NREC – 2019 (December 1, 2019)
Annual report: Building a South Dakota Corn No-tillage N Recommendation Algorithm that Considers Improvements in Soil Health,

Prepared by David Clay and Dwarika Bhattarai

Summary

Many long-term South Dakota no-tillage farmers report that their fertilizer recommendations have decreased. A common perception is that these practices are linked to improved soil health resulting from the adoption of cover-crops and the adoption of reduced or no-tillage systems. In response to this perception, some soil testing laboratories are conducting soil health assessments, the NRCS and the SD Soil Health coalition has been demonstrating the impact of tillage on soil health and resiliency using the rainfall simulator and the buried underwear tests (http://igrow.org/agronomy/corn/tighty-whities/), and commercial products have been created that allows farmers to estimate N mineralization (https://solvita.com/soil/).

The impacts of cover crops, tillage, and plant diversity on soil and plant health is well documented in the scientific literature. For example, research indicating that crop management affects the soil micro-community was conducted in Andover and Trail City, South Dakota showing the bacteria to fungi ratio (measured using the PLFA technique) could be increased by planting a winter cover crop containing a Brassica (mustard family). Changes in the microbial composition are important because different organisms have different responsibilities in the soil. For example, bacteria decompose soil organic materials and release organic acids and siderophores that increase the availability of many nutrients, whereas in addition to increasing nutrient solubility, fungi enhance the transport of nutrients to the plant roots.

Benefits from a diverse microbial community can be integrated into fertilizer recommendations through multiple mechanisms including creating system recommendations (for example, tillage based recommendations in North Dakota) or basing the recommendation on changes in a measured soil property (carbon recommendation in Nebraska). We will explore both techniques in the creation of an algorithm that considers how interactions between management and soil biology affects N cycling. We believe that integrating soil health into the N recommendation will improve accuracy and reduce costs.

In year 1, experiments were initiated at seven South Dakota sites. At this point, all sites have been harvested and the soil sample analysis for water infiltration, microbial community structure, microbial respiration, and initial inorganic N have been completed. We are in the process of analyzing the soil and plant results from year 1. The data from the experiment are summarized below. During year 1, additional support was obtained from NRCS.

Goal and Objective

The long-term goal of this project is to improve South Dakota N recommendations in reduced tillage systems. The objectives are to: 1) build a corn reduced tillage N recommendation algorithm for South Dakota; and 2) as recommended by the board, assess if similar changes are needed for P and K fertilizers.

Results

In 2019, the experiment was conducted at 7 locations and at each site, the impact of 4 N rate (25, 75, 125, and 175 lbs N/a) on yield and nutrient budgets were determined (Table 1).

Each field was in no-tillage for at least 5 years (Table 1) and the plots had the dimension of 15 by 60 ft. The experiment also contained P and K treatments (112 kg P ha^{-1}, 112 kg K ha^{-1} and 112 kg P + 112 kg K ha^{-1}). Soil samples from five depths (0-2”, 2-6”, 6-12”, 12-24”, and 24-36”) were collected from prior to the application of fertilizers and from each plot in the fall following harvest. These initial soil samples were analyzed for 24-hr microbial respiration (0-2”, 2-6” and 0-6”), soil nitrate-N and ammonium-N analysis (all depths). In addition, two soil samples (0-2”) from each block were collected and analyzed for phospholipid fatty acid (PLFA)

The respiration test was conducted using LI-8100A and LI-8150 soil CO_2 flux system (LICOR Biosciences). It was measured in the form of CO_2-C flux and computed as g CO_2-C ha^{-1} hr^{-1}. Soil nitrate-N and ammonium-N was extracted with 1M KCl (10:1). Soil PLFA was extracted following a modified Buyer and Sasser (2012) protocol.

Between the corns V4 and V8 growth stages reflectance was measured using multispectral radiometer (Cropscan, Inc.). In addition, chlorophyll reading was measured using SPAD 502 plus chlorophyll meter (Konica Minolta, Inc.). Grain and stover samples were collected. After the harvest, soil samples from four depths (0-2”, 2-6”, 6-12”, and 12-24”) from each treatment plots were collected, dried, and ground. The economic optimum nitrogen rate (EONR) for each site was calculated based on corn selling prices of 3, 3.75, and 4.5 $/bu and N selling prices of .3, 0.38, and .46 $/lb N.

Table 1. The location of the different experiments conducted in 2019.

SN	Farmer’s name	Location	Abbreviation	GPS coordinates
1	Dan Forgey	Gettysburg	DFO	45.006328, -100.122672
2	Dennis Hoyle	Roscoe	DHO	45.49027778, -99.21666667
3	Bob Speck	Miller	BSP	44.534950, -98.910852
4	Dakota Lakes	Irrigated	DLI	44.292253, -100.004882
5	Dakota Lakes	Dryland	DLD	44.290040, -99.996441
6	Bryan Jorgensen	Ideal	BJO	43.54388889, -99.92555556
7	Scott Carlson	Badger	SCA	44.54241666, -97.282194444

Table 2. At the different studies, the planting, fertilizer application, and harvest dates of the different sites in 2019.

