## 2024 Innovation Grant Final Report

PROJECT TITLE: **Reducing nitrate in a surficial sand aquifer, Mower County MN**

REPORTING PERIOD: Final Report and Invoice due by January 31, 2025
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## Overview of *Sustainable Answer Acre Project* to Date

The study, as originally envisioned, is set-up to be a multi-year replicated trial on a typical corn-soybean rotation under six different nitrogen treatment scenarios involving both conventional tillage and cover crop plots. With funding support from the *MN Corn Growers Associatio*n from 2019 to 2024, we have equipment installed, GW and soil nitrogen samples collected for six years, and soil health measures collected by collaborative study partners for two Years (2020 and 2021).

2019 was the start-up year to define baseline conditions and 2020 was the year to better decide what kind of data collection is needed and to start seeing comparable results.

2021 (corn) was a challenge in terms of groundwater data collection, mainly due to UMN COVID-19 restrictions, late-summer drought, and the construction of a new seeds' storage facility that impacted our study area with groundwater levels lowering considerably. In order to continue collecting water data, some of the PVC pipes were substituted with galvanized pipe, which can go deeper in the soil and reach a lower level of groundwater. However, we were thankfully able to collect soil samples right after harvesting in November 2021, making it possible to compare results between past (2019) and future years, at least in terms of soil nitrate, and structure stability.

During 2022 (soybean), a severe drought affected our sampling ability and full completion of our target objectives. Due to drought, we were unable to collect soil samples of the nitrate and ammonium held in the soil post-harvest (October/November) as we were able to in past years. The late summer lack of precipitation and soil moisture also limited our nitrate data collection from the vadose zone to the spring and early summer months, with no water to collect from wells in late summer or post-harvest.

During 2023 (corn), lack of precipitation again impacted our ability to collect water in our wells. Following the drought from fall/winter 2022, the water-table had fully recovered by May of 2023, though only temporarily. The area experienced an extreme drought. We were only able to collect some spring samples, but no summer or late fall samples due to the lack of soil water. We were also not able to collect soil samples for aggregate stability due to the extreme soil dryness.

In 2024 (soybean), this report year, we had a wet-year with above normal precipitation during the spring and summer, which made water collections from wells possible. We were able to collect a series of monthly samples six times between early May to late October.

Year-to-year precipitation has been extremely variable - from both overly wet in initial years (2019, 2020) to dry/drought (2021, 2022), to extreme drought (2023), which has been challenging in meeting our objectives and goals; however we have been provided an opportunity to gain additional insight on how nitrate moves through soil and into groundwater under different precipitation scenarios. In 2024, we observed that during drought, the land applied nitrate during a corn year is stored on the surface until a substantial rain event the following year (soybean year) can solubilize and move the land applied nitrate into the lower soil profile.

We hope that 2025 provides again a more moderate precipitation climate and collections in a corn year. This will be valuable in completing our understanding of nitrate movement with a typical corn-soybean rotation. Without the complete seasons available (pre-snow-melt, during snow-melt, post-harvest) and full rotations (corn-soybean) we are currently not able to say much to answer some of our key study questions; however, with the data we have from early season and previous years, we are starting to see and document some important patterns and potential trends:

- When precipitation is lower, there is less water leaching of nitrate-nitrogen into the groundwater; and the overwinter soil nitrogen pool remains larger. This creates a "flush" of nitrogen in the spring, when the pool of nitrate is solubilized and travels below the rootzone at the beginning of the growing season. For both 2023 and 2024, the CC plots had less nitrogen leaching to the surficial groundwater than the CV, but both had much lower Nitrate-N in May-June 2023 (corn year, when N fertilizer applied) than in 2024 (soybean year).

- There was less nitrate in groundwater from *cover-crop* than *conventional*. We are starting to document trends. We were able to observe this for a full sampling season in 2024, which was a soybean year. It would be also valuable to have well water samples from a normal precipitation year for corn so we can analyze data on a full crop rotation.

- Soil structure and aggregate stability were better developed in *cover-crop* than *conventional,* at least for post-harvest, when sampled. We suspect that this may be due to a more active and supported biological community of microorganisms. We are curious about other seasons showing similar results.

- One group of soil microorganisms (*Actinomycete*s) were much higher in CC than CV. These filamentous bacteria are considered "free nitrogen fixers" and may be important for both decomposition of crop and cover residues, thereby aiding in both recycling and converting nitrate to ammonia, which is a more plant-available form.

- The use of nitrogen stabilizers may be showing improved nitrate holding ability and less leaching to groundwater. Again, this observation would need to be supported with a more normal precipitation year - within a corn year - hopefully in 2025.

- We suspect that, both the application of nitrogen stabilizers with cover crops, and a well-supported and enhanced soil biological community, may all be useful practices that together help to hold nitrogen in soil and reduce nitrogen loss to groundwater.

Given the completed work to date (site establishment, well monitoring equipment installed and previous years data), we are hopeful that an extension of funding (Year 7, 2025) will both provide another year to address the data deficiencies due to drought. We will then be able to more completely analyze and understand better the nitrate movement through soil and the opportunities to hold nitrate past the growing season under both soybean only years and corn with fertilizer addition years with soil health measures in place.

## 1.) PROJECT ACTIVITIES COMPLETED DURING THE REPORTING PERIOD.

(*Describe project progress specific to goals, objectives, and deliverables identified in your project proposal.*)

**Project Goal**: define current agronomic practices on sandy soils and substrate, then evaluate six practices that limit or alter nitrate movement beyond the root zone into the saturated zone.

**Project Overview:** The 8-acre Sustainable Answer Acre study site is monitored on 21 plots with 6 different treatment scenarios which include both 3 management types: *conventional tillage* (CV), *cover crop* and *conservation tillag*e (CC), and control *(grassland*, GR). The cropland plots are treated with three fertilizer strategies that are applied to corn in rotation with soybeans. We are collecting water samples from shallow and deep groundwater wells to measure nitrate levels below each management type and treatment, collecting soil samples to analyze for nitrate, as well as comparing soil health measures (i.e., structure and aggregate stability, biological) to see there are observed differences that can explain the differences in nitrate levels by management type observed. *See the 2023 proposal for more information.*

### 1.1 Project Progress - Overview by Each Objective

First, we highlight prior years (2019 to 2023), followed by our 2024 progress:

- During **2019** (Year 1), we started working on objectives 2, 3 and 4 (*see 2019 report*).
- In **2020** (Year 2, soybean year), we were able to compile and provide preliminary results from the field data collection for soil health measures and nitrate data (*see 2020 repor*t).
- For **2021** (Year 3, corn year), we were unable to work on field collection and other related tasks due to restrictions imposed for COVID-19 (*see 2021 report*). However, we were able to collect data on the soil biology along with some physical soil health measures (Objective 1).
- During **2022** (Year 4, soybean year), a severe drought affected our sampling ability and full completion of our target objectives. Due to drought, we were unable to collect soil samples of the nitrate and ammonium held in the soil post-harvest (October/November) as we were able to in past years. The late summer lack of precipitation and soil moisture also limited our nitrate data collection from the vadose zone to the spring and early summer months, with no water to collect from wells in late summer or post-harvest. While we were unable to collect additional samples in 2022 due to drought, we were able to review and analyze past results from 2019, 2020, and 2021. (*see 2022 report*).

