residual Legume N	0 lbs N/ac	0 lbs N/ac
At Planting	60 lbs N/ac	60 lbs N/ac 5/24/21
Pop up/in-furrow	0 lbs N/ac	0 lbs N/ac
Pre-Emerge	0 lbs N/ac	0 lbs N/ac
Side-dress	60 lbs N/ac	101 lbs N/ac 6/23/21
Total Applied N	220 lbs N/ac	231 lbs N/ac
Pre-Harvest Field Measured Yield	223 bu/a	248 bu/a
Calculated Nitrogen Use Efficiency	0.99 lbs N/bu	0.93 lbs N/bu
Precip 10/1/2020 - 10/1/2021		51 inches
Precip Planting - 10/1/2021		23 inches

The amount of soil nitrate measured in this field, 26 lbs/A, is low in comparison to Berks 1 & 2. One major difference is the solids content of the manure for each site - it is much higher for the Berks County farm.

Notice the rainfall event in mid-June and the corresponding increase in leaching losses. This event prompted a higher sidedress rate that eventually resulted in higher yields. The increased yield of 25 bu/A resulted in an additional 10 lbs/A of phosphorus removal.

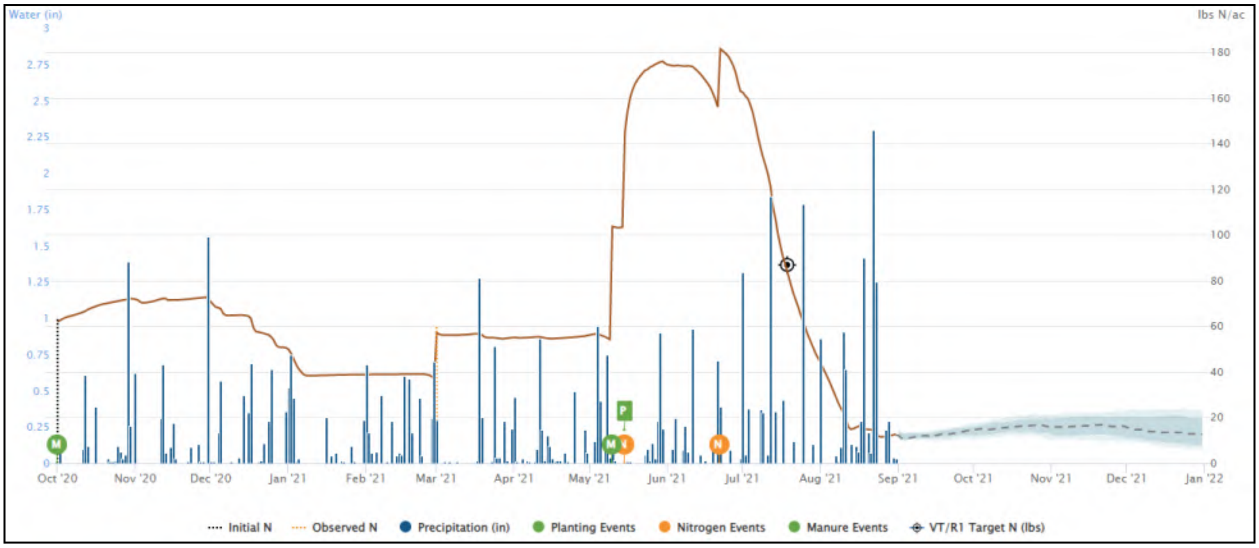
Chester County Site 2 - 36.10 Acres

Dominant Soil Types: Glenelg silt loam, 8 to 15 percent slopes
Chester silt loam, 3 to 8 percent slopes
Chester silt loam, 0 to 3 percent slopes
Soil Health Practices In Place: Continuous No-Till, Forage Cover Crop

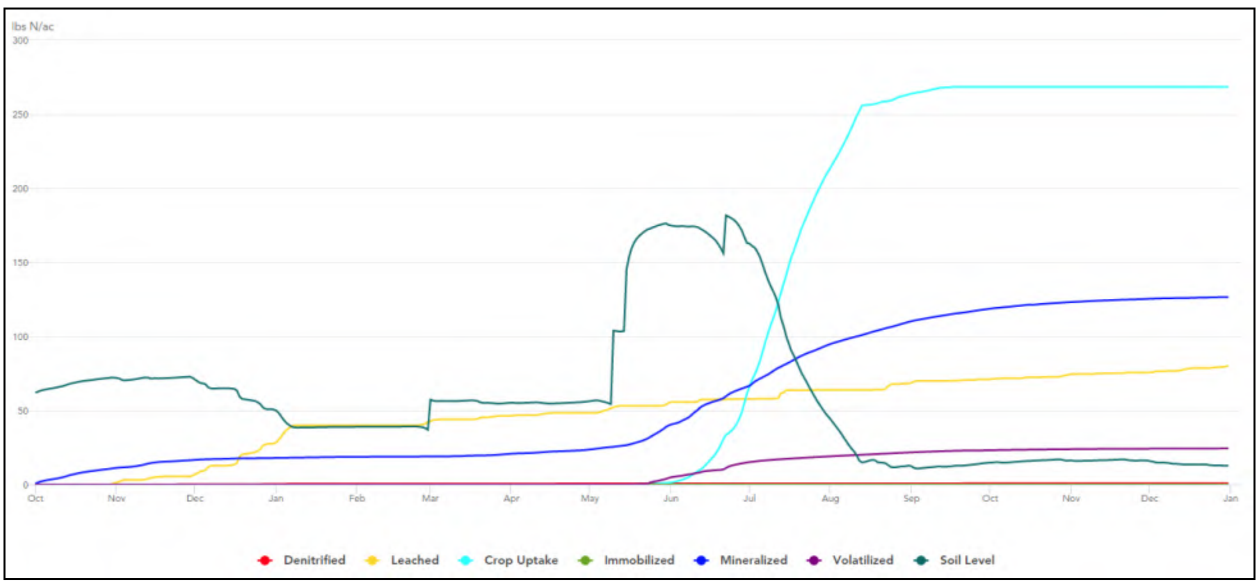
Chester County Sites 1 & 2 are at the same dairy farm. The farm implements a 1-year corn silage / small grain silage rotation and has a long history of 3+ manure applications annually. Site 1 is a Manor soil type, while Site 2 is a Chester soil type.

Soils Map: Chester County Site 2

Events & Nitrogen Availability: Chester County Site 2



Nitrogen Loss vs Contribution vs Uptake: Chester County Site 2



Again, the leaching losses of December and January are likely due to the model not recognizing a cover crop was present. Rainfall at this site was different from the rainfall at Chester 1, so the model adjusted sidedress rates accordingly.

Mass Balance vs. the Model: Chester County Site 2

	Mass Balance	Granular Nitrogen Model
Pre Season Nitrate Soil Test	NA	60 lbs N/ac (Sampled on: 5/13/21)
Yield Goal	220 bu/ac	220 bu/ac
Manure App	12k dairy early fall 12k dairy spring	12k dairy 10/1/20 12k dairy 5/20/21
Available N from manure	76 lbs N/ac	61 lbs N/ac
Residual Manure N	24 lbs N/ac	0 lbs N/ac
Residual Legume N	0 lbs N/ac	0 lbs N/ac
At Planting	60 lbs N/ac	60 lbs N/ac 5/23/21
Pop up/in-furrow	0 lbs N/ac	0 lbs N/ac
Pre-Emerge	0 lbs N/ac	0 lbs N/ac
Side-dress	60 lbs N/ac	40 lbs N/ac
Total Applied N	220 lbs N/ac	221 lbs N/ac
Pre-Harvest Field Measured Yield	203 bu	203 bu
Calculated Nitrogen Use Efficiency	1.08 lbs N/bu	1.08 lbs N/bu
Precip 10/1/2020 - 10/1/2021		52 inches
Precip Planting - 10/1/2021		25 inches

The amount of soil nitrate measured in this field, 26 lbs/A, is higher than site 1, but low in comparison to Berks 1 & 2. Manure solids content difference between the Berks & Chester farms may be part of the difference. Soils differences between Chester 1 & Chester 2 may also be part of the difference.

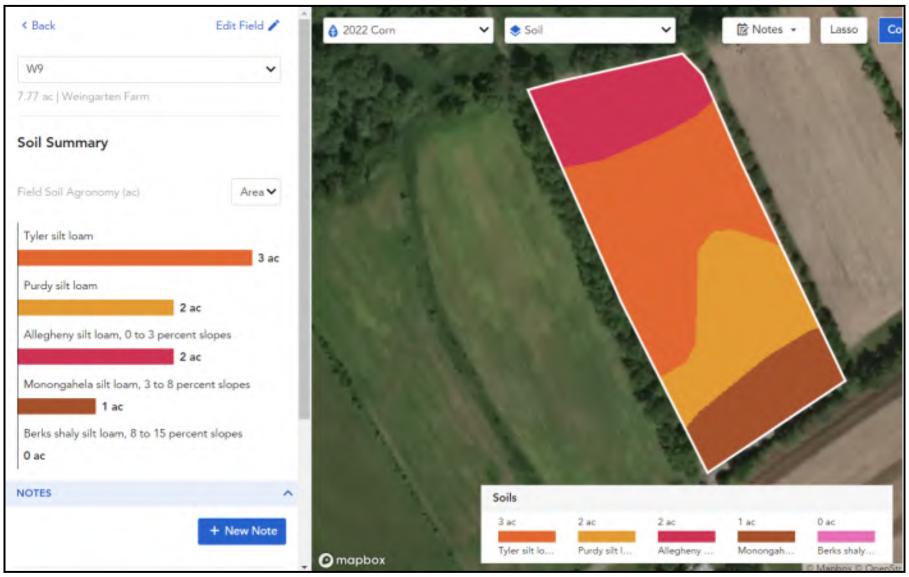
The model calculated less of a sidedress need than the mass balance calculation. NUE were identical for the comparisons.

Cumberland County Site 1 - 7.77 Acres

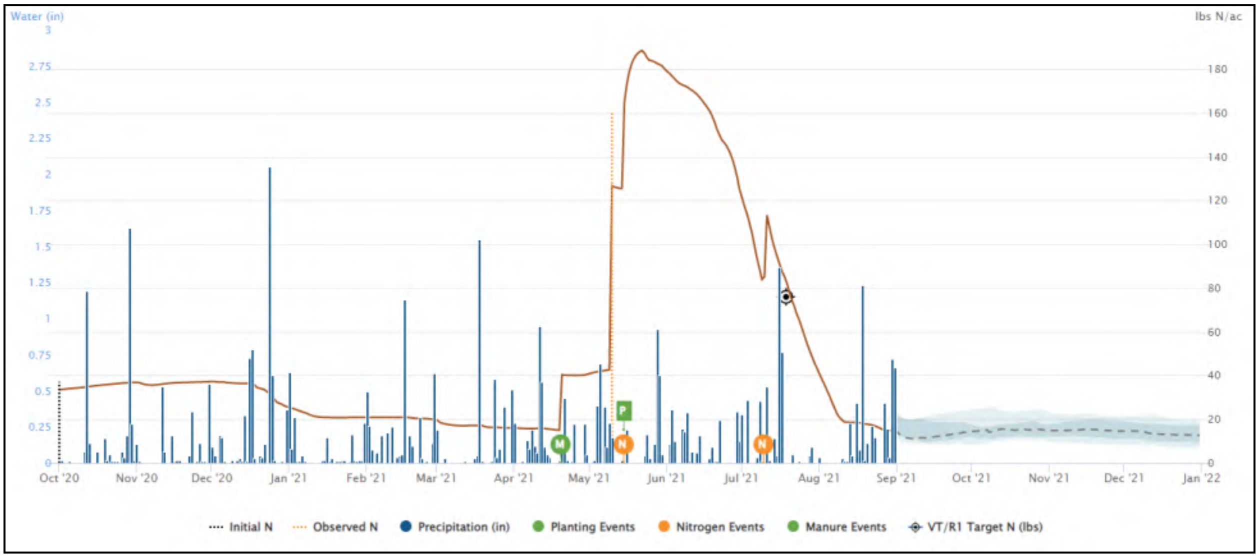
Dominant Soil Type: Tyler silt loam
Soil Health Practices In Place:
Continuous No-Till, Multi-Species Cover Crop, Green Planting

Cumberland County Sites 1 & 2 are at the same hog farm. The farm implements a 2-year corn and wheat/multi-species cover crop rotation and applied hog manure to the cover crop in fall. Site 1 is a Tyler Silt Loam while Site 2 is a Monongahela Silt Loam.