SN	Sites	Planting date	Fertilizer application	Harvest date
1	Dan Forgey	05/14/2019	05/14/19	10/08/19
2	Dennis Hoyle	05/26/2019	07/09/19	10/14/19
3	Bob Speck	06/06/2019	06/24/19	10/14/19
4	Dakota Lakes-I	05/14/2019	05/30/19	10/15/19
5	Dakota Lakes-D	05/15/2019	05/30/19	10/09/19
6	Bryan Jorgensen	05/15/2019	06/13/19	10/19/19
7	Scott Carlson	05/16/2019	06/18/19	10/18/19

Initial Soil Inorganic Nitrogen

In the spring, prior to applying the fertilizer nitrate and ammonium concentrations decreased with increasing depth (Fig. 1). The average NO_3-N concentration for the 0- to- 2 inch depth was 25 ppm, whereas NH_4-N was 46 ppm. The amount of NO_3-N in the surface 2 ft will be used to determine the N recommendation using the current equation.

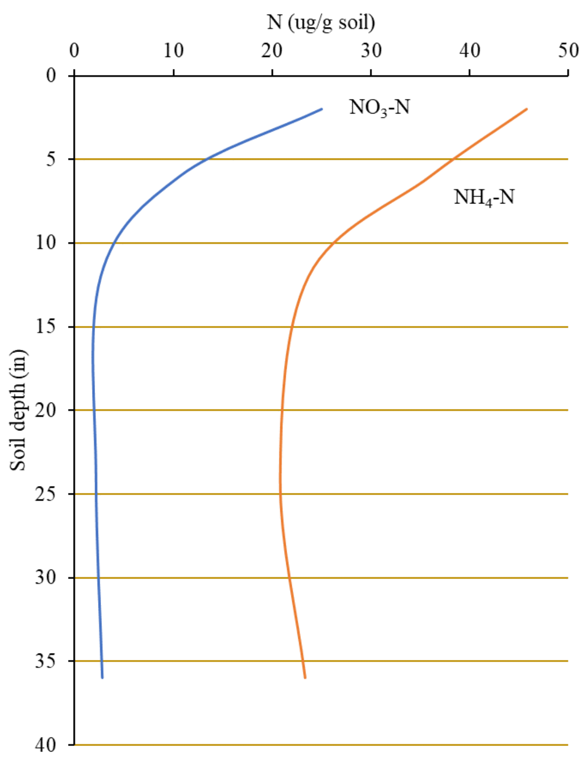


Figure 1. The concentration (ppm) of nitrate-N (NO_3-N) and ammonium-N (NH_4-N) at various soil depths in the spring of 2019. This data is averaged across all sites.

N fertilizer impact on corn yield

For most of the sites, corn yields increased with N rate. However, several of the sites had minimal to no increase in yield with increasing N rate (Fig 2). At Brian Jorgensen (BJO) yield increased by increasing the N rate from 75 to 125 lbs N/a, whereas at Bob Speck applying N did not increase yields. Across sites, the highest yields were observed at Dakota Lakes-Irrigated. The relatively low yields and N responses were attributed to the difficult growing conditions.

Figure 2. Corn grain yield (at 15% moisture content) from different sites and N rates. The letters on the top of each bar represents the mean comparison between the N treatments within each site. Error bar represents the standard error of means. In this chart, DFO is Dan Forgey, DHO is Dennis Hoyle, BSP is Bob Speck, DLI is Dakota Lakes irrigated, DLD is Dakota Lakes dryland, BJO is Bryan Jorgensen, and SCA is Scott Carlson.