- During **2023** (Year 5, corn year), an extreme drought affected our intended sampling plan. While we were able to collect a few spring samples, we were unable to collect groundwater samples in the early summer to later fall; the wells were dry. We did collect bromide tracer data during the spring which showed that the nitrate had yet to move through the soil profile. Much of the nitrate fertilizer was still at the surface due to the lack of rain during the previous year's drought.

- For **2024** (Year 6, soybean year), we had a very wet spring and fall and adequate soil water that moved down into the vadose zone. We were able to collect 6 months of well data for nitrates as well as soil nitrate samples in fall. Initial analysis shows that all 6 months of the shallow well samples had much lower average nitrate levels in CC plots than CV, with lower in the GR. Surprisingly, we had some extremely high nitrate values (50-80 mg/L). We believe that this was due to a larger nitrate pool at the surface from fertilizer applied during the corn year (2023), which was unable to move due to the drought. However, with the spring rain in 2024 the land applied fertilizer was finally getting solubilized with enough precipitation to infiltrate down into the soil profile and into our surficial wells. The results of the nitrate levels in the surficial well water and for the different treatments (CC, CV, GR) are shown in this report.

The following is an outline of accomplishments in 2024 for each objective and current status. We included our study objectives from our 2023 grant proposal (*in italics*) with a brief reporting of our progress. We then describe in greater detail our 2024 *Project Achievements* (*see section 2.1 below*) and *Challenges Encountered* (*3.0*).

*Objective 1: define the current soil biology and nitrogen pool (vadose zone); can soil biology help retain water and solute? We will examine samples for microbial activity in plots where cover crops are used, non-cover crop plots and continuous perennial cover.*

We have data from soil health measures collected in 2020 and 2021 and have reviewed and analyzed the data. This information provides our *Before* for our BACI study. We planned to do a repeat of the soil health measures in 2023 to be used as our *After* for our BACI study, but were not able to due to the extreme dryness of the soil in fall when samples would have been collected. The samples from 2023 were intended to provide the start year of our *After* analysis. We plan to collect the soil health measures in fall of 2025, hoping that climate conditions allow. We will duplicate the same techniques and measures as were collected in 2020 and 2021.

*Objective 2: back-calculate the current aquifer mass of nitrogen-based N-inputs from the past; it is critical that we define a starting point to evaluate the effectiveness of BMPs.*

Well placement occurred in year one (2019), and lower depth galvanized pipe was placed at four locations in 2021. Currently, we have data that can be used from the early season and previous years (2019 to 2021) that will be used as background *(Before*). Unfortunately, with the lack of precipitation due to drought in 2022 and 2023, we were not able to collect GW samples during the late season (*After*). With funding carried over from 2023, we were able to place two more additional galvanized wells so that we now have two wells in each of our treatment plots (CV, CC, GR), which allows for replication. We also have three upgradient and three downgradient wells around the SAA project site. We were able to collect samples from all of our wells in 2024 (soybean year) and plan to again in 2025 (corn year). We will need a complete series of data from a more normal precipitation year to fully analyze BMPs effectiveness (*Afte*r) with both cover crops and fertilizer treatments for corn as well as soybeans. A full spring to fall sampling is necessary in order to observe the full timeline of nitrate movement through soil during summer and over winter into the next growing season. We then can see if soil health practices hold nitrate better over this critical time-frame when crops are not growing.

Objective 3: *measure nitrate below each treatment plot before soil thaw, after soil thaw to capture the snow melt, and after harvest.*

Both the galvanized wells within management types and the shallow wells within both the management type and fertilizer treatments are used for this objective. We are interested in seeing if there are seasonal differences in nitrate-N levels during different seasons. Early season samples were able to be collected in 2023 until drought. In 2024, we were able to collect a complete season of samples for a soybean year. We hope that we can collect a full season in 2025 for a corn year to complete the crop rotation for our analysis.

In year 4 (2022) and year 5 (2023) we were not able to utilize our bromide tracers due to the lack of precipitation and water in our wells for our sampling timeline due to drought. We believe that the bromide tracers were still being held up within the soil profile. Snow-melt and precipitation during 2024 (Year 6) did help to move the tracer down into the vadose zone where we were able to collect samples to determine the recharge below the root zone for the 2024 climatic conditions. With funding, we plan to collect bromide samples as a budget item in 2025.

*Objective 4: measure and observe if there are seasonal differences in Structure Index and wet-aggregate stability between spring and fall (post-harvest).*

Analysis on our first set of aggregate stability collections and results (2020 and 2021) focused only on late season sampling. Due to drought, we were not able to sample in 2023. We plan to collect these same physical soil health measures (wet-aggregate stability and Structure Index) in 2025, funding allowing.

## 1.2 Project Achievements for 2023 and 2024: Sampling and Data Analysis by Component

Below is a summary of sampling or activities completed during 2023 (until drought in summer) and 2024 for each component. Data review of outliers and calculations of statics for each sampling component were completed by staff from Mower SWCD, UMN, and Caddis Fish Consulting, LLC. Full analysis is planned after we have a good corn year of data from 2025. This is needed for our *After* analysis to compare with 2020 and 2021 (*Before*) for both a corn and soybean year in rotation.

### Achievement 1, Objective 2 - Samples collected from galvanized pipe wells

The deeper galvanized pipe wells are used to observe flow-paths and concentrations of nitrates and rates of change as background conditions are monitored in order for us to observe flow paths and nitrate concentrations to measure *input*, *within*, and *output* of solubilized nitrate-N to calculate the *mass balance* (objectives 1 and 2) using wells upgradient of our site (*input/entrance/background*) as well as below our site (*output/exit*) to measure the change in GW nitrate after flowing through our experimental plots.

Groundwater sampling occurred using standard operating procedures. We measured soluble nitrate and bromide (a tracer) following procedures used by Magner and Alexander (2002) and Brooks et al. (2013). Water samples were collected by staff from Mower SWCD and analysis run by staff from UMN.

In 2024, we were able to place two new wells; one additional in our CV and one additional in our CC which now allows replication under each of our management types. With the two additional galvanized wells added, there are now six galvanized wells that have been intentionally positioned around our study site, two per management type. Additionally, there are three upgradient and three downgradient wells that provide the input (upgradient) and output (downgradient) for calculating our nitrate-N *mass balance*.

In 2023 and 2024 all wells were operating as intended, although the drought of 2023 limited sample collection to only the early season months (April to June) as there was no water in the wells in later summer and fall.

During 2023, we collected a total of 26 groundwater samples from eight wells (4 galvanized, and 4 PVC pipe wells).

In 2024, with more consistent precipitation, nitrate-N samples were collected between April (pre-plant) to late October (post-harvest). In 2024, we collected a total of 92 samples from 12 wells (6 galvanized and 6 PVC pipe wells).

We plan to collect again in 2025 under a corn year. That will be needed to calculate the *mass balance* for under both a full soybean and full corn year. We are also aware now that there is another dewatering plan in the near future, but not anticipated as early as 2025 for our corn year.

Analysis of the data will occur after completion of the sampling planned for 2025.

**Figure 1.2a** – In 2020, a dewatering activity for construction, southeast of SAA created a cone of depression and lowered the GW table below our study site. To remedy the lower level of GW access, we installed the first set of galvanized pipe in 2021. Image from NCC.

**Figure 1.2b** – Bottom tip of the galvanized pipe installed during the Spring and Summer 2021 with two additional in fall 2023.

### Achievement 2, Objectives 2, 3, and 4 – Shallow GW nitrate samples collected

The sample collection is set up to monitor nitrates through seasons and under each management type (*conventional tillage* and *cover crop*) to see how nitrate levels change during seasons and are responding both to soil health measures in addition to nitrogen inhibitors over corn-soybean-corn rotations.