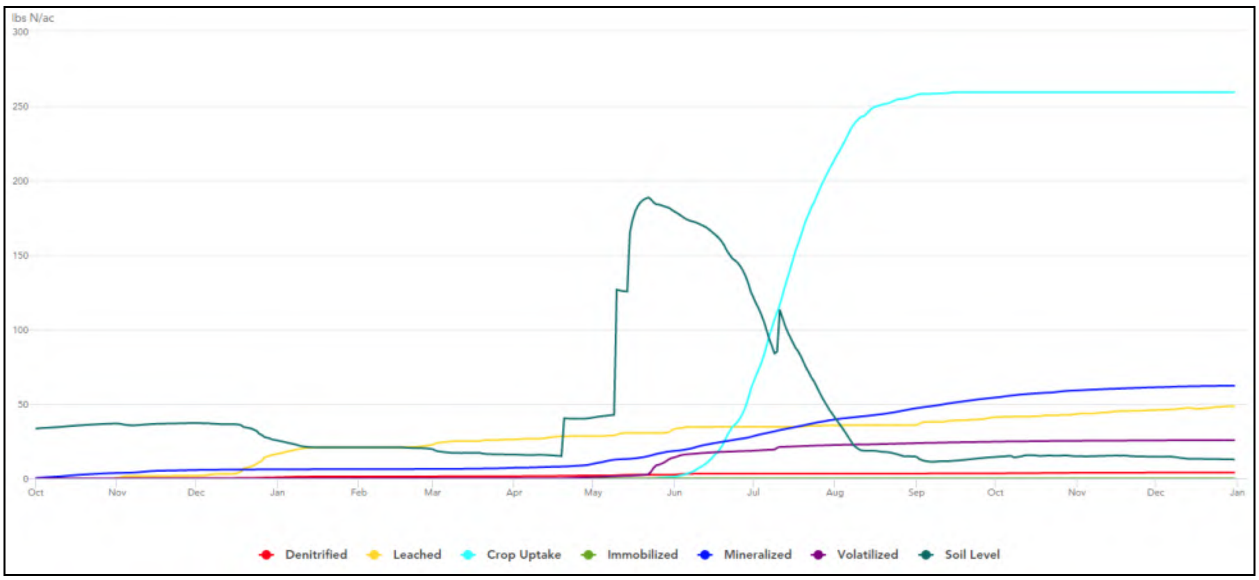
Soils Map: Cumberland County Site 1



Events & Nitrogen Availability: Cumberland County Site 1



Nitrogen Loss vs Contribution vs Uptake: Cumberland County Site 1



Note volatilization losses were higher in this site than previously presented sites. The at-planting application was injected, so calculated volatilization losses may not be from the fertilizer application.

This site had a clover, annual ryegrass, wheat and radish multi-species cover crop established in August of 2020, followed by a manure application in October. This is the “Multi-Species Grass Dominant” scenario presented in Part B of this report. A picture of the cover crop is shown below.

Notice the soil nitrate sample results in the field. It is much higher than anticipated for a cover cropped field

Mass Balance vs. the Model: Cumberland County Site 1

	Mass Balance	Granular Nitrogen Model
Pre Season Nitrate Soil Test	NA	40 lbs N/ac (Sampled on: 5/10/21)
Yield Goal	175 bu/ac	175 bu/ac
Manure Applications	4000 gal hog early fall	4000 gal Hog 10/1/20
Available N from manure	47 lbs N/ac	(41) lbs N/ac
Residual Manure N	20 lbs N/ac	0 lbs N/ac
Residual Legume N	60 lbs N/ac*	0 lbs N/ac
At Planting	60 lbs N/ac	60 lbs N/ac 5/10/21
Pop up/in-furrow	0 lbs N/ac	0 lbs N/ac
Pre-Emerge	0 lbs N/ac	0 lbs N/ac
Side-dress	0 lbs N/ac	50 lbs N/ac 6/10/21
Total Applied N	187 lbs N/ac	150 lbs N/ac
Pre-Harvest Field Measured Yield	140 bu/a	197 bu/a
Calculated Nitrogen Use Efficiency	1.34 lbs N/bu	0.76 lbs N/bu
Precip 10/1/2020 - 10/1/2021		46 inches
Precip Planting - 10/1/2021		19 inches

*Expected clover cover crop residual

The model recommended an additional 50 lbs of nitrogen at sidedress compared to the mass balance calculation. The result was significant yield increases. Part of the reason for this difference was the cover crop outcome. The operator had planned a clover dominant mix to provide nitrogen. Seeding ratios were mixed up and the site became dominated by annual ryegrass that probably led to immobilization issues.

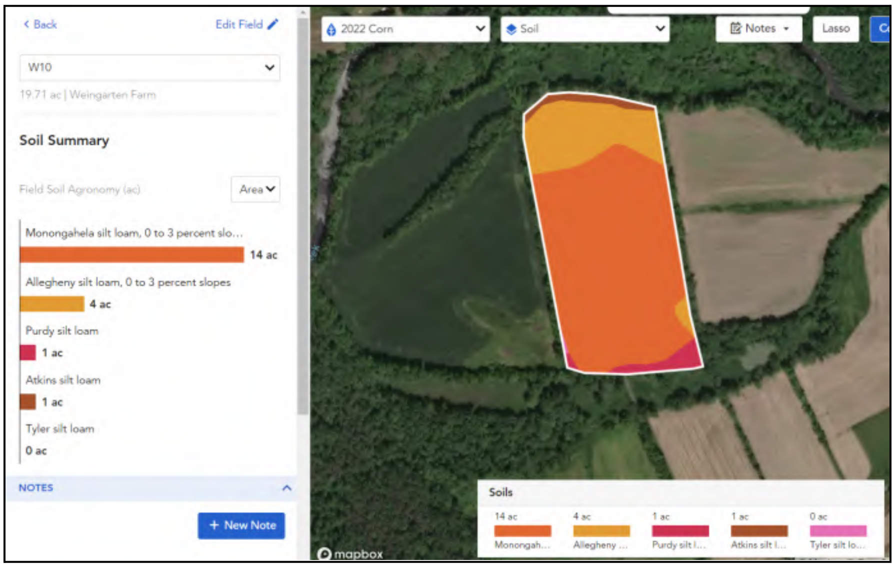
The increase of yield by 57 bushels resulted in additional phosphorus removal of 22.8 lbs/acre

Cumberland County Site 2 - 19.71 Acres

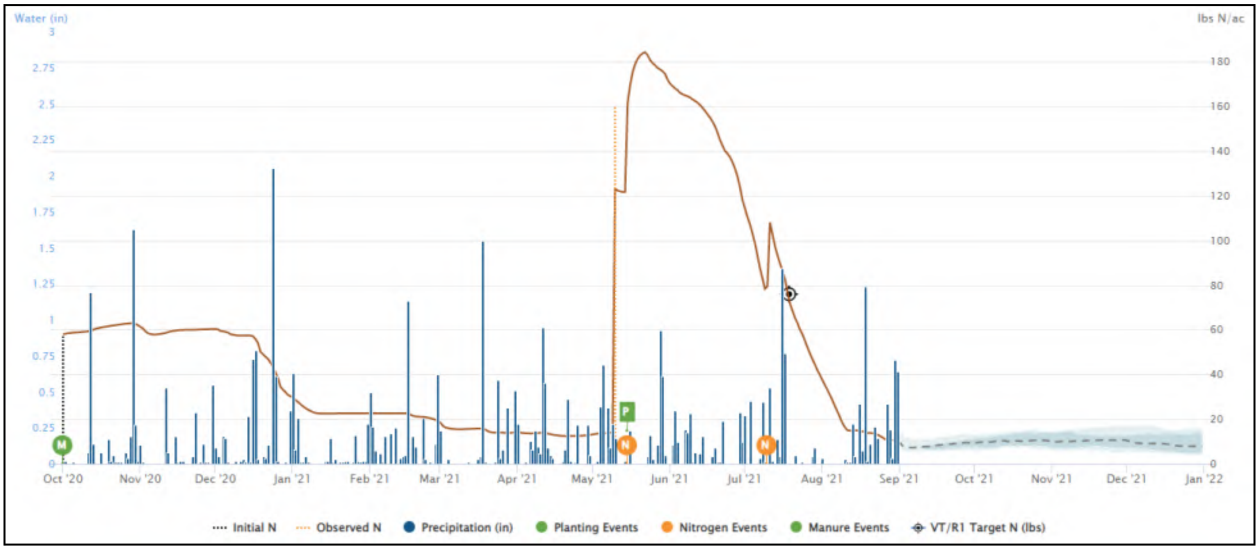
Dominant Soil Type: Monogahela silt loam, 0 to 3 percent slopes
Soil Health Practices In Place: Continuous No-Till, Multi-Species Cover Crop, Green Planting

Cumberland County Sites 1 & 2 are at the same hog farm. The farm implements a 2-year corn and wheat/multi-species cover crop rotation and applied hog manure to the cover crop in fall. Site 1 is a Tyler Silt Loam while Site 2 is a Monongahela Silt Loam.

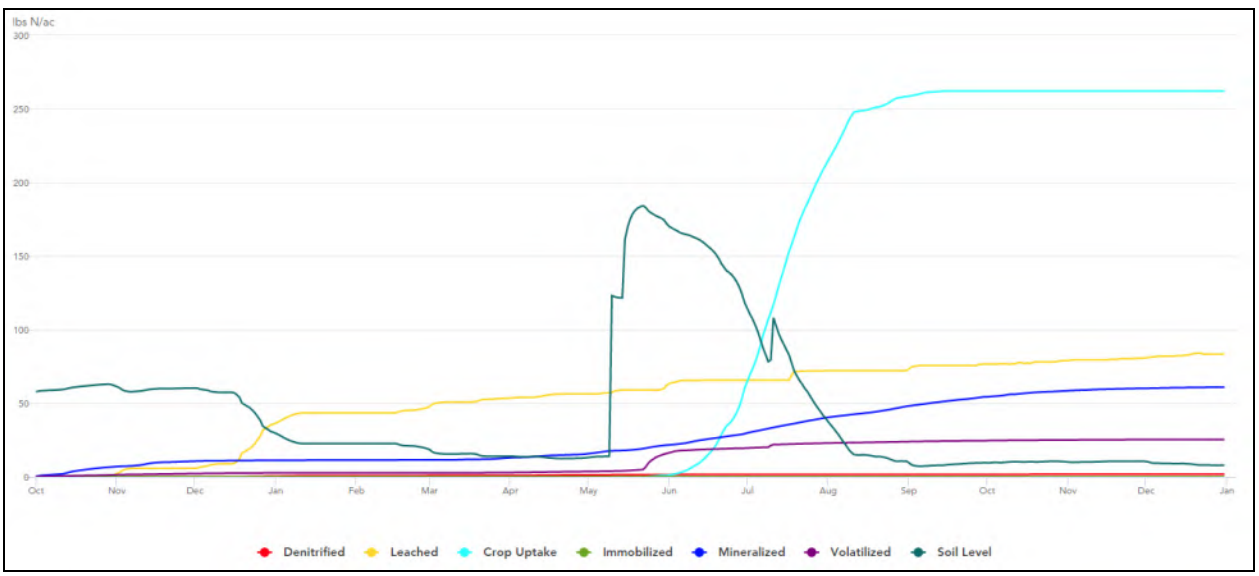
Soils Map: Cumberland County Site 2



Events & Nitrogen Availability: Cumberland County Site 2



Nitrogen Loss vs Contribution vs Uptake: Cumberland County Site 2



Note volatilization losses were higher in this site than previously presented sites. The at-planting application was injected, so calculated volatilization losses may not be from the fertilizer application.

Mass Balance vs. the Model: Cumberland County Site 2

	Mass Balance	Granular Nitrogen Model
Pre Season Nitrate Soil Test	NA	66 lbs N/ac (Sampled on: 5/10/21)
Yield Goal	175 bu/ac	175 bu/ac
Manure Applications	4000 gal hog early fall	4000 gal Hog 10/1/20
Available N from manure	47 lbs N/ac	(41) lbs N/ac
Residual Manure N	20 lbs N/ac	0 lbs N/ac
Residual Legume N	60 lbs N/ac*	0 lbs N/ac
At Planting	60 lbs N/ac	60 lbs N/ac
Pop up/in-furrow	0 lbs N/ac	0 lbs N/ac
Pre-Emerge	0 lbs N/ac	0 lbs N/ac
Side-dress	0 lbs N/ac	50 lbs N/ac
Total Applied N	187 lbs N/ac	176 lbs N/ac
Pre-Harvest Field Measured Yield	146 bu/a	187 bu/a
Calculated Nitrogen Use Efficiency	1.26 lbs N/bu	0.94 lbs N/bu
Precip 10/1/2020 - 10/1/2021		46 inches
Precip Planting - 10/1/2021		19 inches

*Expected clover cover crop residual

The model recommended an additional 50 lbs of nitrogen at sidedress compared to the mass balance calculation. The result was significant yield increases. Part of the reason for this difference was the cover crop outcome. The operator had planned a clover dominant mix to provide nitrogen. Seeding ratios were mixed up and the site became dominated by annual ryegrass that probably led to immobilization issues.