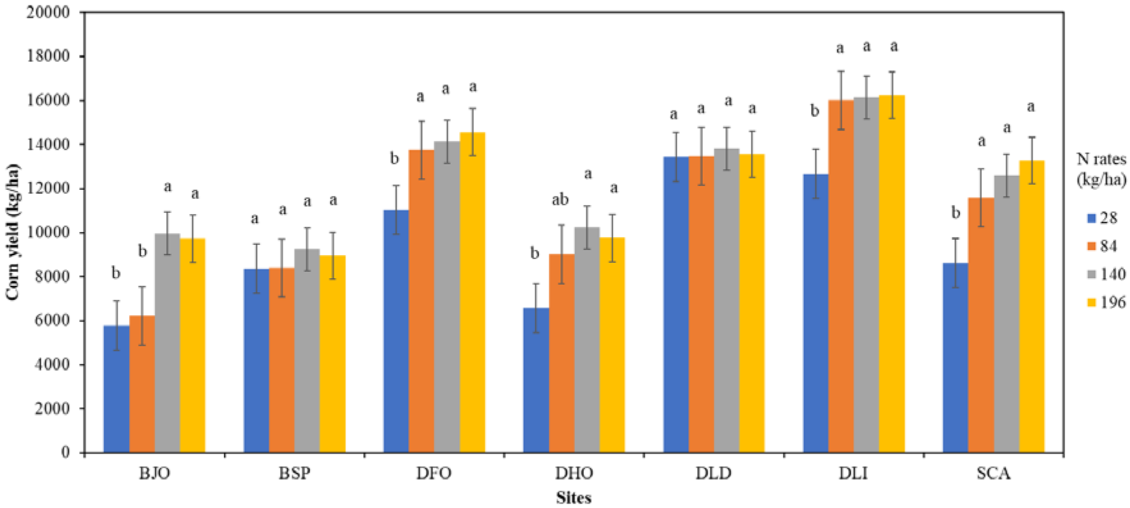


Table 3. Corn yield (kg ha^{-1}) at various N rates (kg ha^{-1}) and at different sites in long term no-till conditions at South Dakota. In this chart, DFO is Dan Forgey, DHO is Dennis Hoyle, BSP is Bob Speck, DLI is Dakota Lakes irrigated, DLD is Dakota Lakes dryland, BJO is Bryan Jorgensen, and SCA is Scott Carlson.

N rates	Corn yield						
	BJO	BSP	DFO	DHO	DLD	DLI	SCA
lbsN/a				bu/a			
25	92b	133	176a	105b	214	202b	138b
75	99b	134	219a	144a	215	256a	185a
125	159a	148	226a	163a	221	258a	201a
175	155a	143	232b	156a	217	259a	212a
p-value	0.044	0.514	<0.001	0.026	0.739	0.029	0.003

The economic optimum N rates were dependent on the corn selling price and the N purchase price. Increasing the cost of N reduced the N rate and increasing the corn selling price increased the N rate. In the experiment the EONR ranged from 14 to 148. Future analysis will compare the soil health measurement with the N response. Across the sites, in 2019 adding additional P and K did not increase yields.

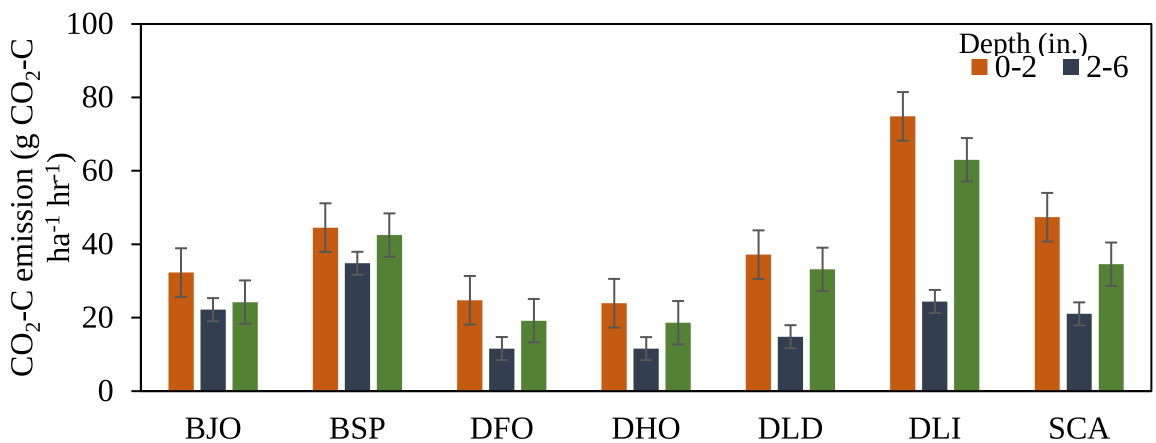
Table 4. Economic optimum nitrogen rate based on quadratic plateau model for all experimental sites. The corn selling price in this chart was \$3.75/bu and N purchase price was 0.384/lb N. In this table, DFO is Dan Forgey, DHO is Dennis Hoyle, BSP is Bob Speck, DLI is Dakota Lakes irrigated, DLD is Dakota Lakes dryland, BJO is Bryan Jorgensen, and SCA is Scott Carlson.

Sites	EONR (lbN/a^1)
BJO	150
BSP	88
DFO	105
DHO	119
DLD	14
DLI	86
SCA	148

Soil health measurement: 24 hour Soil Respiration

The 24 hour soil respiration tests of dried and rewetted soil varied with depth and site. The highest respiration rates were observed at the Dakota Lakes-irrigated site (DLI) (Fig. 2). Across the sites, the CO_2-C emission from the 0- to- 2, 2- to-6 in depths were 43.11 and , 23.48 g CO_2-C ha^{-1} hr^{-1} respectively. This test is often referred to as the Haney test (Haney et al., 2018). As the data set is completed we will calculate a modified soil health score (Haney et al., 2019). Haney et al. (2018) defines the score using the equation, $SHS = \frac{1\ day\ CO2}{10} \times \frac{WEOC}{100} \times \frac{WEON}{10}$, where WEOC is active organic C and WEON is active organic N. Testing of this score, showed that there was a poor relationship between soil test N + applied/corn yield and the measured score. Clearly improvements are needed. We believe that a score that considers water infiltration, aggregate stability, soil organic C, the microbial community structure, or the tillage and rotation will improve the predictability.