In 2023, we collected 166 samples from our shallow wells in each treatment plot (21 plots). Due to drought, we were only able to collect early season (April to June).

In 2024, we collected 545 samples, spanning across pre-planting (April/May) through the growing season (June through Sept) and post-harvest (late October). This was a soybean year. We were able to review preliminary statistics and boxplots from this year's data for the shallow wells. Some of the results are included later in this report.

We also hope to collect during the 2025 corn year, and precipitation allowing, it will provide the full season sampling needed (pre-planting to post-harvest). Full analysis will be completed after the 2025 growing season.

### Achievement 3, Objective 3 - Tracer tests conducted, results received

In 2023, we collected 9 bromide tracer samples from three of the galvanized pipe-wells. In 2024, we collected 25 samples. These samples were collected by Mower SWCD and UMN staff and sent to Ion Chrom Analytical, St Paul, MN and analyzed for bromide tracer concentrations as well as nitrate, nitrite, and other anions.

These bromide tracer tests are used to identify the down gradient flow path and travel time as the water containing the tracers, potassium bromide in this case, recharges into and travels through the vadose zone and aquifer. We choose to use potassium bromide because it is a conservative anion tracer, meaning that it travels with the water through the vadose zone and the aquifer without being absorbed or degraded.

Typical values should be in the range of 1.0 to 2.0 ppm. For our 2022 results with 18 samples the range was low at 0.002 (the minimum reported range) to 0.03 ppm. For 2023, levels were again low for all 9 samples due to the summer drought (range 0.03 to 0.037). The lack of higher concentrations of the Bromide Tracer may also suggest that the nitrate values reported for both 2022 and 2023 are also lower than the concentrations would be if precipitation was more normal during these same-time sampling events. In comparison, for 2024, we had a wet spring and summer and our bromide tracer levels were higher (25 samples, range 0.161 to 17 ppm, median 1.44 ppm). We also saw a spike in nitrate-N levels in 2024 as well, indicating that the pool of nitrate in dry years was stored in the soil profile and moved with adequate precipitation in 2024.

**Achievement 4, Objective 1 - Soil nitrate samples collected**

We used soil samplers (probes) to collect multiple soil samples in each plot at two depths (0-12” and 12-24") over all 21 plots.

In 2023, we were able to collect spring samples (60 samples on 4/26) for the corn year with three BMP fertilizer treatments but were not able to collected post-harvest samples due to the severe drought.

In 2024, we collected some spring samples (21 samples on 4/15) within each treatment type for a soybean year without fertilizer additions, and then with enough rain, we were also able to collect post-harvest samples on all plots by fertilizer treatment and management type (60 samples on 11/15).

We will need to have corn year data in 2025 to complete the rotation analysis. Analysis of the soil nitrate measurements will be completed after all data collection is finished.

**Achievement 5 - Objectives 1 and 2 - Physical and biological measures**

We consider the biological and physical soil measures collected in 2020 and 2021 as our project baseline (*Before, Objective 2*).

In 2023, we had hoped to collect additional soil samples, but due to drought, were not able.

We hope to collect the same physical and biological measures again in 2025 with which to compare and track BMP effectiveness overtime (*After, Objective 2)*.

**Achievement 6 - Final Report to MN Corn Growers Association, submitted on time**

We consider this an achievement, as multiple staff coordinate the seasonal work and provide data for this valuable project.

## 2.) IDENTIFY ANY SIGNIFICANT FINDINGS AND RESULTS OF THE PROJECT.

(*This could include photo documentation of the project at various stages if you haven't already provided these as well as final relevant images of the project at completion. Any data analysis (<u>especially Level 3 Grants</u>), graphics or record of observations throughout the growing season or during the field day event are also anticipated.)*

### 2.1 Differences Observed in water runoff and infiltration between Management Systems

In July 2022, NCC had a field demonstration with farmers comparing soil aggregate formation between conventional tillage and soil health (conservation tillage/cover crop) plots using a combination of both soil samples in field (Image 2.1) and graphics provided in a handout.

**Image 2.1** - a) Steve Lawler, Mower SWCD demonstrates. b) Great turnout with local producers and farmer leaders.

We used a demonstration kit that simulates both infiltration and permeability of the soil. This method collects both runoff water (stormwater) and gravitational water (under the soil profile) resulting from a simulated 1 inch rainfall event. We used an in-situ sample from a *conventional* plot and one from a soil health (*conservation/cover-crop*) plot.

The results were strikingly different. The *conventional* sample had poor infiltration and most of the simulated rainfall ran off as stormwater with a heavy sediment load. There was very little gravitational water. The soil health (*conservation/cover-crop*) sample had some stormwater but the water was fairly clean and there was a high volume of gravitational water.

This demonstration verified the effect of aggregate stability and soil structure development on stormwater and sediment generation. As we told the observers, multiply these small samples by the surface area of typical watersheds and one can begin to understand the cumulative effect and significance of soil stability on water quality.

## 2.2 Results by Each Sampling Component

### *2.21 Nitrates in Surficial wells, lower for Cover Crop than Conventional*

We have spring samples from 2023 and a full year of samples from 2024. We believe that we are seeing a notable pattern in our results, where *cover-crop* (CC) plots are achieving lower nitrate in GW than for *conventional* (CV) plots for multiple years (2020, 2021, 2023, 2024) and across seasons. For 2023 there was a 25% average difference in groundwater levels between CC and CV, with 2024 higher at 35%. The difference with grassland is verification that we have little if any cross contamination between plots. We think that this pattern is potentially showing a response from covers and biology.

Table 2.21a. 2023 groundwater Nitrate-N averages collected from each management type.

| 2023 | 4/24 | 5/21 | 6/12 |
|---|---|---|---|
| CV | 12.1 | 14.3 | 14.1 |
| CC | 9.2 | 10.8 | 10.7 |
| Diff (CV-CC) | -2.9 | -3.5 | -3.4 |
| GR | 0.3 | 1.1 | 1.3 |

Table 2.21b. 2024 groundwater Nitrate-N averages collected from each management type.

| 2024 | 5/06 | 6/10 | 6/24 | 7/9 | 8/5 | 10/31 |
|---|---|---|---|---|---|---|
| CV | 16.7 | 31.0 | 31.6 | 34.0 | 21.9 | 21.4 |
| CC | 10.5 | 25.2 | 20.0 | 15.3 | 13.8 | 15.6 |
| Diff (CV-CC) | -6.2 | -5.8 | -11.6 | -18.7 | -8.1 | -5.9 |
| GR | 3.3 | 3.5 | 1.5 | 1.5 | 1.3 | 2.3 |

Unfortunately, the GW nitrate compared to drinking water standard (10 mg/L), is still above most months. In the tables above, the nitrate levels are color coded based on the 10 mg/L nitrate standard, where green is below the standard, orange is slightly above, and red to deeper red further and further above the standard.

Also, in reflecting on these results, we also saw much higher average GW nitrate levels (2.5x higher) in June 2024 than in 2023. The sample sizes were the same each year and for each management type (n=26-27 samples). We believe that during the drought of 2023 (corn year with fertilizer application), that the pool of nitrogen concentration remains in the soil until new water (snow melt or precipitation) solubilizes the nitrogen and moves it down through the soil profile, which would explain why the nitrate-N levels were much higher in the 2024 spring samples than in 2023.