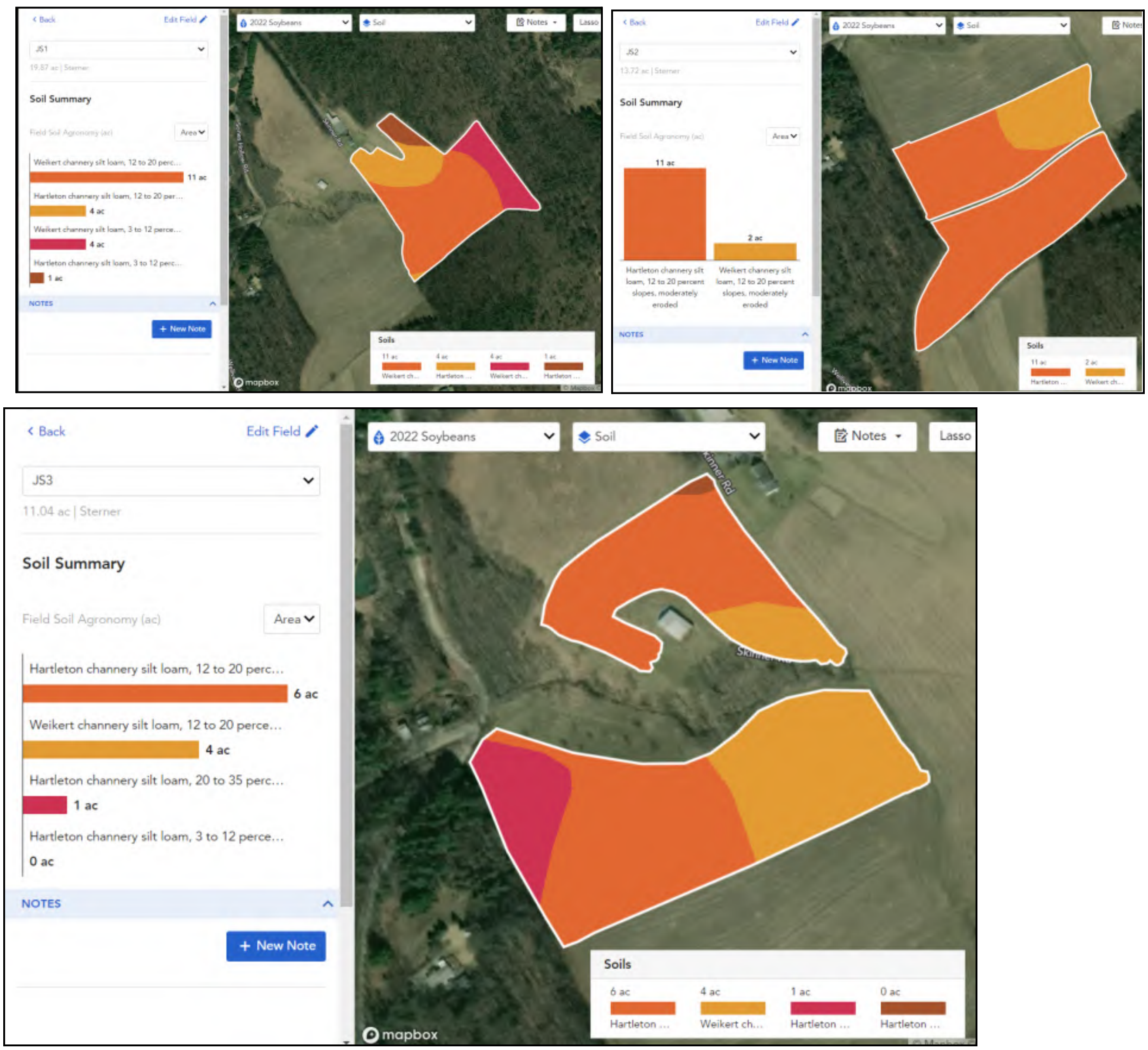
The increase of yield by 41 bushels resulted in additional phosphorus removal of 16.4 lbs/acre.

Columbia County Site 1 - 44.63 Acres

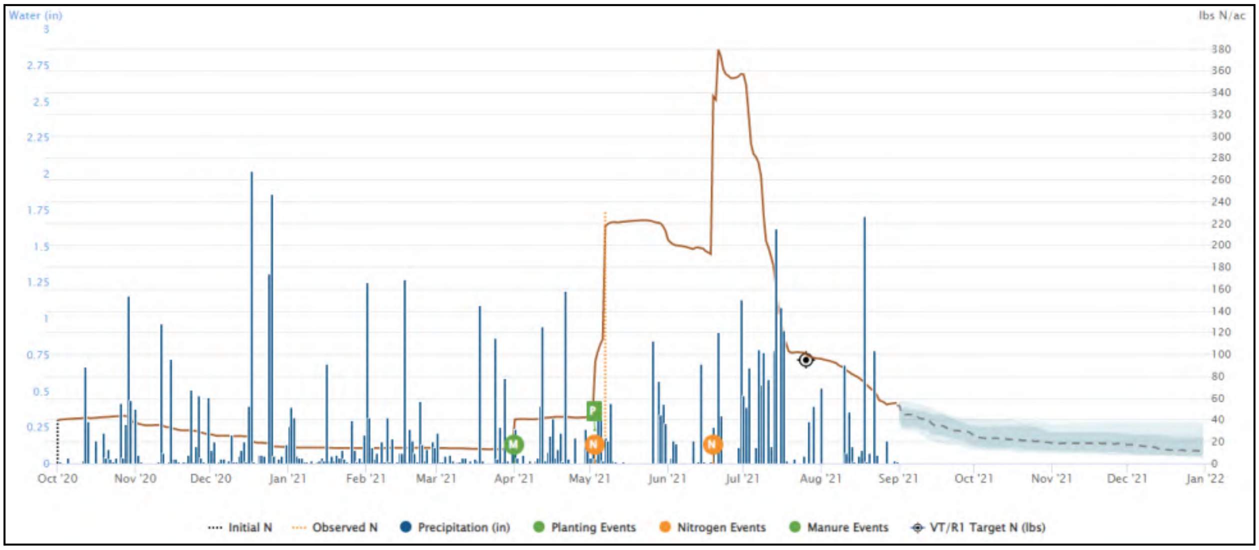
Dominant Soil Types: Weikert Channery Silt Loam, 12 to 20 percent slopes
Hartleton channery silt loam, 12 to 20 percent slopes
Soil Health Practices In Place: Continuous No-Till, Multi-Species Cover Crop, Green Planting

This is a cash grain farm that imports poultry litter to offset phosphorus and potassium needs. They have enough yield data on the farm to develop multi-year analysis yield zones and soil test those yield zones for variable rate fertilizer applications. They implement a 2-3 year rotation that includes multi-species cover crops following wheat and dominant grass covers following corn and soybeans.

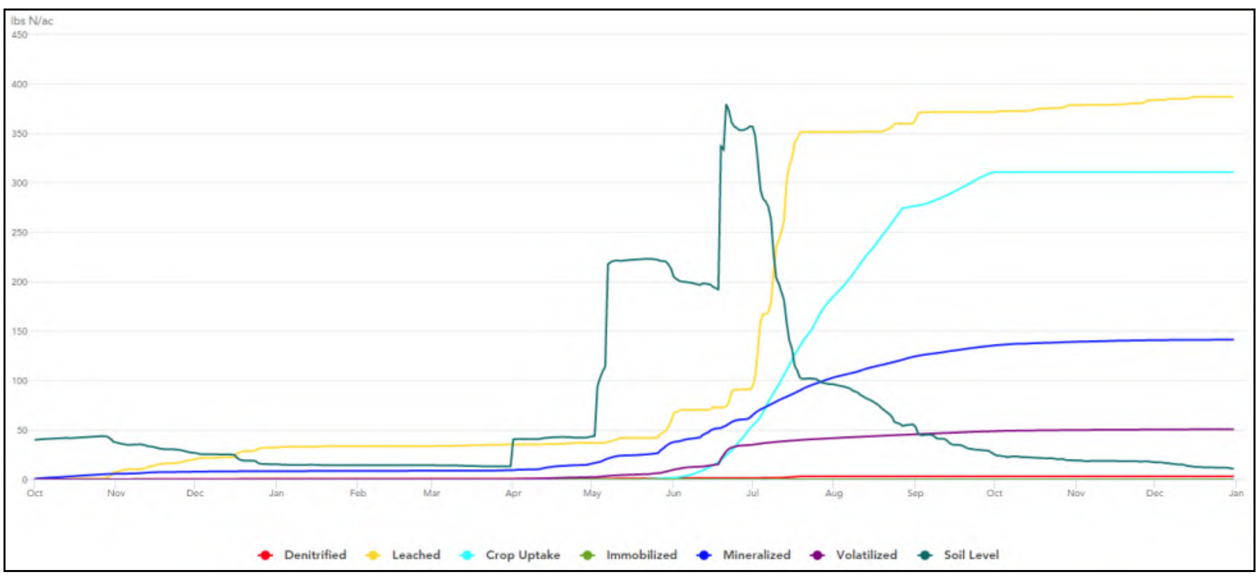
Soils Maps: Columbia County Site 1



Events & Nitrogen Availability: Columbia County Site 1



Nitrogen Loss vs Contribution vs Uptake: Columbia County Site 1



This site was unique in the project for the amount of rainfall received after the initial sidedress application. The initial modeled sidedress recommendation was for 60 lbs to be applied. This application was made on June 23rd. Notice the heavy rainfalls occurring in the field following the sidedress application (top graph), and the corresponding increase in leached nitrate (lower graph). The Granular model calculated around 200 lbs of nitrate leaching per acre! Following the multiple rain events in early July the model recalculated nitrogen needs and prescribed an additional recommendation of 140 lbs to replace the leached nitrogen. The producer did not believe the model and did not have equipment to sidedress tall corn.

Mass Balance vs. the Model: Columbia County Site 1

	Mass Balance	**Granular Nitrogen Model**
Pre Season Nitrate Soil Test	NA	80 lbs N/ac (Sampled on: 5/7/21)
Yield Goal	220 bu/ac	220 bu/ac
Manure Application	4.5 ton layer manure spring	4.5 ton layer manure 4-21
Available N from manure	98 lbs N/ac	(90) lbs N/ac
Residual Manure N	0 lbs N/ac	0 lbs N/ac
Residual Legume N	30 lbs N/ac*	0 lbs N/ac
At Planting	75 lbs N/ac	75 lbs N/ac 5/8/21
Pop up/in-furrow	0 lbs N/ac	0 lbs N/ac
Pre-Emerge	0 lbs N/ac	0 lbs N/ac
Side-dress	0 lbs N/ac	60 lbs N/ac** 6/23/21
Total Applied N	203 lbs N/ac	215 lbs N/ac
Pre-Harvest Field Measured Yield	185.5 bu/a	205 bu/a
Calculated Nitrogen Use Efficiency	1.09 lbs N/bu	1.05 lbs N/bu
Precip 10/1/2020 - 10/1/2021		58 inches
Precip Planting - 10/1/2021		26 inches

*soybean legume contribution

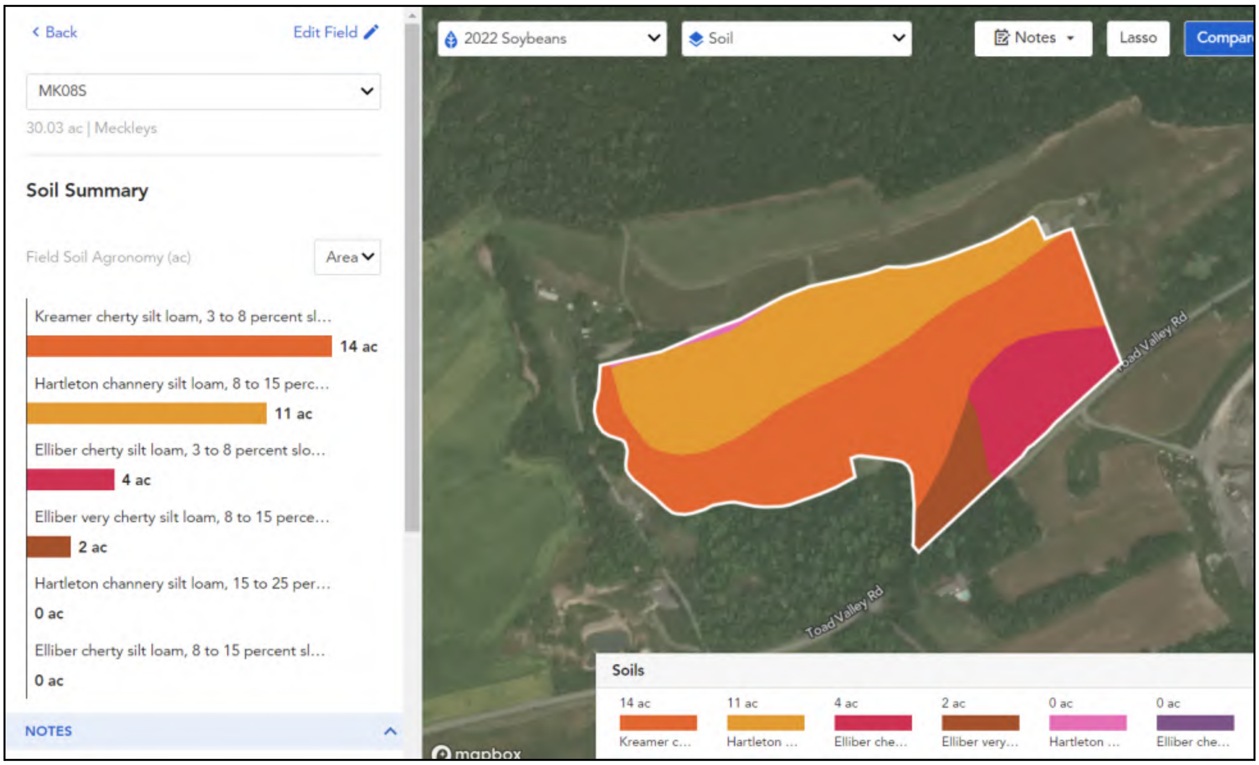
**GCM calculation was for 60+140 lbs of side-dress nitrogen. Producer did not believe the model and only side-dressed 60 lbs