Figure 3. The 24- hour respiration rates of the dried and rewetted samples from the 7 sites. Graph showing the CO_2-C emission from soil various depths and different sites. Error bar represents the standard error of means (SEM). In this chart, DFO is Dan Forgey, DHO is Dennis Hoyle, BSP is Bob Speck, DLI is Dakota Lakes irrigated, DLD is Dakota Lakes dryland, BJO is Bryan Jorgensen, and SCA is Scott Carlson



Soil microbial community structure

Understanding the impact of the microbial community structure on N responses are important because different organisms perform different tasks. In Haney et al. (2018) the microbial community structure is not considered. However, we believe that interactions between management, soils, and management has a profound impact on the microbial community structure and ultimately nutrient efficiency. The microbial community structure are important because fungi are generally more efficient, have slower growth rates, higher C:N ratios, are more tolerant to dry soil and pH conditions, and have greater potential to immobilize N than bacteria (Rousk and Bååth, 2007; Rousk et al., 2009; de Vries, 2009). In addition, fungi do not fix N, however they do increase nutrient uptake through their hyphal network, produce glomalin that builds soil structure, have the ability to produce N_2O through denitrification, and are favored at lower temperatures (Seo and Delaune, 2010; de Vries, 2009; Clay et al., 1990b; Pietikälainen et al., 2005). Selected bacteria have the capacity to fix N_2, release organic acids to solubilize nutrients, produce siderophores that chelate iron, convert ammonium to nitrate, and use nitrate as the final electron acceptor. These findings suggest that climatic changes may impact the microbial community structure and nutrient cycling (Andersen et al., 2014). Our analysis showed that there was large differences between the sites, that need to be explored further (Fig 4 and 5)

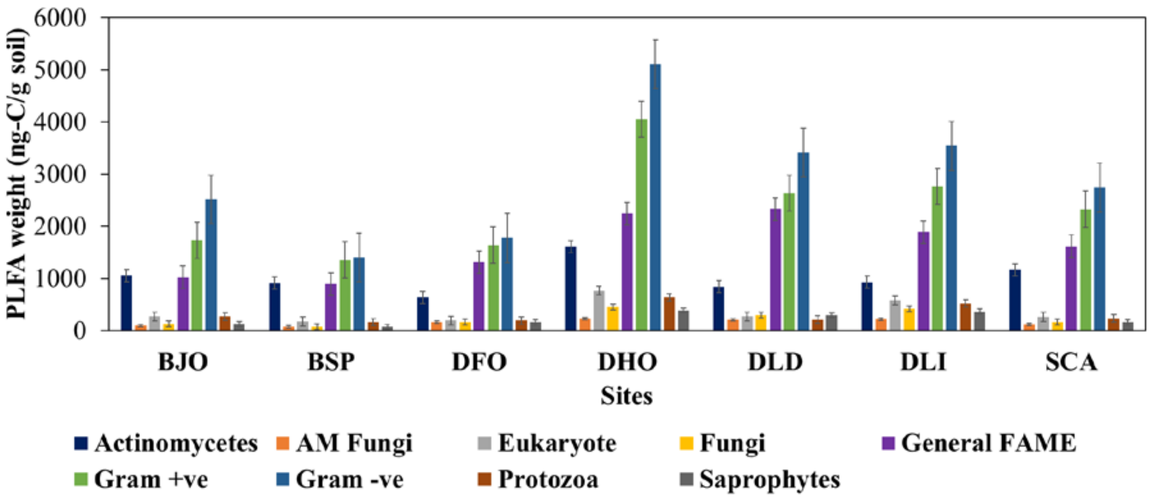


Figure 4. Graph showing the PLFA weight (ng-C/g soil) of different soil microbes types at various experimental sites during spring before fertilizers application. Error bar represents the standard error of means (SEM). In this chart, DFO is Dan Forgey, DHO is Dennis Hoyle, BSP is Bob Speck, DLI is Dakota Lakes irrigated, DLD is Dakota Lakes dryland, BJO is Bryan Jorgensen, and SCA is Scott Carlson.

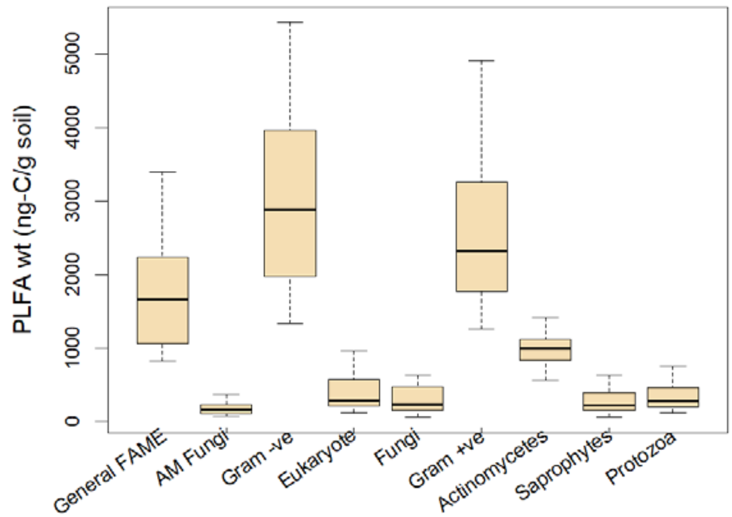


Figure 5. The average and range in the microbial community structure values when averaged across the 7 sites.