### *2.33 Nitrates in Soil Samples, previous years*

We include a few of these observations here, with graphics and tables from our "2021 (Year 3) Final Report". We have collected soil nitrate samples in late October 2024 (soybean year) and will report with findings in our 2025 report after we collect another corn year.

Looking first at *Figures 2.33a* and *b*, soil nitrate levels at 12 to 24 inches are consistently low for CC as compared to CV for both years (2020 and 2021). This is the same result as we see in *Figures 2.33c* and *d* for the 0 to 12 inch depth.

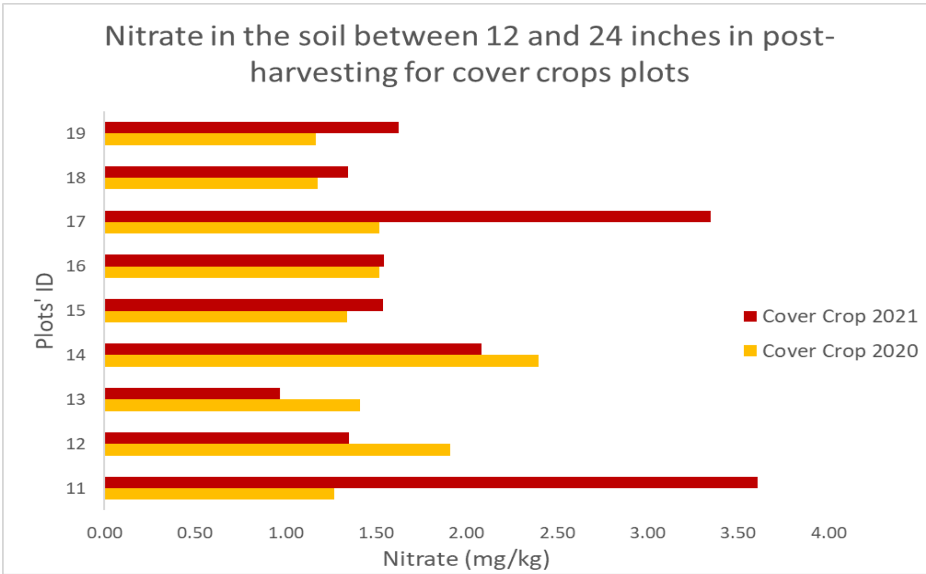


Figure 2.33a. Soil nitrate for the 12-24 inch depth for cover crop plots in 2020 and 2021.

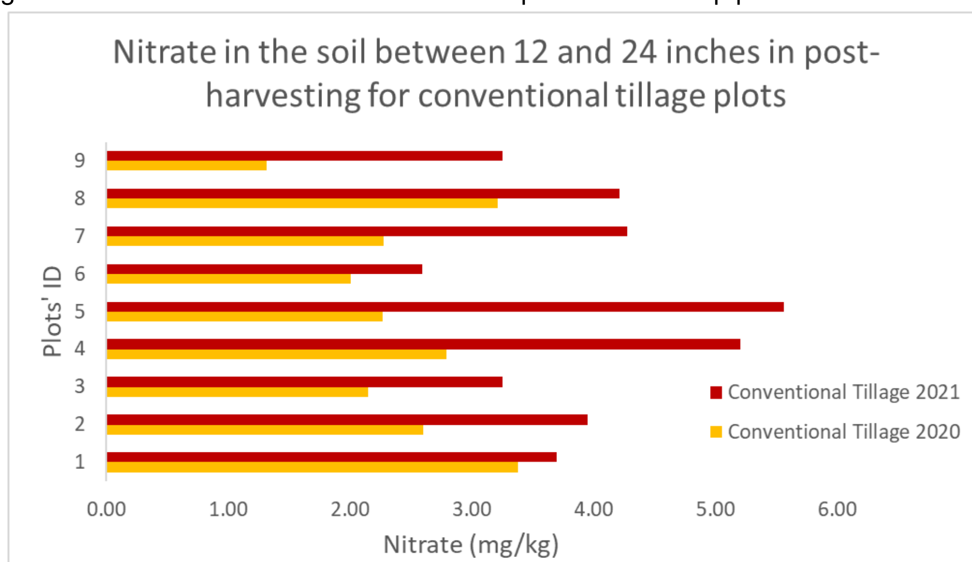


Figure 2.33b. Soil nitrate in the 12-24 inch depth for conventional plots in 2020 and 2021.

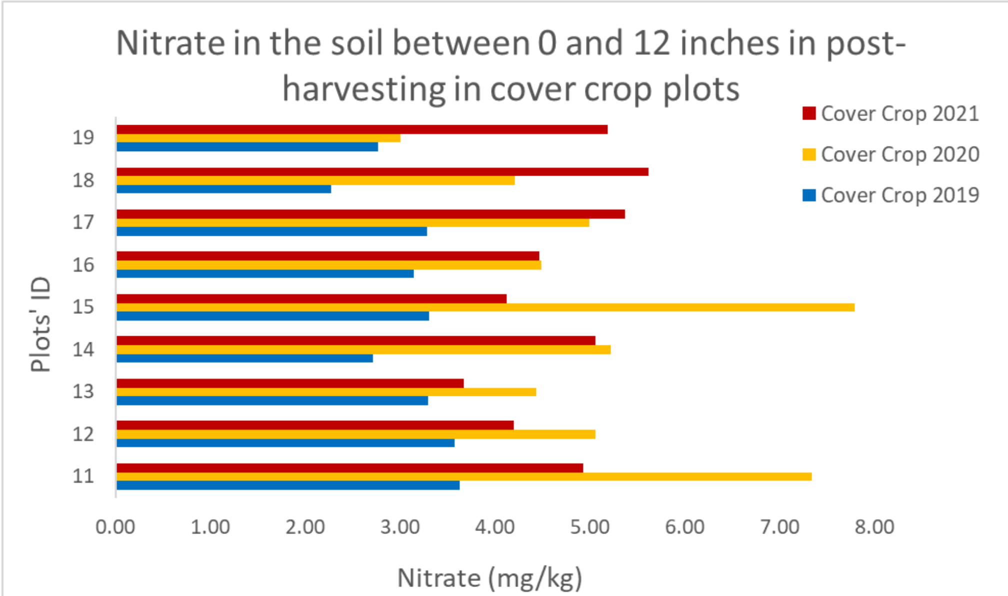


Figure 2.33c. Soil nitrate for the 0-12  inch depth for *cover crop* plots in 2019, 2020, and 2021.