Northumberland County Site 1 - 30.03 Acres

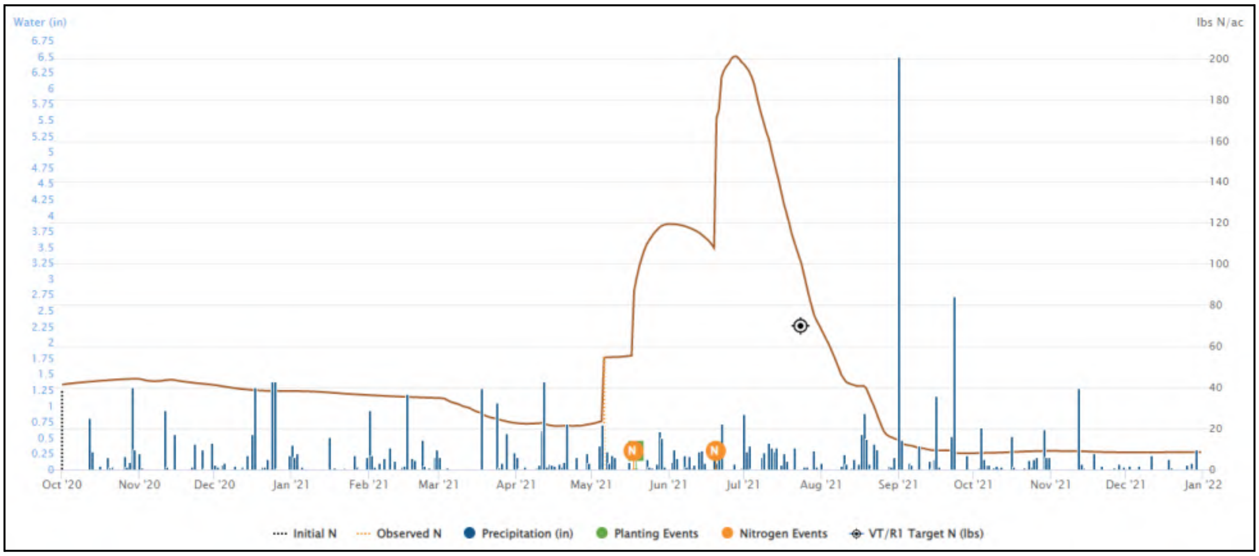
Dominant Soil Types: Kreamer cherty silt loam, 3 to 8 percent slopes
Hartleton channery silt loam, 8 to 15 percent slopes
Soil Health Practices In Place: Continuous No-Till

This farm is a hog farm with an 1,800 acre land base. Manure is applied to this tract to address phosphorus and potassium needs. No manure was applied during the 2021 crop year. The operation implements a 2-3 year rotation of corn, soybeans and wheat.

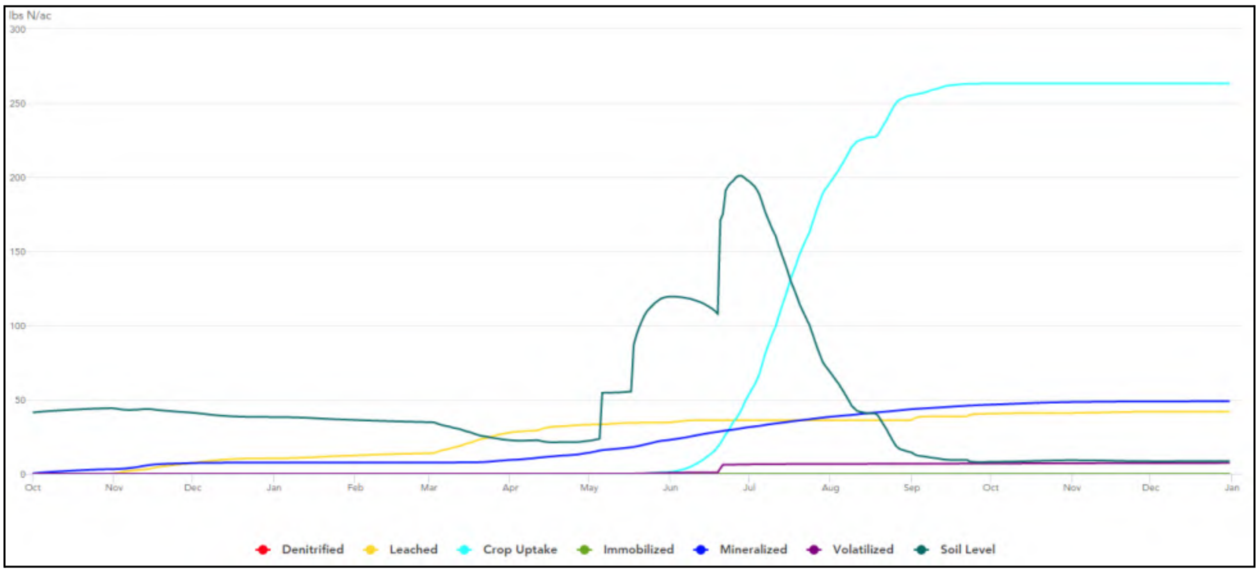
Soils Map: Northumberland County Site 1



Events & Nitrogen Availability: Northumberland County Site 1



Nitrogen Loss vs Contribution vs Uptake: Northumberland County Site 1



Mass Balance vs. the Model: Northumberland County Site 1

	Mass Balance	**Granular Nitrogen Model**
Pre Season Nitrate	NA	56 lbs N/ac (Sampled on: 5/6/21)
Yield Goal	220 bu/ac	220 bu/ac
Manure Applications		
Available N from manure	0 lbs N/ac	0 lbs N/ac
Residual Manure N	7 lbs N/ac	0 lbs N/ac
Residual Legume N	50 lbs N/ac*	0 lbs N/ac
At Planting	60 lbs N/ac	60 lbs N/ac 5/10/21
Pop up/in-furrow	0 lbs N/ac	0 lbs N/ac
Pre-Emerge	0 lbs N/ac	0 lbs N/ac
Side-dress	100 lbs N/ac	134 lbs N/ac 6/21/21
Total Applied N	217 lbs N/ac	250 lbs N/ac
Pre-Harvest Field Measured Yield	168 bu/a	173 bu/a
Calculated Nitrogen Use Efficiency	1.29 lbs N/bu	1.45 lbs N/bu
Precip 10/1/2020 - 10/1/2021		61 inches
Precip Planting - 10/1/2021		32 inches

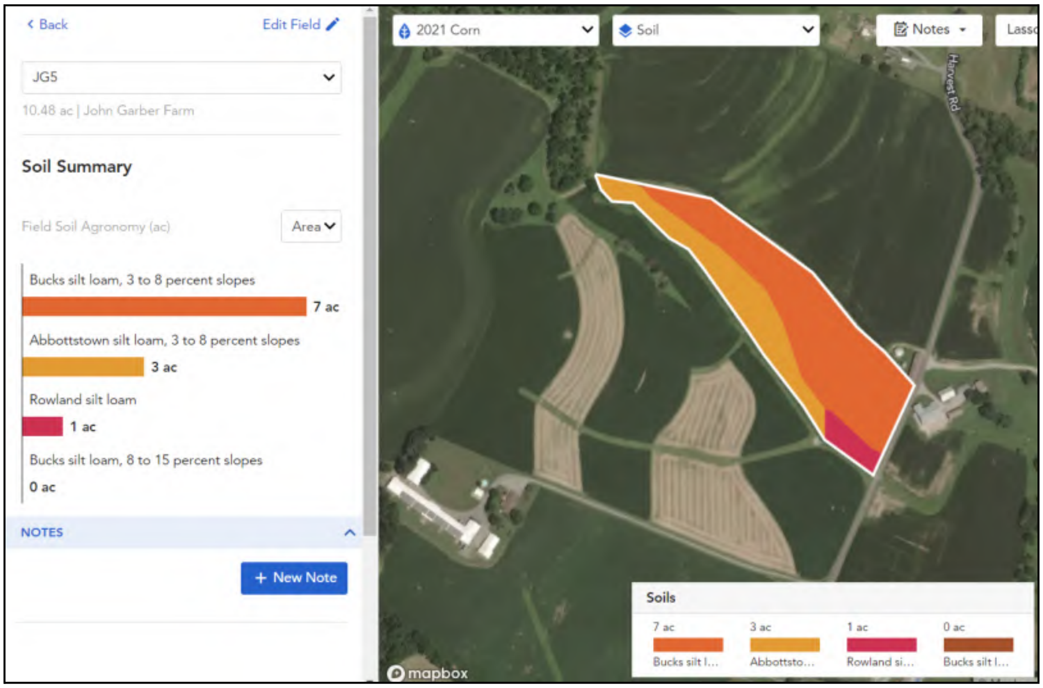
*soybean legume contribution

Lancaster County Site 1 - 10.48 Acres

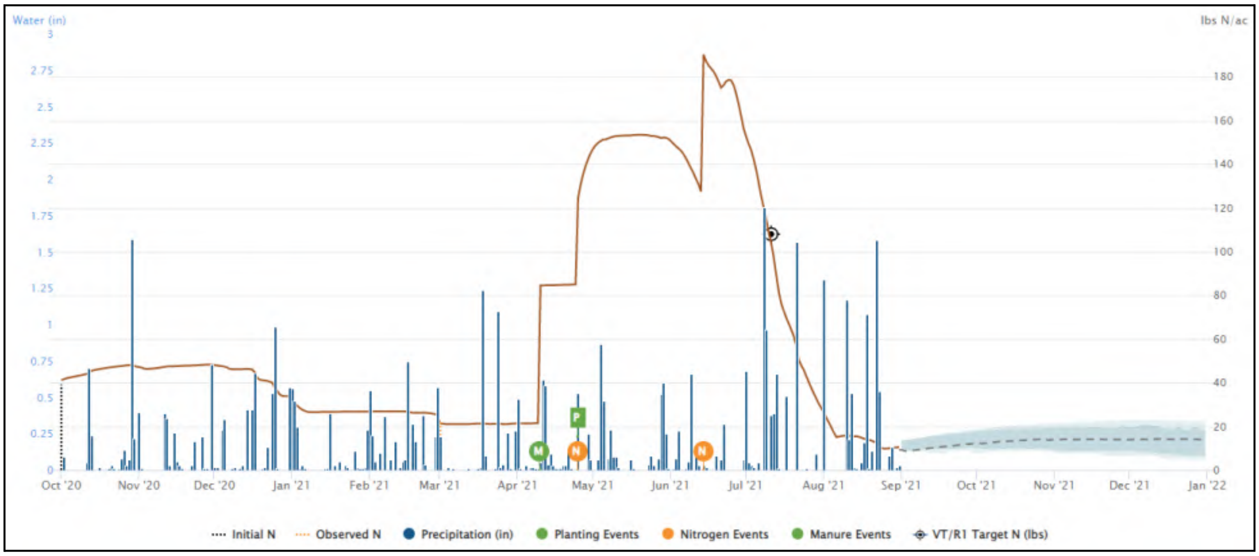
Dominant Soil Type: Bucks silt loam, 3 to 8 percent slopes
Soil Health Practices In Place: Continuous No-till, Cover Crop, Green Planting

This farm is a poultry and hog operation that utilizes the hog manure on site in its 2-3 year rotation of corn, soybean, and wheat. Cover Crops are established after corn and soybeans.