Table 5. Average soil health values from different sites.

Sites	**PLFA weight (ng-C g^{-1} soil)**									**Water infiltration capacity (in hr^{-1})**	**NO3-N (ugg^{-1} soil)**	**NH4-N (ug g^{-1} soil)**
	Actino mycetes	**AM Fungi**	**Eukaryote**	**Fungi**	**General FAME**	**Gram +ve**	**Gram -ve**	**Protozoa**	**Saprop hytes**			
BJO	1059	97.	271	126	1021	1732	2511	271	126	1.25	14.04	70.13
BSP	911	74	175	74	893	1352	1407	162	74	2.16	10.09	47.77
DFO	638	159	192	159	1315	1641	1776	192	159	2.34	21.43	32.58
DHO	1610	227	764	454	2244	4051	5103	637	385	1.52	32.60	26.09
DLD	843	205	269	296	2334	2635	3411	211	296	3.31	22.78	49.49
DLI	931	217	581	415	1887	2765	3539	521	367	1.59	39.56	16.36
SCA	1167	120	264	159	1619	2328	2741	235	159	2.20	34.70	77.85

Water infiltration

Water infiltration is an important soil health value because it provides and index on the amount runoff and erosion. At the 7 sites the soils water infiltration capacity ranged from 1.25 to 3.31 inches per hour. These values are less than the saturated hydraulic conductivities for long-term no-tillage in Nebraska (Blanco-Canqui et al., 2017). The low water infiltration rates for 2019 was attributed to high rainfall and soil moisture contents in 2019.

The field research was completed and we are in the process of completing the laboratory analysis. Most of the data that has been collected was summarized in this report. The next step is to assess why differences in the economic optimum N rates across the sites were observed and start thinking about how we can modify the soil health calculator so that it can be used for N recommendations. Findings from Haney et al. (2018) suggest that the current calculator could be improved. Our goal is to complete this analysis prior next field season

Impacts: None to date

Changes in people: none

Budget: We are not requesting an extension and we anticipate that the funds will be expended by the completion of year 1.

	year 1	year 2	year 3
Project leader	11,101	11,434	11,777
Laboratory coordinator	7,622	7,851	8,087
Graduate student	21,584	22,232	22,900
Undergraduate student	8,000	8,000	8,000
Benefits	4,883	5,062	5,246
Total salaries	53,190	54,579	56,010
Travel	6,000	6,000	6,000
Materials and supplies	2,000	2,000	2,000
Publications	0	1,000	2,000
Contractual	28,014	28,014	28,014
Total costs	89,204	91,593	94,024

Reference:

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Summary

In years 1 and 2, experiments were initiated at seven South Dakota sites each year. At this point, all sites have been harvested from year 2 and the soil sample analysis for microbial community structure, and initial inorganic N have been completed. We are in the process of analyzing the soil and plant results from year 1 and 2. The data from the experiment are summarized below. We have completed 13 site years. Seven of those studies were collected in 2019, which was very wet and 6 were conducted in 2020, which was relatively dry.

At the completion of the 2021 growing season, we should have at least 18 study sites. As discussed, data from these studies represent a wide range of conditions. Based on this information we will build a corn reduced tillage N recommendation model for South Dakota farmers. The findings will be shared annually with the individual producers, neighbors, and agronomists. Blogs will be prepared and distributed through social media and non-technical guides published in the South Dakota Corn Best Management Practice Manual. The potential impacts include improved profitability resulting from more accurate recommendations, and findings that will determine if P and K recommendation warrant similar modifications. Additional support is provided by NRCS.

Goal

The long-term goal of this project is to improve South Dakota N recommendations in reduced tillage systems. The objectives are to: 1) build a corn reduced tillage N recommendation algorithm for South Dakota; and 2) as recommended by the board, assess if similar changes are needed for P and K fertilizers.

Justification

Nitrogen management in no-till system can be different as compared to tillage system. The presence of surface residues can help to conserve soil moisture and reduce the loss of N through volatilization. In addition, reduced tillage systems are known to promote topsoil soil organic carbon, and microbial biomass and activities (Krauss et al, 2020). Nitrogen mineralization is primarily driven by soil microbial biomass (Li et al, 2019), which can be related to increased N availability to plants. This concept matches with the results from N fertilizer recommendation in long term no-till corn for North Dakota (https://www.ag.ndsu.edu/publications/crops/north-dakota-fertilizer-recommendation-tables-and-equations). Moreover, no-till farmers from South Dakota have reported decreased N fertilizer rate in corn. So, this research focuses on determining the N fertilizer rates for no-till corn in South Dakota considering the improvements in soil health.