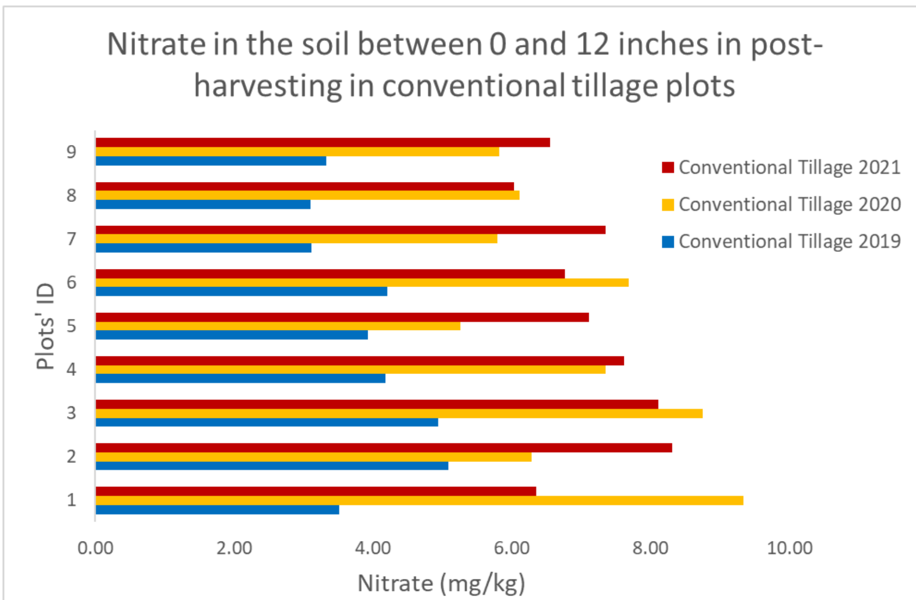


Figure 2.33d. Soil nitrate for the 0-12 inch depth for *conventional* plots in 2029, 2020 and 2021.

We also note that there was a difference in the precipitation totals and number of rain events between years (*see* precipitation graphs in *Section 3.2 below*). This climate difference between years could also be a factor in the amount of soil nitrate remaining in the post-harvest soil samples.

This can be a factor when the amount of water entering the soil and surpassing the plant uptake and soil moisture saturation levels varies, as could depending on rain events and time of year when sampled. That would have an effect on both the speed and dilution of nitrate moving below the soil profile and into the vadose zone. Hence, the extremely variable precipitation patterns and totals (wetter in 2019, transitioning to dry in 2020 and 2021), may also be a factor here. Years 2020 and 2021 were more normal transitioning to dry years and 2019 was a wet year, so the 0 to 12 inch Nitrogen-N levels could be higher than 2019 which was a wet year. due to the excess soil nitrate still being held in the soil during the dry years.

Another thing to note is that this study involves a corn-soybeans rotation timeline. Nitrate holding enhancer treatment is only applied during corn years (2019, 2021). Other years (2020, 2022), soybeans were grown and no nitrogen stabilizers were applied.

We had again a corn year in 2023, but drought was a factor this year as well. In 2024 (soybean), we had plenty of rain and did collect post-harvest samples. We need a normal precipitation year for corn and fertilizer treatments to compare results and for our understanding of how to address the question of how much soil nitrate is held up in soil verses enters the vadose zone. Hopefully, this will occur for us in 2025 (corn year). This is needed in order to meet our study objectives.

### *2.34 Soil Health Measures*

We collected two separate sets of data to compare results for: a) Nitrate Treatments within Management Types (20 plots). and b) by Management Type Only (9 plots). Physical and Biological Measures were collected in 2020 and 2021. We had hoped to in 2023, but were unable due to drought. We hope to collect the same physical and biological measures again in 2025. We highlight a few notable differences from the 2020/2021 sampling below.

*2.341 Physical Soil Structure Results*

***2.341a - Structure Index Score*** - The Structure Index Score (SI score) is a physical rating on a 0 to 100 scale where higher scores reflect how well the top layer (0 to 12 inches) is holding together in the field while visible pore spaces are present. Soils with better structure (higher scores) have typically higher water infiltration rates and internal water permeability. Better vertical water movement can reduce erosion, limit stormwater generation, increase microbial activity and nutrient mineralization.

Both years (2020 and 2021) show higher SI scores for *cover crop* than *conventional*; while *grass* had the highest (*Figure 2.341a*).

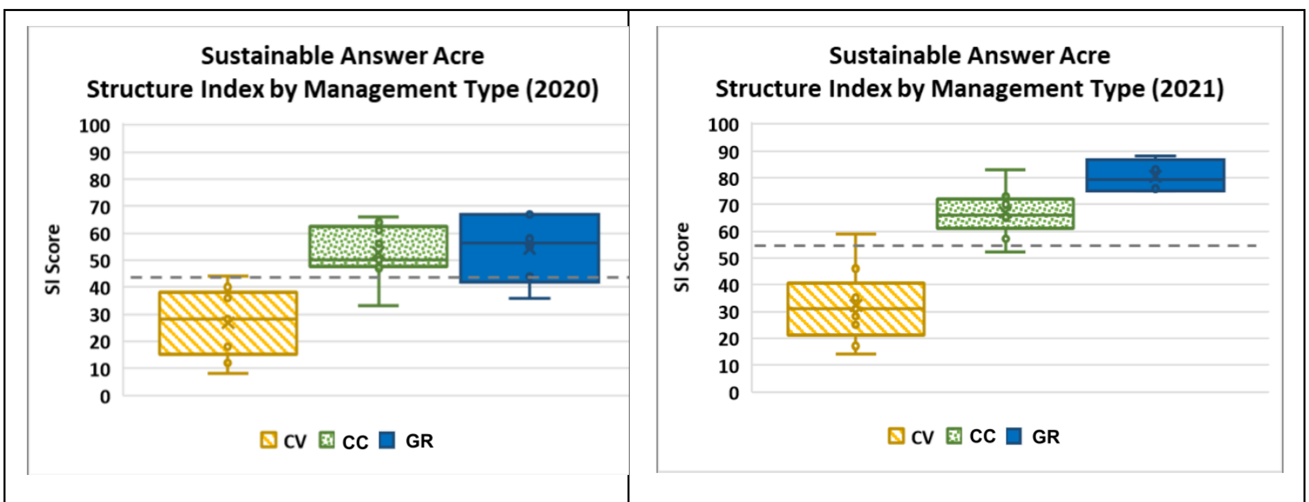


**Figure 2.341a** - Structure Index Scores (SI score) by Management Type and Year. Please note: the dotted line is the average SI score across all samples collected that year; this line is higher in 2021 than 2020.

This difference is very notable, especially in 2021 (*see Table 2.341a below*). We are not sure what accounted for this even greater difference observed, even for Grass. Most importantly, the rating of the SI scores demonstrate very good soil structure for the *conservation/cover crop* plots and relatively poor soil structure at the *conventional*.

**Table 2.341a -** Comparison of SI scores by Management and difference in scores between years.

| Management Type | Average SI Scores by Management Type and Year | SI Score difference between years (2021-2020) |
|---|---|---|
| Conventional 2020 | 26.7 (-) | +6.5 |
| Conventional 2021 | 32.2 (- -) | |
| Cover Crop 2020 | 32.2 (+) | +34.8 |
| Cover Crop 2021 | 67.0 (+) | |
| Grass 2020 | 54.4 (+) | +26.1 |
| Grass 2021 | 80.5 (+++) | |

*Note: the + and - are ratings to show the degree of difference as compared against the all-sample average within each year (dotted lines in Figure 2.34a above).*

***2.341b - Aggregate Stability (AgS)*** - Higher values (% stable fraction) means that the soil is more able to resist erosion due to wind and water. Better aggregate stability may also allow for higher water infiltration rates. Only one year of data was analyzed (2020). Due to staff change, AgS samples were not processed in time. We planned to collect in 2023, but were not able due to drought. We hope to collect again in 2025 with which to compare the 2020 results. The results from 2020 show that there was slightly higher AgS for *cover crop (Figure 2.341b, Table 2.341b* than for *conventional.* Both are lower than for *Grass*.