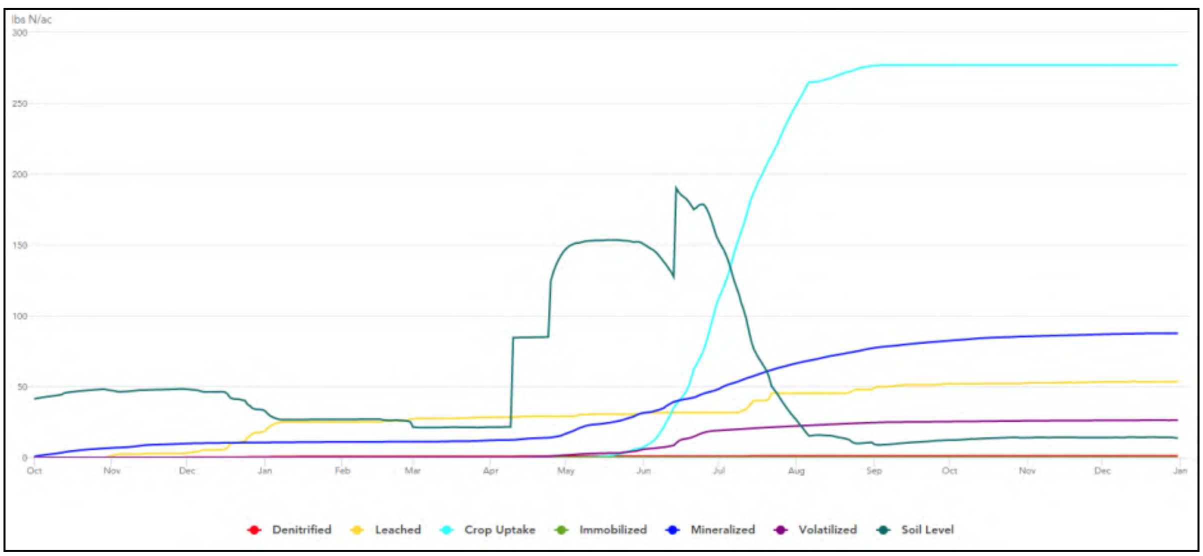
Soils Map: Lancaster County Site 1



Events & Nitrogen Availability: Lancaster County Site 1



Nitrogen Loss vs Contribution vs Uptake: Lancaster County Site 1



This site is the “Small Grain Vegetative” scenario presented in Part B of the report. See picture (at right) of the cover crop. The model is calculating leaching losses in the December timeframe that probably assume no cover crop is present. July leaching correlates to July rainfall events.

Mass Balance vs. the Model: Lancaster County Site 1

	Mass Balance	**Granular Nitrogen Model**
Pre Season Nitrate Soil Test	NA	32 lbs N/ac Sampled on: 4/30/21
Yield Goal	220 bu/ac	220 bu/ac
Manure Application	4000 gal hog surface applied spring	4000 gal hog surface applied 4/10/21
Available N from manure	74 lbs N/ac	(72) lbs N/ac
Residual Manure N	20 lbs N/ac	0 lbs N/ac
Residual Legume N	45 lbs N/ac*	0 lbs N/ac
At Planting	60 lbs N/ac	60 lbs N/ac 4/29/21
Pop up/in-furrow	0 lbs N/ac	0 lbs N/ac
Pre-Emerge	0 lbs N/ac	0 lbs N/ac
Side-dress	30 lbs N/ac	60 lbs N/ac 6/14/21
Total Applied N	229 lbs N/ac	152 lbs N/ac
Pre-Harvest Field Measured Yield	212 bu/a	221 bu/a
Calculated Nitrogen Use Efficiency	1.08 lbs N/bu	0.68 lbs N/bu
Precip 10/1/2020 - 10/1/2021		48 inches
Precip Planting - 10/1/2021		24 inches

*soybean legume contribution

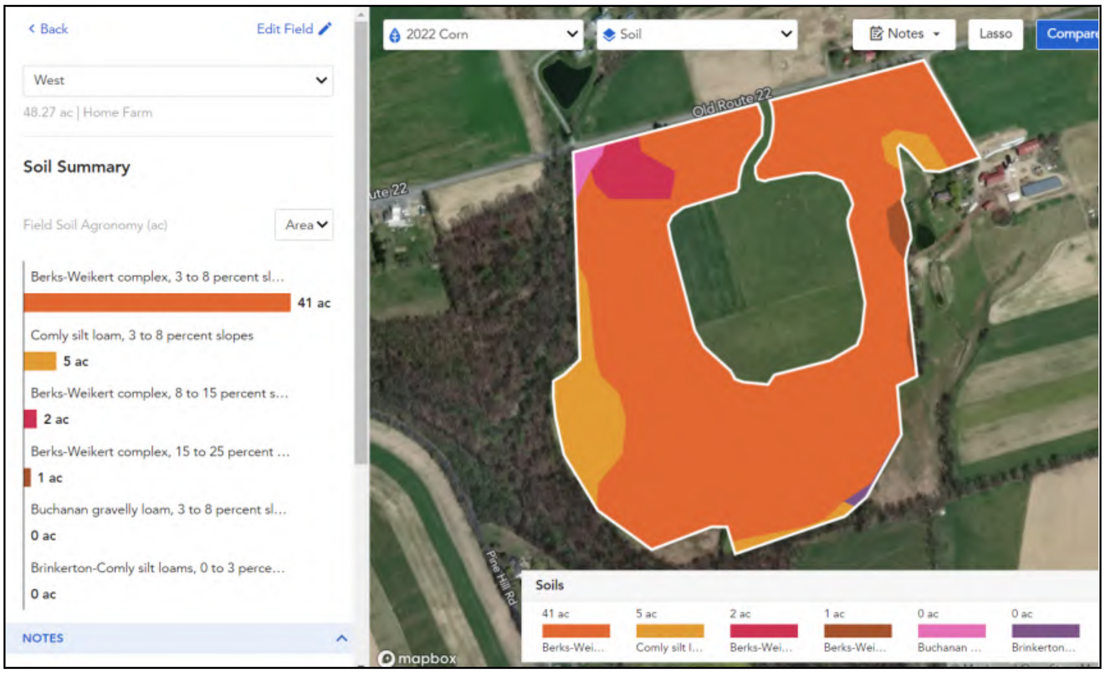
This site has done extensive cover cropping for many years. The pre-season soil nitrate sample results were lower than expected, and overall recommended nitrogen applications were lower with the model compared to the mass balance calculation. A yield response to increased sidedress rates indicates that immobilization was an issue in the cover cropped field. The lower overall nitrogen rate indicates that the model underestimated mineralized nitrogen for the site.

Berks County Site 3 - 48.27 Acres

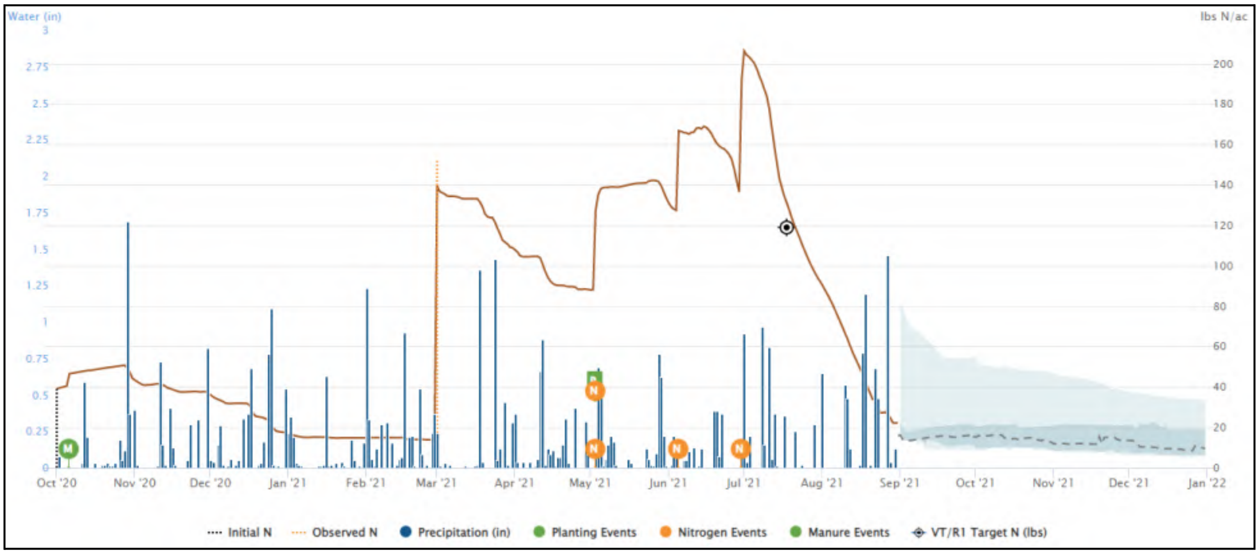
Dominant Soil Type: Berks-Weikert complex, 3 to 8 percent slopes
Soil Health Practices In Place: Continuous No-Till, Cover Crop

This is a cattle and poultry operation that utilizes a 2-year rotation of corn followed by small grain silage & soybeans. Cover crops are established after soybeans and manure is applied for most crops. The operation makes multiple passes across the field to “spoon feed” nutrients and has regularly achieved corn yields in excess of 275 bu/A over the past few years.

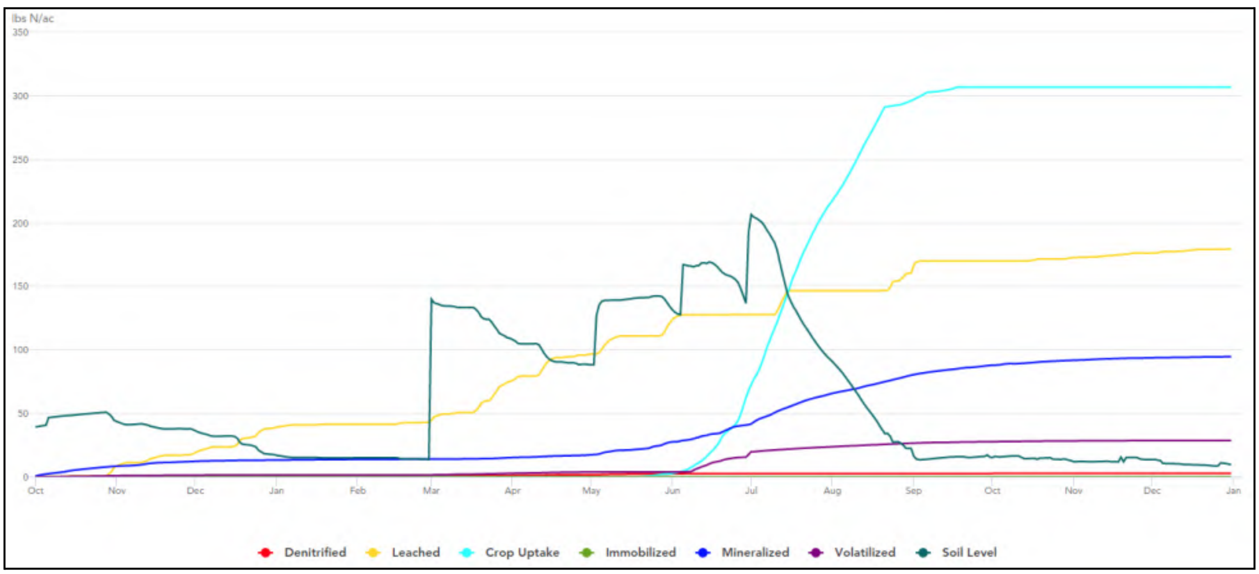
Soils Map: Berks County Site 3



Events & Nitrogen Availability: Berks County Site 3



Nitrogen Loss vs Contribution vs Uptake: Berks County Site 3



Notice the leaching losses in this field - they occur in early spring and throughout the early part of the growing season on a shaly soil with above average drainage. Multiple side-dress applications helped to overcome yield loss due to late season nitrogen deficiency.

Mass Balance vs. the Model: Berks County Site 3

	Mass Balance	**Granular Nitrogen Model**
Pre Season Nitrate Soil Test	NA	152 lbs N/ac (Sampled on: 3/1/21)
Yield Goal	275 bu/ac	275 bu/ac
Manure Applications	7000 gal heifer slurry early fall	7000 gal heifer slurry 10/1/21
Available N from manure	30 lbs N/ac	(9) lbs N/ac
Residual Manure N	24 lbs N/ac	0 lbs N/ac
Residual Legume N	55 lbs N/ac*	0 lbs N/ac
At Planting	60 lbs N/ac	60 lbs N/ac 5/1/21
Pop up/in-furrow	1 lbs N/ac	1 lbs N/ac 5/1/21
Pre-Emerge	0 lbs N/ac	0 lbs N/ac
Side-dress	110 lbs N/ac	60 + 60 lbs N/ac 6/5/21 + 6/29/21
Total Applied N	280 lbs N/ac	333 lbs N/ac
Pre-Harvest Field Measured Yield	218 bu/a	272 bu/a
Calculated Nitrogen Use Efficiency	1.28 lbs N/bu	1.22 lbs N/bu
Precip 10/1/2020 - 10/1/2021		49 inches
Precip Planting - 10/1/2021		22 inches

*soybean legume contribution

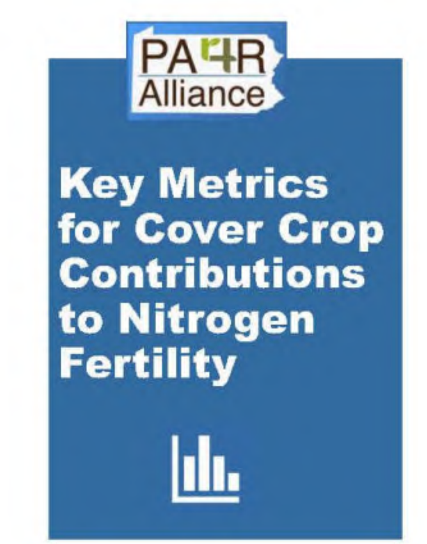
The soil nitrate sample was very high for this site, indicating a large reserve of convertible soil nitrogen present in the field. This matches with the high levels of calculated leaching for the field even though fertilizer applications were not excessive and stabilizers were used in each application. The site responded to late season nitrogen applications to provide additional nitrogen during the grain fill period.