Soil health is referred to the continued capacity of soil to function as a living ecosystem, which can be achieved by promoting living soil organisms through better soil and crop management practices. A study in South Dakota by Reese et al (2014) reported increase in bacteria to fungi ratio by planting winter cover crops including Brassica family. As mentioned at the beginning, soil microbial communities increase with the adoption of no-till practices.

In our research, we are working to find the relationship between soil microbial communities, soil physical and chemical properties including N availability, and corn yield. Benefits from a diverse microbial community can be integrated into fertilizer recommendations through multiple mechanisms including creating system recommendations (for example, tillage-based recommendations in North Dakota) or basing the recommendation on changes in a measured soil property (carbon recommendation in Nebraska). We will explore both techniques in the creation of an algorithm that considers how interactions between management and soil biology affects N cycling. We believe that integrating soil health into the N recommendation will improve accuracy and reduce costs.

Sites description and experimental design:

Similar to 2019, the experiments were conducted in 7 sites (Table 1) and at each site, six different N treatments (0, 40, 80, 120, 160 and 200 lbs. N $acre^{-1}$) were replicated four times (except for one site, DLI) and arranged in RCB design. Urea (46:0:0) fertilizer (treated with urease inhibitor) were broadcasted as the source of N before corn V4 growth stage. Each site was applied with recommended rate of P and K fertilizers based on soil test results. Based on 2019 corn yield, we have made a few adjustments on N treatments; we have also added a control plot (0 lb. N $acre^{-1}$). We are working with soil health research group from Missouri on P, K and S study at the same sites. Each field is in no-tillage for at least 6 years and the plot had the dimension of 15 ft wide and 50 ft long.

Table 1. List of different farmer's field, their location and GPS coordinates.

SN	Farmer's name	Field Name	GPS coordinates	Location
1	Bryan Jorgensen (Cover Crop)	BJC	43.571695, -99.941256	Ideal
2	Bryan Jorgensen (no CC)	BJO	43.572251, -99.941283	Ideal
3	Dan Forgey	DFO	44.937546, -100.123753	Gettysburg
4	Dennis Hoyle	DHO	45.490052, -99.215640	Roscoe
5	Dakota Lakes Dryland	DLD	44.292695, -99.996898	Pierre
6	Dakota Lakes Irrigated	DLI	44.291651, -100.001732	Pierre
7	Scott Carlson	SCA	44.499152, -97.300031	Badger

At DLI site, there was no uniform corn emergence (Fig. S1); we had to reduce our replication to three blocks. Compared to 2019, we have added a cover crop treatment at Bryan Jorgensen's field while we could not conduct the experiment at Bob Speck's site as the farmer could not plant corn. At Bryan Jorgensen's field, corn in the experiment without cover crop were planted at 30 inches row spacing whereas the one with cover crops were planted at 60 inches row spacing and cover crops were planted at corn V3 growth stage. The cover crop species planted were oats (12 lbs. acre-1), flax (2 lbs. acre-1), mung bean (4 lbs. acre-1), gaur (2 lbs. acre-1) and red clover (1 lb. acre-1).

Soil samples from four depths (0-2", 2-6", 6-12", and 12-24") from each block were taken prior to the application of fertilizers and from each treatment were taken after corn harvest. In addition, soil samples (0-2”) from each block were taken before planting corn, at corn V6 and VT growth stages, and after harvest for phospholipid fatty acid (PLFA) analysis. Between the corn V8 and V10 growth stages reflectance was measured using multispectral radiometer (Cropscan, Inc.). Corn ears were harvested from 100 sq. ft. area and calculated the yield at 15% moisture. Grain and stover samples were collected.

Soil nitrate-N and ammonium-N were extracted with 1M KCl (10:1). Soil PLFA was extracted and analyzed using a modified Buyer and Sasser (2012) protocol. Soil pH and EC were measured using XL-60 dual channel pH/conductivity meter (Fisher Scientific).

Detailed agronomic information for each site are presented in Table 2.

Table 2. Agronomic information of different experiment sites.

SN	Field name	Planting Date	Fertilizer application	Previous crop(s)	Corn maturity	Plant population (per acre)
1	BJC	4/29/20	5/19/20	Wheat	100 days (AV5799) 104 days (P046AM)	24500
2	BJO	4/29/20	5/19/20	Wheat	100 days (AV5799) 104 days (P046AM)	24500
3	DFO	5/11/20	5/21/20	Wheat	96 days (DK 46-18)	25000
4	DHO	5/15/20	6/17/20	Sorghum + Oats+ millet	88 days (Organic)	27000
5	DLD	4/30/20	6/11/20	Oats + Barley	99 CRM (P9998AM)	21000
6	DLI	4/24/20	6/15/20	Oats + Barley + Peas + Rape	104 CRM (P0421AM)	35000
7	SCA	4/27/20	5/12/20	Soybean	97 days (AP970)	32000