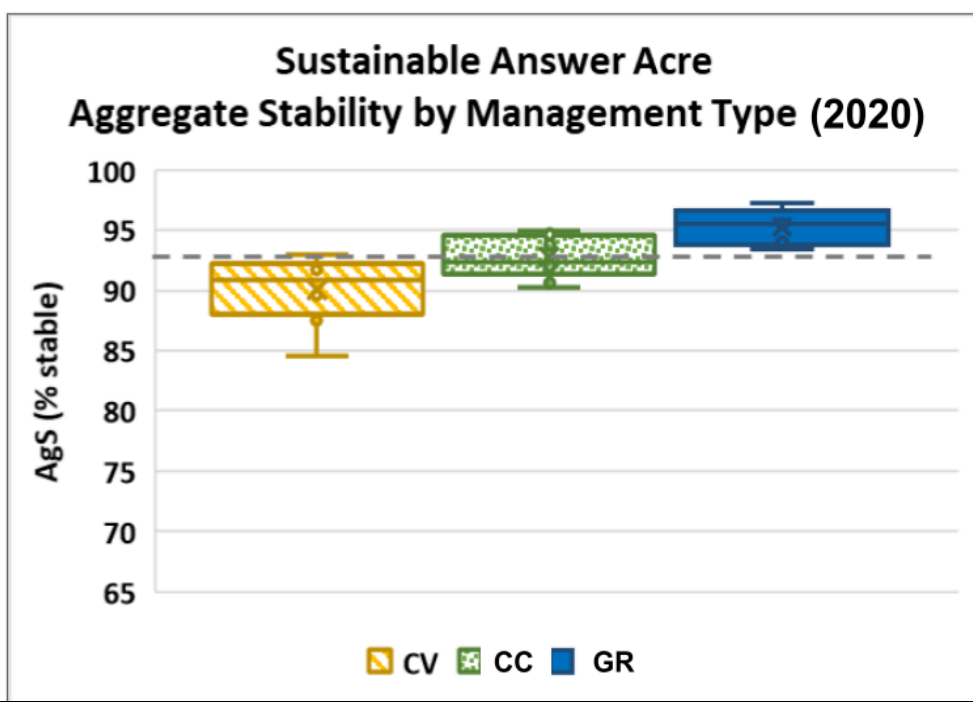

**Figure 2.341b** - Aggregate Stability (2020). The dotted-line is the *All Sample Average* (Table 2.341b).

**Table 2.341b** - Average *Aggregate Stability* for three Management Types.

| Physical Soil Health Measure | Year | CV | CC | GR | All Sample Average |
|---|---|---|---|---|---|
| **Aggregate Stability** (% stable) | 2020 | 90.0 (-) | 92.7 (=) | 95.3 (+) | 92.3 |

*Note: the + and - in parentheses are compared against the All Sample Average within each year.*

Our results for *SI score*s and *Aggregate Stability* are similar as to what was found for another Mower County Study "Results of the Hormel Foundation-Mower Health Initiative Comparative Cropland Study (2018-2020)" where soil health plots (*conservation tillage/cover crop*) had a much higher SI score (56.8) than *conventional* (17.3); and both were lower than benchmark (*perennial cover, grass,* SI Score 99.9).

With these results for this study and supported by another Mower Study showing similar results, we think that this difference is related to a better, more active soil biology. While *Structure Index* and *Aggregate Stabilit*y are both considered physical measures of soil health, indirectly, these two can also be biological measures. Additionally, an active and supported soil biology can enhance the capture and storage of nitrates. Well-developed soil aggregates are built by the bacterial glues adhered to soil particles and bacterial enzymes can pull out trace minerals and nutrients. These particles are pulled together with fungal hyphae (when present) and hold the sands/silts/clay with bacteria in a sort of yarn-like matrix near and around plant roots. The plant then supplies food as sugars (complex carbohydrates) while the bacteria and fungi reach out and supply nutrients and water far into the soil and back to the plant. A well-formed matrix of these biologically formed and stable aggregates also allows for better development of soil structure with pore spaces for oxygen to flow-through and crop roots to grow deeper allowing for additional soil moisture and nutrients to be accessed by plants.

In future years, we would like to measure and observe if there are seasonal differences or if *Structure Index Scores* and *Aggregate Stability* remains stable over winter into spring, or is lost over winter when crops or newly seeding cover crops are not growing or roots are young and shallow and therefore not continuing to supply food (exudates) to maintain the soil biology (bacteria, fungi) that hold the soil aggregates together. If there is a difference, then a PLFA in spring and fall as well as microscope assessment work would be useful to confirm activity of soil microorganisms that are providing this difference in physical soil measures.

### *2.342 Biological Results*

In order to determine if the microbial community is present and active, and potentially contributing to soil structure and stability (through a better soil biology), we also collected biological samples in 2020 and 2021 to analyze for enzymes and microbial groups through lab procedures

(Enzyme analysis, Pox-C, PLFA). This information will serve as the baseline (*Before*) in our BACI design. We were unable to start collection on our After in 2023 due to drought. We plan to collect in 2025 for this data to be our (*After*) with which to compare our *Before*.

## 3.) CHALLENGES ENCOUNTERED.

(*Describe any challenges that you encountered related to project progress specific to goals, objectives, and deliverables identified in the project proposal.*)

The previous year, 2023 was an extreme drought in the region. 2024 was a much better year in terms of precipitation. While we collected a few well water samples in 2023, we applied the 2023 funding to our 2024 sampling year which was a soybean year in our corn-soybean rotation. However, we have yet to have a normal precipitation for a corn year. Our two other corn years experienced a severe (2021) and extreme (2023) drought. We are applying for funding for an additional year (2025, Year 7) that will hopefully allow us to collect nitrate-N samples to compare with our soybean year (2024). We have applied for another year of funding (2025) through the MNGA grant. Without this additional dataset, unfortunately, there will not be much we can say to more fully answer or address our project goals and questions regarding fate and transport of nitrate for a corn-soybean rotation.

One additional challenge in 2024 was the early frost. While we were able to collect well nitrate data in late October, a hard frost occurred in early November, before we could do the annual tillage on the conventional plots. We are planning to attempt a spring plowing prior to planting in 2025.

### 3.1 Sampling limitations in 2023 due to drought

This severe lack of rain on another corn year greatly limited our sampling and so we were not able to compare needed results for completing our project objectives. More specifically:

**Nitrates in GW analysis, sample collections affected by drought** - Due to lack of precipitation, fewer months were collected this year. The late summer lack of precipitation and soil moisture limited our nitrate data collection from the vadose zone to the spring and early summer months, with no water to collect from wells in late summer and fall. This data is needed in order to extrapolate information on the timing and movement of nitrate through soil and what amount, if any, is being held within the soil profile longer with either the nitrate inhibitors or soil health practices. At least 5 years of data collection would provide a more complete picture of the degree of nitrate leaching to surficial groundwater over several corn-soybean-corn rotations. Time is needed because water movement in the vadose zone will pulse depending on recharge volume and time of year. Further, groundwater movement under the plots will vary depending on hydraulic conductivity and gradient. Given the size of the plots we believe residual groundwater is still moving under the plots from west to east at a rate of 400-4000 ft/year. Going forward, we anticipate changes in soil nitrogen and groundwater nitrate concentrations based on the treatment systems design.

**Deeper groundwater levels due to drought, coupled with dewatering event -** Additionally, the dewatering for construction, coupled with the lack of precipitation has lowered the GW level more than 1O ft since the start of this project (2018/2019 baseline year). This adds to the length of time required for water to travel through the soil profile and vadose zone where we can capture the concentrations of nitrate and bromide tracers in our wells. Another year of construction and dewatering is anticipated with an expansion planned after 2025. We hope to collect data in 2025 (corn year) prior to that event. Due to that, 2025 would likely be our last year to sample for comparable data for this project.