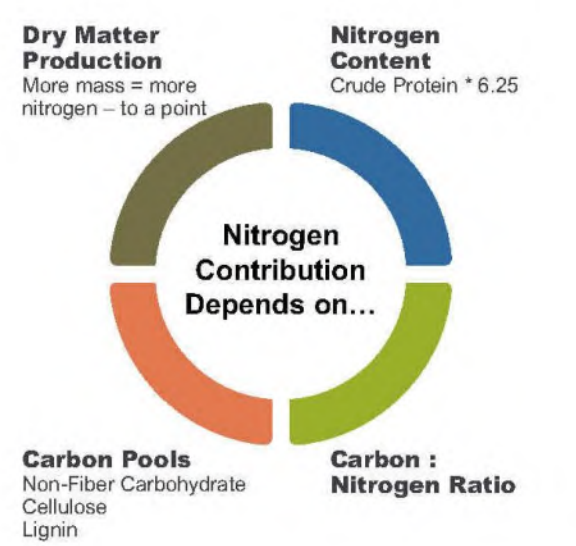
Part B: Cover Crop Quantification

The Use of Crop Models to predict Cover Crop Contributions to Nitrogen Fertility

Methodology for this CIG project included measuring both cover crop and soil parameters useful for quantifying soil health contributions to fertility. Fourteen of the participating farms implemented continuous no-till + annual unharvested cover crop, allowing direct measurements of cover crop characteristics and site specific modeling of nitrogen mineralization from the cover crop. Twenty fields were chosen from the 14 cooperators. Locations within each field were determined using remote sensing plant health imagery. Cover crop biomass was hand harvested & weighed, while nutrient concentration as well as forage characteristics were measured through lab analysis. Collected information was then entered into the Granular Crop Model and modeled using site specific soil & site specific weather data. The average nitrogen contribution of the mineralized cover crop was calculated.

Cover crop contributions to nitrogen fertility will be site specific, influenced by manure & fertilizer management, soil type, precipitation, accumulated growing degree days prior to termination, planting date, seeding rate and species selection. While higher biomass generally produces more nitrogen, availability of nitrogen is closely tied to the carbon pools present in the biomass and the overall carbon:nitrogen ratio. Covers with high non-fiber carbohydrates will cycle nitrogen quicker than covers with high lignin. Farm management of cover crops is highly influential in determining nitrogen contributions.





Most fields measured in this project fit into the following categories – small grain terminated in vegetative stage, small grain terminated after heading, multi-species dominant legume, multi-species dominant grass. There were a handful of sites planted more than one month past the optimal planting date for the chosen cover crop species and were considered a separate "later planting" category. Examples of each category are presented below.

Nutrient Uptake by Cover Crops in Selected Sites

Measured nutrient uptake from participating sites. Total uptake was calculated by in-field measurements of biomass production and lab analysis of collected biomass. All numbers are reported in lbs/acre.

Operation/Farm/Field	Nitrogen	Phosphorus (P_2O_5)	Potassium (K_2O)	Calcium	Magnesium
Small Grain Vegetative (Lancaster County)	118.2	56.8	233.4	12.9	6.5
Small Grain Heading (Adams County)	118.3	44.1	236.3	13	4.2
Small Grain Late Planting (Franklin County)	26.5	10.2	56.3	5.2	1.4
Multi-Species Dominant Grass (Cumberland County)	164.7	54.5	274.1	42.4	10.3
Multi Species Dominant Legume (Columbia County)	105.5	31.3	140.2	30.1	9
Multi Species Late Planting (Northumberland County)	53	12.7	64.1	4.5	1.7

It is important to remember that total nitrogen uptake does not equal total nitrogen availability. Availability of cover crop generated nitrogen will be based on cover crop carbon pools, soil moisture, soil temperature, soil microbial activity, and time. Also, mineralized nitrogen from cover crops are exposed to many of the same nitrogen loss pathways as fertilizer and manure - leaching, immobilization, denitrification, etc..

Simulated Mineralization from Above Ground Cover Crop Biomass

Cover Crop nitrogen mineralization simulated using the Granular Crop Model. Values were generated using site specific soils data + site specific weather data. The numbers below are the calculated average annual contribution over that period. Forage analysis details: DM=Dry Matter, N=Nitrogen, NFC=Non-Fiber Carbohydrate, CP=Crude Protein.

Operation/Farm/Field	Total Biomass (lbs/ac)	Forage Analysis Details	Nitrogen mineralized from cover crop by:		
			Tassel Emergence	Black Layer	End of Year
Small Grain Vegetative (Lancaster County)	4,959	High N High NFC	42.7	52.6	58.8
Small Grain Heading (Adams County)	5,206	High N Low NFC	33.2	45	52.4
Small Grain Late Planting (Franklin County)	1,535	Lowest CP	8.3	10.8	12.3
Multi-Species Dominant Grass (Cumberland County)	5,171	High DM Low NFC	47.8	63.9	74
Multi Species Dominant Legume (Columbia County)	4,708	High DM High N High NFC	36.8	46.3	52
Multi Species Late Planting (Northumberland County)	2,136	Low DM Low CP High NFC	18.1	22.9	25.8

This chart shows cumulative nitrogen mineralization. The Small Grain Vegetative - Lancaster County site mineralized 42.7 lbs of nitrogen from the above ground portions of the cover crop by tassel emergence. It mineralized another 9.9 lbs of nitrogen between tassel and black layer (total of 52.6 lbs), and another 6.2 lbs of nitrogen between black layer and the end of the calendar year (total of 58.8 lbs). Tassel emergence and black layer are two important growth stages in corn development. By tassel, around 75% of the total nitrogen needed by the plant has been taken into the plant. All of the cover crop nitrogen mineralized by this growth stage can contribute to corn yield. Between tassel and black layer corn plants slowly lose the ability to uptake nitrogen as the plant cannabilizes biomass (including roots) to transfer carbohydrate into grain. When the plant achieves black layer, carbohydrate transfer to grain stops and no additional nitrogen from the soil will contribute to yield. Cover crop nitrogen mineralized between tassel and black layer may partially contribute to yield. Any cover crop nitrogen mineralized after black layer has no contribution to yield. The Small Grain Vegetative - Lancaster County site averages 42.7 lbs of nitrogen per acre that can directly contribute to corn fertility and 16.1 lbs per acre that may mineralize too late for direct contribution to yield. This 16.1 lbs per acre has the same risk of leaching as over-applied fertilizer or manure if a cover crop is not established again after corn harvest.

Modeling Cover Crop Outcomes

The Granular Agronomy Nitrogen Service is constantly being updated with new features and functionality. The results from the CIG participants, as well as sites throughout the country, resulted in some changes in the Granular Nitrogen Modeling platform's ability to provide cover crop data. Here are some results from pre-release testing of a new version of the Granular Crop Model (V4.0.5) that highlight the potential benefits the new functionality can bring.

This exercise uses the "Small Grain Vegetative - Lancaster County" site as an example, using typical practices performed there, including manure and cover crops. The new model version allows for simulation of cover crop development and termination along with the regular corn crop. These features are expected to be released to the software for the 2022-23 growing season.

Example Field: Small Grain Vegetative - Lancaster County
Weather History: 2021-2022 weather through May 26, 2022, then 8 days forecast, then 2021 weather for the balance until December 31, 2022.
Soil Type: Lansdale loam, 3 to 8 percent slopes
Previous Crop: Corn, 160-200 bu/ac range, harvested on October 10, 2022
Tillage: No-Till
Seed & Fertilizer Applications:

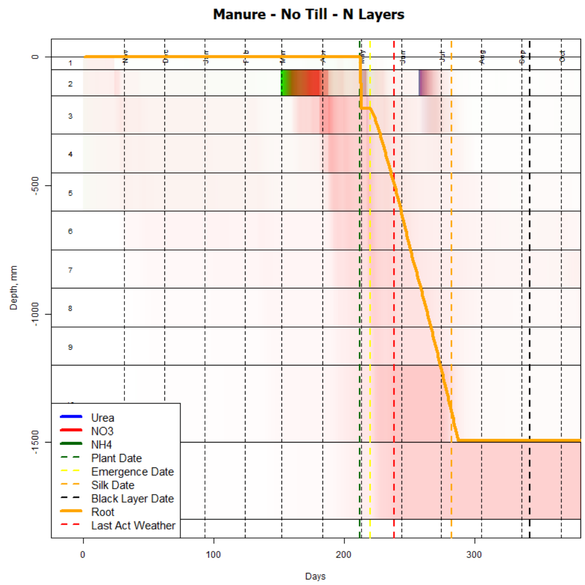
- 3000 gallons/ac of hog manure applied on March 1, 2022, injected at 4" depth, with an estimated 125 lbs N/ac of inorganic nitrogen and ~20 lbs N/ac as mineralizable organic nitrogen.
- 30 lbs N/ac as UAN injected at 4" depth on May 1, 2022 with no stabilizer. Corn is planted the same day - Pioneer P1185AM is planted at 32,000 seeds per acre.
- 90 lbs N/ac as UAN injected at 4" depth on June 15, 2022 with no stabilizer.

Variables

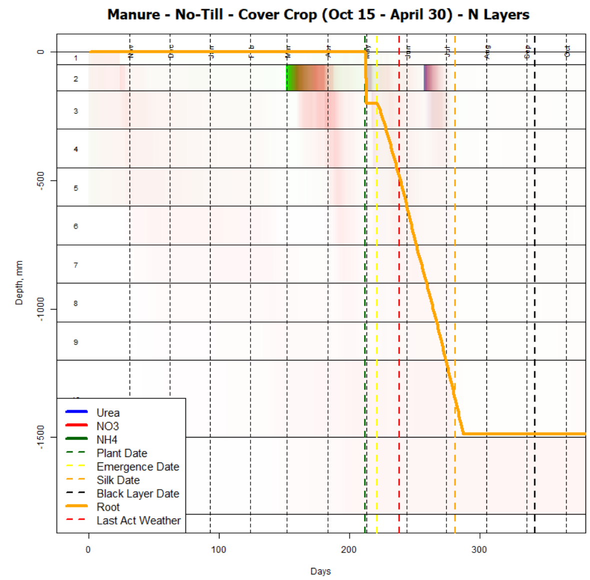
1. No Cover Crop
2. Cover Crop of cereal rye drilled on <u>October 15, 2021</u>, terminated on <u>April 30, 2022</u>
3. Cover Crop of cereal rye drilled on <u>October 15, 2021</u>, terminated on <u>April 15, 2022</u>
4. Cover Crop of cereal rye drilled on <u>November 15, 2021</u>, terminated on <u>April 30, 2022</u>