CRM – Comparative Relative Maturity for Pioneer corn

Results and discussion

Initial soil inorganic nitrogen

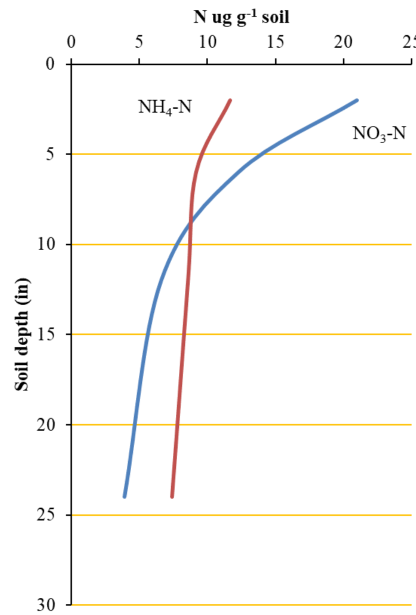


Figure 1. The concentration (µg g^{-1} soil) of nitrate-N (NO_3-N) and ammonium-N (NH_4-N) at various soil depths in the spring of 2020. This data is averaged across all sites.

In the spring, prior to applying the fertilizer nitrate and ammonium concentrations decreased with increasing depth (Fig. 1). The average NO_3-N concentration for the 0-to-2-inch depth was 21 ppm, whereas NH_4-N was 12 ppm. The amount of NO_3-N in the surface 2 ft will be used to determine the N recommendation using the current equation.

Table 3 showed the NO_3-N and NH_4-N from different experiment sites at various depths in Spring 2020, prior to planting corn. The data from Dakota Lakes Dryland should be re-run because of an issue with the N analyzer.

Table 3. Corn yield (bu a^{-1}, 15% moisture) at various N rates (lbs a^{-1}) and at different sites in long term no-till conditions at South Dakota,2020. In this table, BJC is Bryan Jorgensen with cover crops, BJO is Bryan Jorgensen, DFO is Dan Forgey, DHO is Dennis Hoyle, DLD is Dakota Lakes dryland, DLI is Dakota Lakes irrigated, and SCA is Scott Carlson. The number '20' after each site name represents year 2020.

Depth	BJC20	BJO20	DFO20	DHO20	DLI20	SCA20
inches			NO_3-N (µg g^{-1} soil)			
0-2	25.10	32.98	4.82	15.78	19.46	23.21
2-6	12.57	14.97	5.15	19.73	10.97	9.80
6-12	6.86	6.32	3.60	8.81	6.65	7.39
12-24	2.82	3.13	4.25	4.69	5.09	3.76
			NH_4-N (µg g^{-1} soil)			
0-2	13.89	17.38	4.74	8.91	4.00	17.39
2-6	11.14	12.13	5.06	7.53	3.17	14.44
6-12	9.05	10.93	6.03	8.33	4.01	11.93
12-24	6.44	9.72	5.96	5.57	4.36	11.60

N fertilizer impact on corn yield

Corn yields significantly increased with N rate in Dan Forgey (DFO) and Scott Carlson (SCA) sites only (Table 4, Fig. 2). At DFO, yield was highest at 120 lbs N $acre^{-1}$ whereas at SCA, yield was highest at 160 lbs N acre^{-1} but significantly similar to the yield at 120 lbs N acre^{-1}. At Dakota Lakes, we could not use the control treatment as the manager had planned to apply 30 lbs N acre^{-1} as pre-plant. The average yield was greatest at Dakota Lakes irrigated site whereas the lowest yield was recorded at Dennis Hoyle (DHO) site. The low yields and N responses were attributed to the difficult growing conditions and poor corn performance (Fig. S2).

Table 4. Corn yield (bu a^{-1}, 15% moisture) at various N rates (lbs a^{-1}) and at different sites in long term no-till conditions at South Dakota,2020. In this table, BJC is Bryan Jorgensen with cover crops, BJO is Bryan Jorgensen, DFO is Dan Forgey, DHO is Dennis Hoyle, DLD is Dakota Lakes dryland, DLI is Dakota Lakes irrigated, and SCA is Scott Carlson. The number '20' after each site name represents year 2020.

N rates	Corn yield						
	BJC20	BJO20	DFO20	DHO20	DLD20	DLI20	SCA20
lbs N a^{-1}	bu a^{-1}						
0	116	141	150^{c}	73	NA	NA	128^{d}
40	128	156	155^{bc}	68	150	236	171^{c}
80	120	165	165^{b}	61	163	280	196^{b}
120	133	172	181^{a}	69	169	279	205^{ab}
160	123	167	164^{b}	61	171	281	214^{a}
200	138	174	163^{bc}	61	158	282	214^{a}
p-value	0.270	0.152	0.004	0.696	0.562	0.069	<0.001