**Bromide Tracer analysis, impacted by drought -** The lack of precipitation due to drought in 2023 also greatly limited movement of our Bromide tracers down through the soil profile and into the vadose zone. The results of these tracer tests are needed in order to estimate the rate at which nitrate travels through the system. We hope to collect in 2025.

**Soil Nitrate analysis, impacted by drought in 2023 -** Our intent is to track the nitrogen pool in the vadose zone before, during and after harvest. Due to drought, we were unable to collect soil samples of the nitrate and ammonia held in the soil post-harvest as we were able to in past years. We are hoping to collect additional soil nitrate samples during 2023 with field staff support from NCC. These samples are necessary in order to observe the full timeline of nitrate movement through soil during summer and over winter into the next growing season. This data is needed so we can estimate what nitrogen is most at risk of leaching beyond plant roots. We then can see if soil health practices hold nitrate better over this critical time-frame when crops are not growing.

**Aggregate Stability and Structure Index**, not collected in 2023 or 2024. These physical measures are targeted for corn years. We did have one year of collection 2021, and was planned as a repeat in 2023 but due to the drought conditions in fall, we did not sample. We hope to collect in 2025 (another corn year) so we have two years for comparison. Initial results of Structure Index showed that there was notably better soil structure for CC than CV.

**Local weather station probe, missing or damaged** - In 2022, NCC had a local weather station probe that went missing (stolen) or was damaged and lost. This local weather data is needed to more accurately measure both the amount of precipitation as well as solutes in precipitation. While there are two weather stations nearby (Austin and Dobbins Ck), these locations are too far away to capture accurate rainfall at the SAA site, especially for isolated rain showers and storm events. We hope to have the soil moisture and weather equipment up and running in 2025.

## 3.2 Documentation of summer drought conditions in 2023 with above normal conditions in 2024

The figure below (Figure 3.2a), shows the precipitation events between early spring (4/1) to late fall (11/1) in both 2023 and 2024, recorded at the Mower County station near Dobbins Creek, east of Austin, MN. Visual analysis shows that 2024 had a much wetter spring than 2023 and while there was less precipitation mid-summer in 2024, there were more substantial rain events that would be needed in order to surpass soil and plant evaporation rates in the shallow rooting zone (dashed horizontal line, set at 0.75 inches for no particular reason except to aid discussion and year-to-year comparisons). For 2023, there were very few precipitation events with substantial rainfall totals. A total of 5 inches of rain fell during the 10 days following corn planting. No appreciable rain fell until June 25th. As a result, all nitrogen product topdressed since planting did not incorporate into the soil for 3-5 weeks. Corn was exhibiting moisture stress since the end of the second week of June. Soil probes indicated that moisture levels at the 7.9 inch depth were below the wilting point until June 25-26th when approximately 0.75 inch of precipitation fell. This lack of rain resulted in not having enough water to infiltrate down into the vadose zone far enough to allow for us to sample water from our wells, as occurred in 2023 (corn) as well as fall of 2022 (soybean).

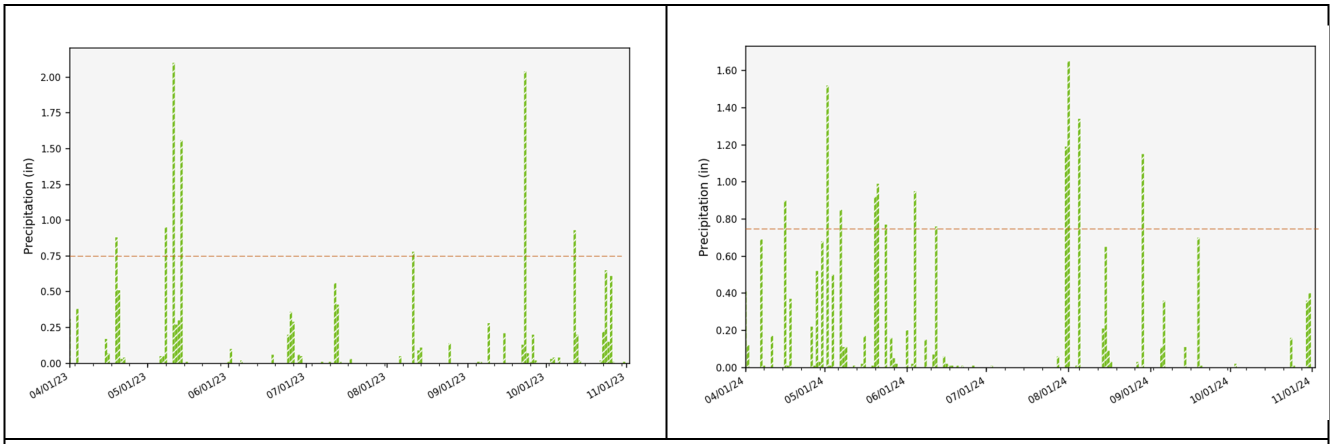


**Figure 3.2a.** Precipitation for 2023 (corn) and 2024 (soybean). Dotted line at 0.75 inches of rain for events considered "substantial".

The following figure (Figure 3.2b) provides a comparison with 2022 (soybean). Note the lack of late summer/fall precipitation, drought.

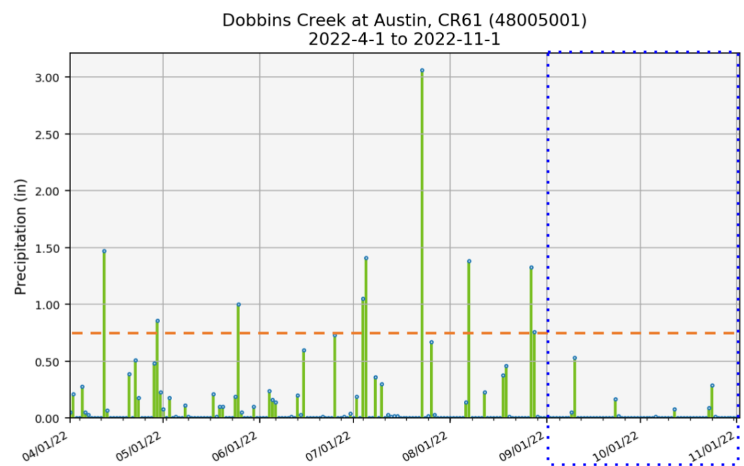


**Figure 3.2b.** Precipitation for 2022 (soybean). Note the lack of late summer/fall precipitation.

Precipitation records for other years (2018-2021) in Figure 3.2c below. Year 2019 (startup year) had many more rain events with much larger total rainfall during September/October (mid-summer lack of rain, but wet fall), which followed a very wet year (2018). Then compare 2020 (wet summer, but fairly dry fall; soybean) and 2021 (much drier summer and fall; corn).