Nitrogen Forms & Concentration across Time and Soil Depth

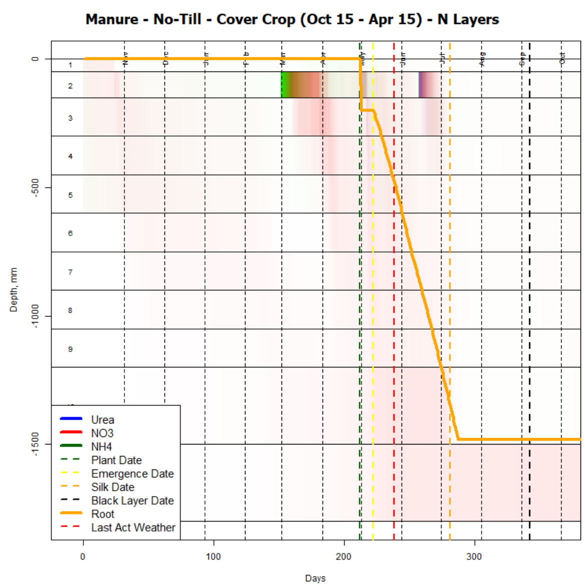
No Cover Crop



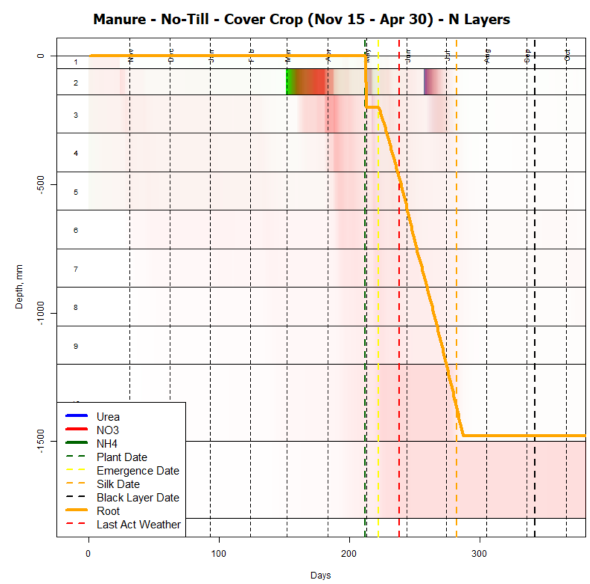
October 15 / April 30 Cover Crop



October 15 / April 15 Cover Crop



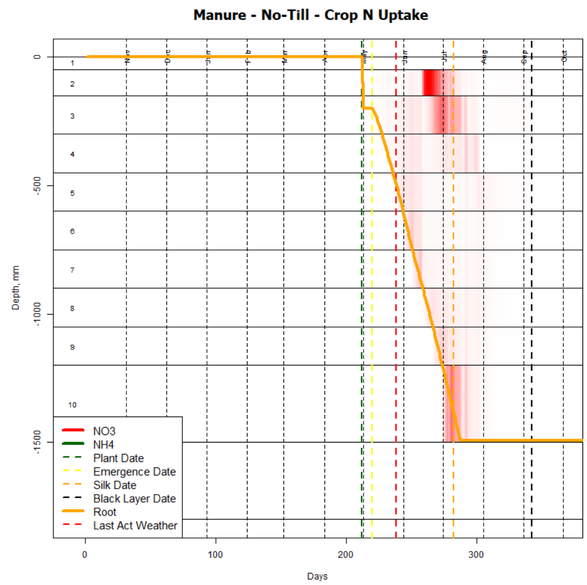
November 15 / April 30 Cover Crop



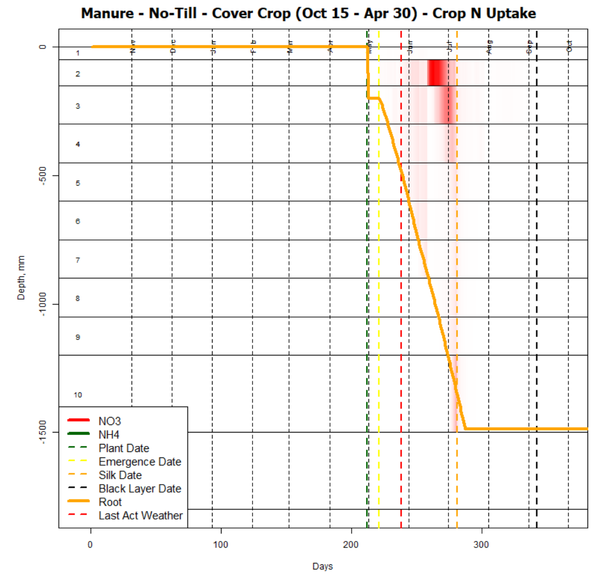
These graphs illustrate that without cover crops, nitrogen from the manure is quickly converted from ammonium to nitrate and starts to leach downward, with some of it residing just below the final rooting depth of the crop (orange line). With early seeded cover crops, nitrogen is captured before leaching, but delaying seeding of fall cover crops still allows nitrogen to leach into lower levels, similar to that of no cover crops.

Corn Crop Nitrogen Uptake across Time and Soil Depth

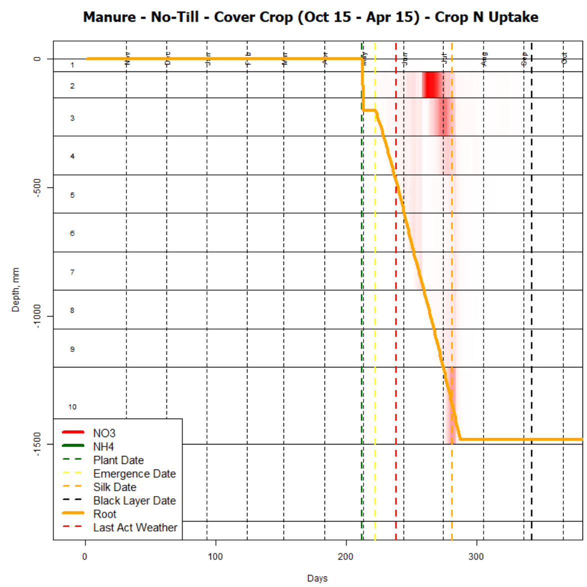
No Cover Crop



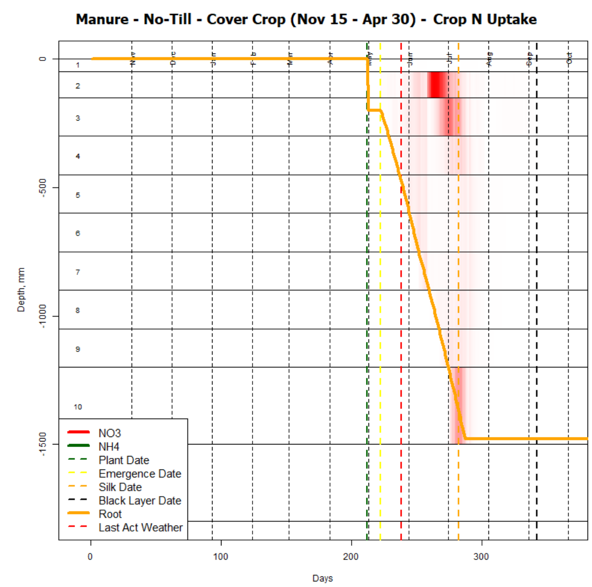
Cover Crop October 15 / April 30



Cover Crop October 15 / April 15



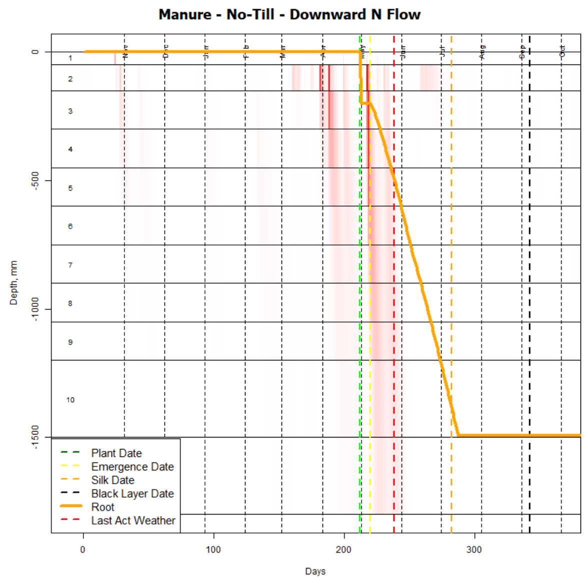
Cover Crop November 15 / April 30



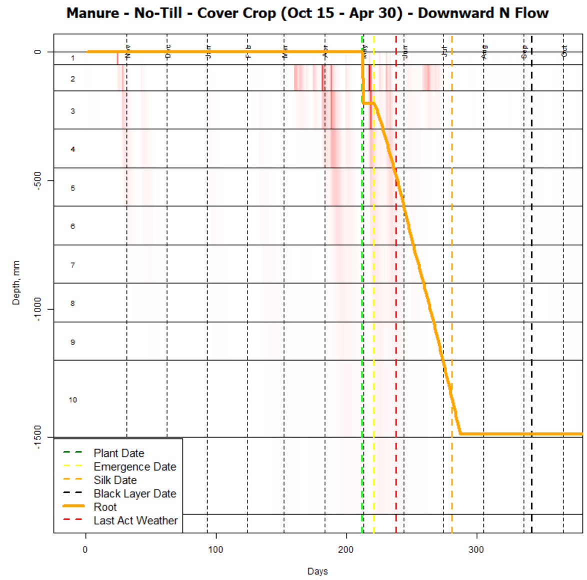
These graphs further show how the corn crop takes up nitrogen at various depths. Without cover crops (left) nitrogen is taken up across a wider range of depths, including at layer 10 (4 to 5 feet deep). With cover crops, crop N uptake is more focused on layers 2 and 3 (2 to 12 inches). Less nitrogen is exposed to loss with the rye cover crop.

Downward Nitrate Flow (Leaching) across Time and Soil Depth

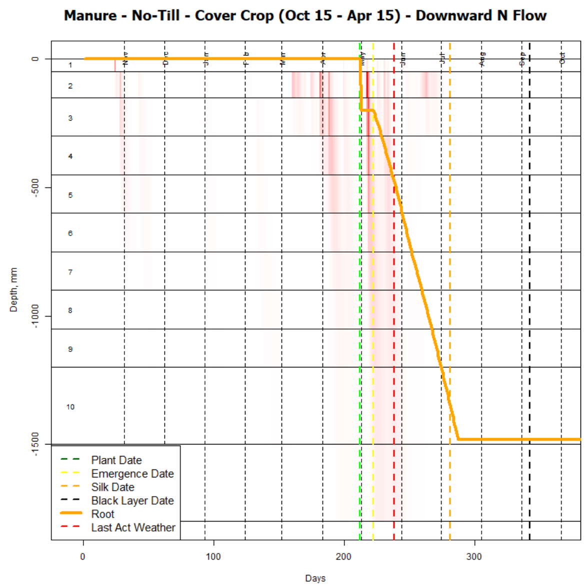
No Cover Crop



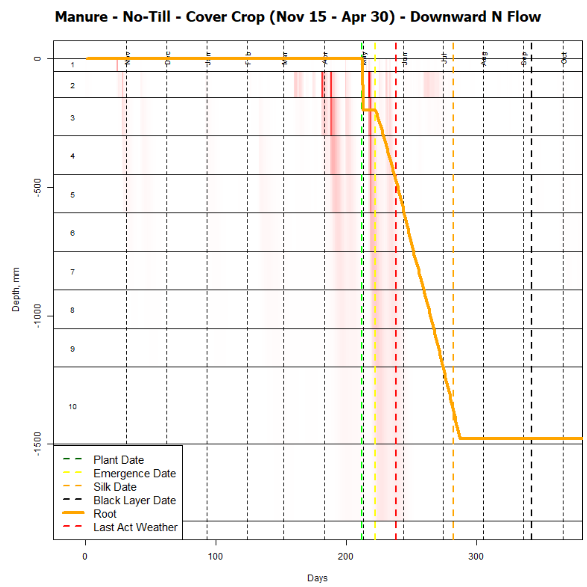
Cover Crop October 15 / April 30



Cover Crop October 15 / April 15



Cover Crop November 15 / April 30

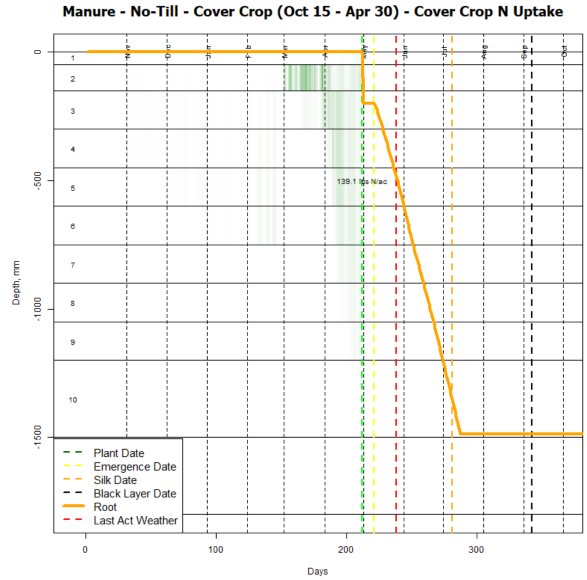


These graphs show the intensity of downward nitrogen flow based on treatment. Where no cover crop exists there is substantial downward nitrogen flow as nitrate, but with cover crops initiated in October and terminated in April there is significant reduction in downward nitrogen flow.

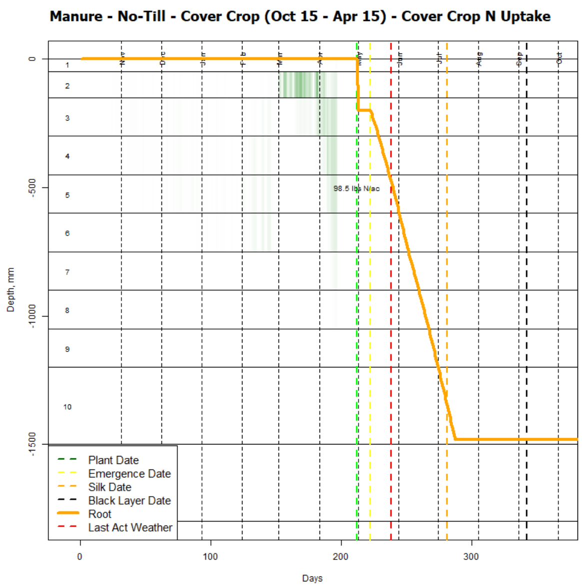
Cover Crop Dynamics - Nitrogen Uptake

No Cover Crop

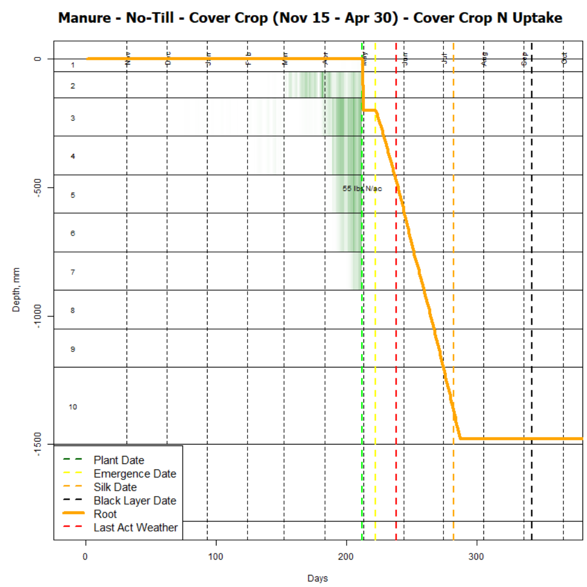
Cover Crop October 15 / April 30



Cover Crop October 15 / April 15



Cover Crop November 15 / April 30

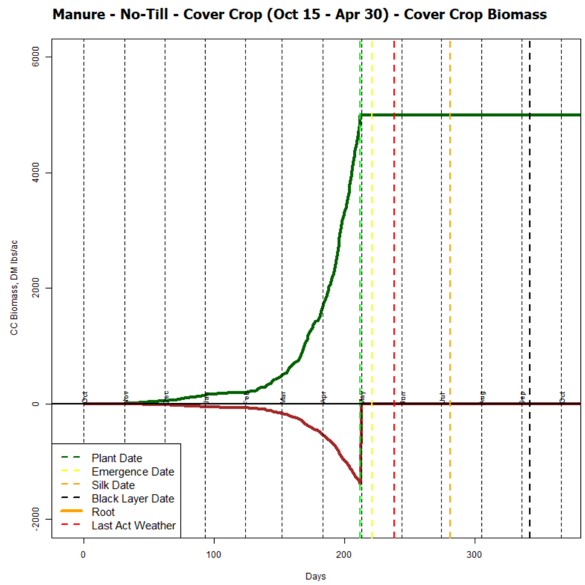


With early seeding and late termination, the model output shows that a large amount of nitrogen can be captured and taken up by the cover crops. With earlier termination, a reduction of about 40 lbs N/ac for 15 days is experienced. For later seeding and termination, however, nitrogen uptake is reduced and highly concentrated in April.

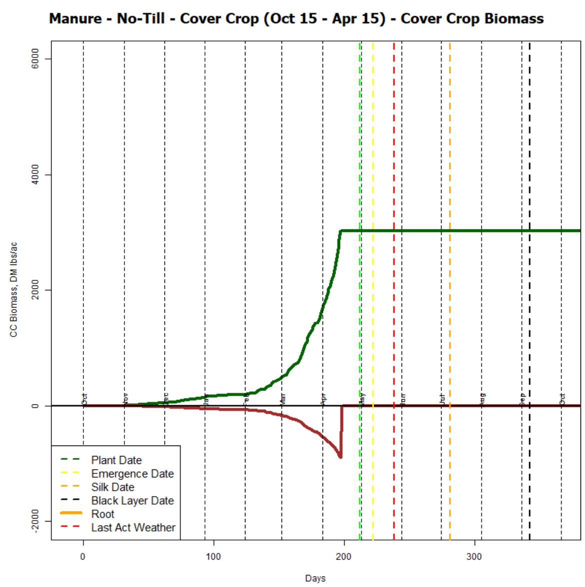
Cover Crop Dynamics - Biomass Development

No Cover Crop

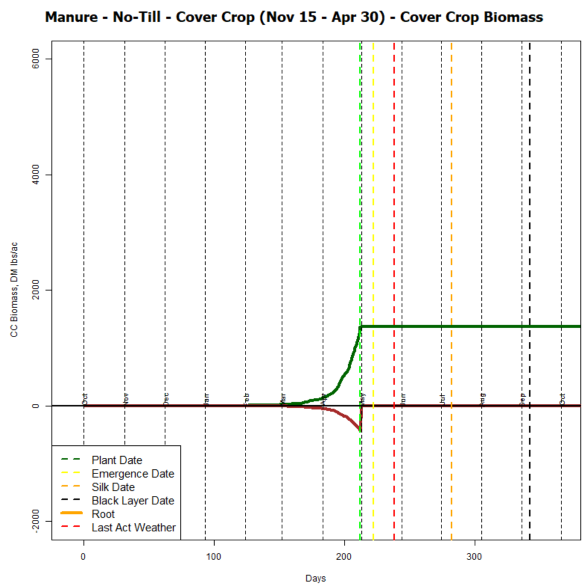
Cover Crop October 15 / April 30



Cover Crop October 15 / April 15



Cover Crop November 15 / April 30



Allowing the early seeded cover crop to grow right up until planting allowed for around 5,000 lbs/ac dry matter of above ground biomass to develop. Terminating it 15 days earlier allowed for 3,000 lbs/ac dry matter of development. Seeding and terminating later reduced the above ground biomass to less than 1,400 lbs/ac dry matter.

This illustrates how the crop model can be used to simulate different management strategies and the potential outcomes of them, including environmental ones.

Simulated Metrics	**No Cover Crop**	**October 15 / April 30 CC**	**October 15 / April 15 CC**	**November 15 / April 30 CC**
Yield, bu/ac	202.0	180.8	193.6	201.4
Plant N Uptake, lbs/ac	218.0	166.2	180.5	202.3
N leaching below 3 feet, lbs/ac	140.6	50.8	78.6	106.2
N leaching below 6 feet, lbs/ac	60.8	27.8	42.6	53.4
CC Biomass, above ground, DM lbs/ac	—	4,995	3,033	1,373
CC Biomass, below ground, DM lbs/ac		1,392	900	432
CC Nitrogen Uptake, lbs/ac		139	98.5	55

A goal of utilizing cover crops and terminating them at the proper time is to A) keep free nitrates from leaching and B) increasing the nitrogen (and potentially phosphorus) nutrient uptake upon mineralization of the cover crop. As seen here, moving the termination date of early seeded rye cover crop from April 30 back to April 15, in this simulation, increased yield by 14 bu/ac and crop N uptake by 14 lbs N/ac. Cover crop biomass was reduced by about 2,000 lbs/ac dry matter and cover crop N uptake by 41 lbs N/ac.

These simulations are examples of how a farmer, along with a trusted advisor, can utilize this modeling technology to simulate different management strategies with cover crops in order to maximize key metrics, whether they be yield, nutrient uptake, or reduction of nitrogen loss via leaching. Each field and year will be different, but by using these tools one should be able to dial in practices that work well generally across years and then dial in for particular years as they develop.

Using the same input values as before, but utilizing an Economic Optimum Nitrogen Rate (EONR) solver routine with the Granular Crop Model along with 20 years of prior weather history instead of the 2021 weather data, optimum nitrogen rates were determined for the June 15 application of UAN. Each year's weather was simulated individually, with the EONR of each determined. Then, an overall EONR rate was determined by selecting the median rate from among the 20 different outcomes.

$8.00 per bushel of corn and $1.00 per pound of N were used in the solving algorithm. This "solver" is currently being evaluated for inclusion not yet implemented into the Granular Nitrogen Management software.

Simulated Metrics	**No Cover Crop**	**October 15 / April 30 CC**	**October 15 / April 15 CC**	**November 15 / April 30 CC**
Economic Optimum Nitrogen Rate, lbs/ac	40	105	95	55
Median Crop N uptake, lbs N/ac	196.7	195.6	198.6	195.7

To achieve economic optimum yields with a full season of cover crops terminated on April 30, an additional 65 pounds of nitrogen was found to be required at late-vegetative side dressing vs no cover crop. This was reduced to 55 lbs N/ac of additional N required for early terminated cover crop, and only 15 lbs N/ac more for late seeded cover crops. This illustrates the balance that is required when using cover crops to capture free nitrogen and then release it in time for the crop to use it or apply more nitrogen than without the cover crop.

Part C: Project Review

The results of this project showed that the Granular Agronomy Nitrogen Service (GANS) product can perform at the same level as a mass balance calculation for provided farms with a recommended rate of nitrogen fertilizer to achieve the desired yield goal. This can be confirmed by a comparison of the end-of-year nitrogen use efficiency (NUE) numbers generated by each method.

The crop model also provided for new opportunities for in-field nitrogen management

1. Accounting for measured soil nitrate levels in the soil. Soil nitrate tests are not new, but the ability to incorporate a pre-season soil nitrate test into the model allowed for soil supplied nitrogen to be quantified. It was also a unique opportunity to talk to participants about soil health & historic management contributions to nitrogen fertility. Pre-season soil nitrate levels varied greatly among participants and were very site specific. It was generally higher on dairy farms with a long history of manure application.
2. Quantification of in-season nitrogen loss. Nitrogen loss occurs throughout the year and can be equally impactful on manure nitrogen, fertilizer nitrogen, and soil supplied nitrogen. Current mass balance calculations account for a certain amount of nitrogen loss from manure and soil supply sources, but fail to account for losses occurring from fertilizer sources. Furthermore, mass balance calculations are unable to identify the timing of nitrogen losses and calculate whether nitrogen losses will result in yield loss. The ability of the GANS product to quantify nitrogen loss by pathway and time was helpful for visually showing participants which loss pathways were active in their fields. It allowed for discussion on manure and fertilizer management changes that can reduce overall nitrogen loss. On occasion, the model was able to identify yield limiting N loss in time for participants to take action through a late season sidedress application.

Recommendations for using nitrogen modeling in cost share and regulatory programs.
Nitrogen modeling through a comprehensive product like Granular Agronomy is a viable option for farms to show that planned nitrogen applications meet guidelines and criteria for cost share & regulatory programs focused on improving water quality. Farms will still need to show compliance with phosphorus regulations and soil conservation plan requirements. There are a few items that should be considered when incorporating nitrogen models into water quality programs.

1. Farms should work with an individual trained in both the modeling program and state nutrient management regulations. This is important for ensuring the quality of model outcomes through program/regulation accepted background data and inputs. In PA, the models should be run by individuals that hold state nutrient management planner certifications and can provide proof that they have completed training for the modeling product that will be used.
2. Cost share & regulatory programs should stipulate that field-specific data be used. Pre-season nitrate samples, actual manure analysis, presentation of all applications and accurate application dates are all important for the quality of model outcomes.
    a. Participating farms may want to use modeling platforms for generating variable rate nitrogen prescriptions. Decision zone development processes for variable

rate nitrogen should include multi-year yield analysis. The use of decision zones should also be consistent with other regulatory criteria, including the use of Phosphorus Index tools and soil testing.

3. Reporting and verification of data. Current cost share & regulatory frameworks have successful methods of oversight through plan review and recordkeeping review processes. Farms using a nitrogen model will need to work with the product designers to ensure enough background information on fields can be provided to agencies so agency staff can verify program requirements have been met. The GANS product offers a year-end report that is customizable.

Current Limitations to the Granular Agronomy Nitrogen Service (and what is being done to address them).

The Granular Agronomy Nitrogen Service was developed for use primarily in corn/soybean rotations in the Midwest US, and therefore did not have built into it various features that are found more commonly in the Northeast US. However, these features are being addressed in future versions of the Nitrogen Service.

- **Cover Crops** - Granular has done research and trials into the development, breakdown and release of nitrogen found in cover crops. This project contributed to that knowledge base. As a result, a forthcoming version of the Granular Crop Model (GCM) contains a sub-model that simulates the development, N and water uptake, and release of N upon termination of select cover crops, including both cereals and legumes. Testing is being performed throughout 2022 to validate the simulated effects.
- **Tillage** - Incorporating residue into the soil or leaving it on the surface has different effects on mineralization and return of N to the soil. At present the Granular Agronomy Nitrogen Service assumes a tillage practice will take place on November 1 of the prior season, incorporating 50% of the previous crop's residue to a depth of 6" (150 mm). Efforts are being made to allow a user to specify if and what tillage is performed within the software. These would include dates and tillage type, with typical values of incorporation and depth associated with the tillage type.
- **Prior Manure N Credits** - Currently, the Granular Agronomy Nitrogen Service only considers the mineralized nitrogen from a manure application made in the current growing season. However, it is common in the Northeast to have manure applications from year to year, resulting in residual nitrogen from prior applications becoming mineralized and available in the current year. Additional manure settings are being developed to simulate 2nd and 3rd year manure residual nitrogen for the Granular Agronomy Nitrogen Service.
- **Prior Legume N Credits** - Corn and soybeans are the only two prior crops available in the Granular Agronomy Nitrogen Service currently. However, it is recognized that legume crops like alfalfa and clover are often terminated prior to corn, and those legume crops contribute residual nitrogen that becomes mineralized. Because of this, additional prior crops, like alfalfa, are planned to be included in the Granular Agronomy Nitrogen Service.