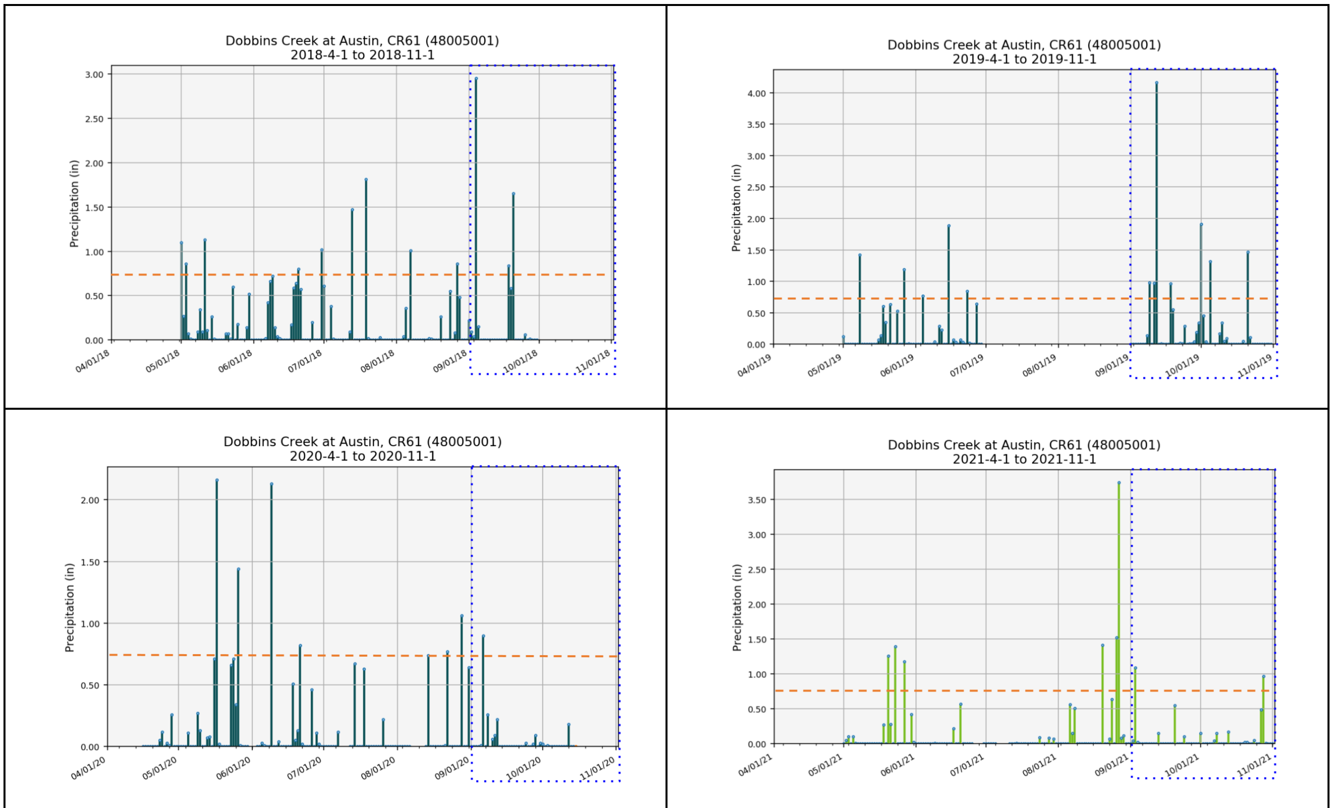


**Figure 3.2c** - Comparison of Precipitation Patterns by Year (2018 to 2021)

The next figure (*Figure 3.2b*) is from the Minnesota Department of Natural Resources website (Year to Date Precipitation Chart | Minnesota DNR (state.mn.us). The graph shows the precipitation accumulation for 2024 (blackline, 2rd from top) as compared to normal (green line, 3nd from top). Observing the black line between July and August, 2024 was wetter than the wettest year on record (2016, light blue line). On July 6th 2024, the accumulated precipitation (28.8 in) was 10 inches higher than the wettest/normal years which were the same on this date (18.8 and 18.9 mg/L, respectively). Less rain in the later summer and fall brought the 2024 precipitation totals through October 31, 2024 (37.4 in) to only 4.3 in. higher than normal (33.1 in).

The following figure shows the rainfall for 2024 as Year to Date Precipitation.

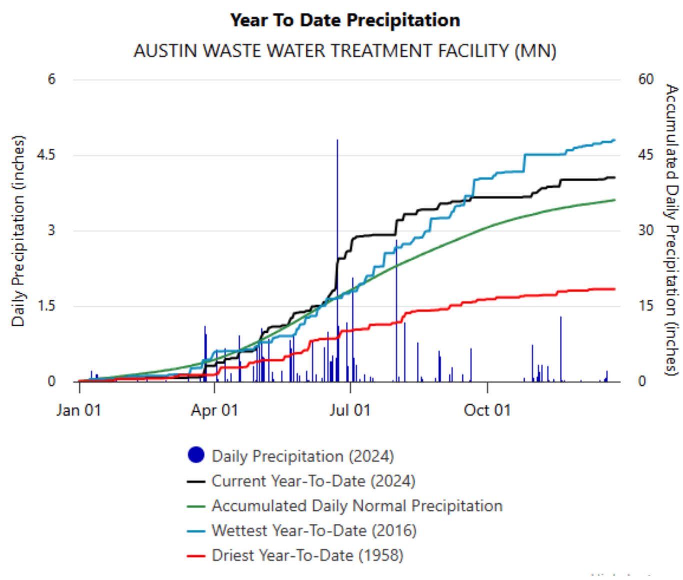


**Figure 3.2a** - Documentation precipitation records for 2024 compared to wettest and driest years on record.

While challenging at times, these year-to-year differences have also allowed us to view nitrate movement in soil and groundwater under different precipitation patterns. For example, we are finding that when precipitation is lower, there is less water leaching of nitrate-nitrogen into the groundwater; and the overwinter soil nitrogen pool remains larger. In contrast, this excess nitrogen pool was solubilized and infiltrated with adequate rain events in 2024 and the nitrate levels were very high (up to 6-8x the drinking water standard). Nitrate data from a normal year of precipitation and a corn year (hopefully in 2025) would provide a better picture of precipitation effects of nitrate movement through soils across different precipitation conditions, crops, and cropland treatments (i.e., tillage, cover crop, fertilizer application). This is needed for us to develop a reasonable nitrogen budget for a corn-soybean rotation.

## 4.) EDUCATION AND OUTREACH ACTIVITIES

*(Describe any opportunities to engage with farmers, influencers or the media about your project.*

Staff from MSWD hosted the Riverland College Soil and Agronomy labs at the SAA site for 4 occasions in 2024.

**Image 4.1**: Riverland students, Riverland Professor, Nick Schiltz and NCC employees, Dave Vaughan and Megan Solland talking about crop production and soil health at the SAA.

### Media

The *Sustainable Answer Acre* project is featured on the Mower SWCD Project Page:

Research – Mower County Soil & Water Conservation District (mowerswcd.org)

### Journal Article, in future

UMN will prepare a peer reviewed manuscript for journal publication at the end of the project (*potentially in 2028*).

## 5.) HOW CAN WE HELP?

*(Please let us know how we can improve the experience for the next generation of projects.)*

We are very grateful for the continued support of the *MN Corn Growers Association* and other collaborators for this *Sustainable Answer Acre* project.

Without additional funding and samples in 2025, we will not be able to fully produce the analysis required in order for us to answer the key questions that we identified for setting up this *Sustainable Acre Answers* study (see *Objectives* above). With the plots placed, cooperation of farmers, and sampling equipment installed already, we are able to prioritize funding for water vadose zone samples. We would also be able to analyze and compare our nitrate samples along with the soil health measures collected in 2020 and 2021 (*Background*, baseline) and planned for 2025 (*After*, tracking

BMP performance overtime). 2025 will be another corn year which will be important for the *After* of our study.