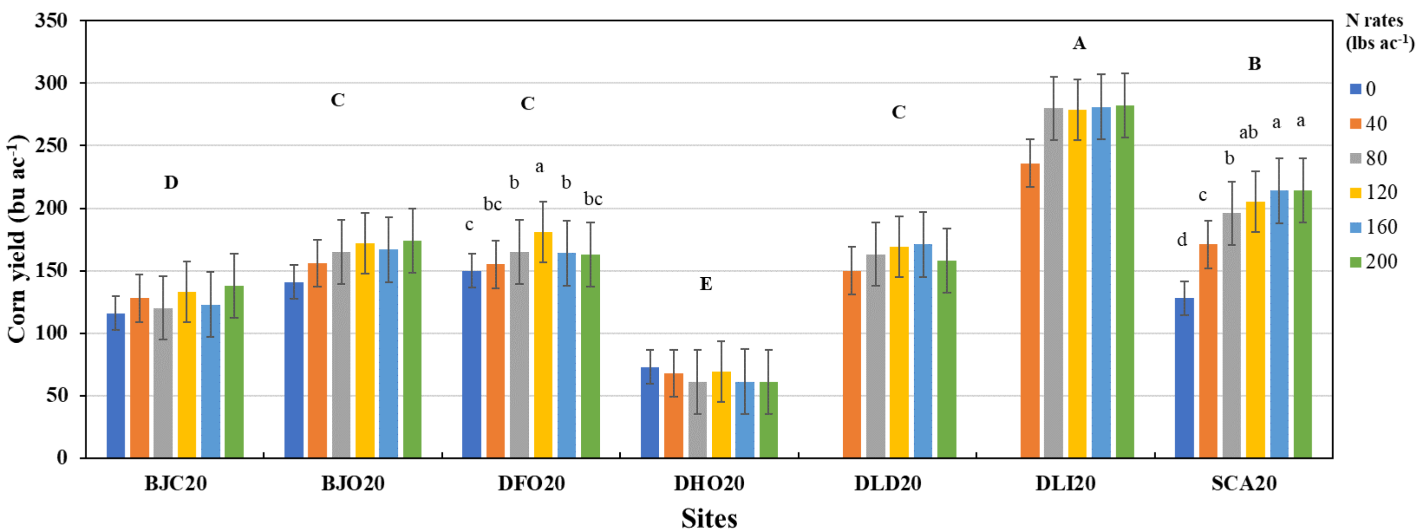


Figure 2. Corn yield (bu a^{-1}, 15% moisture) at various N rates (lbs a^{-1}) and at different sites in long term no-till conditions at South Dakota,2020. In this chart, BJC is Bryan Jorgensen with cover crops, BJO is Bryan Jorgensen, DFO is Dan Forgey, DHO is Dennis Hoyle, DLD is Dakota Lakes dryland, DLI is Dakota Lakes irrigated, and SCA is Scott Carlson. The number '20' after each site represents the year 2020. Lowercase alphabets above each column represent yield differences in response to N treatment within a site and uppercase alphabets represent yield differences between sites. Bars represent standard error.

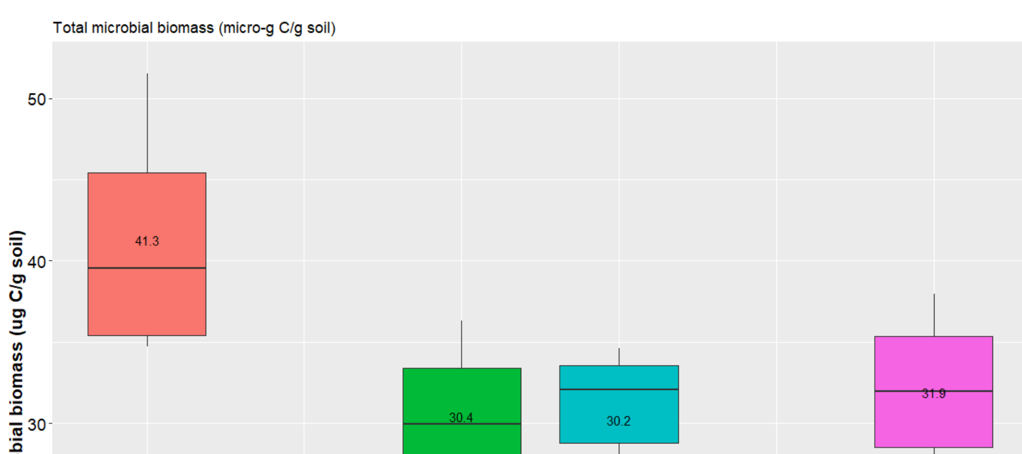
The economic optimum N rates (EONR) were dependent on the corn selling price and the N purchase price. Increasing the cost of N reduced the N rate and increasing the corn selling price increased the N rate. In the experiment the EONR ranged from 26 to 144 (Table 5). Future analysis will compare the soil health measurement with the N response. Control treatment (0 lb N $acre^{-1}$) was not included in the calculation of EONR.

Table 5. Economic optimum nitrogen rate based on quadratic plateau model for all experimental sites. The corn selling price in this chart was $3.68/bu and N purchase price was 0.387/lb N In this table, BJC is Bryan Jorgensen with cover crops, BJO is Bryan Jorgensen, DFO is Dan Forgey, DHO is Dennis Hoyle, DLD is Dakota Lakes dryland, DLI is Dakota Lakes irrigated, and SCA is Scott Carlson. The number ‘20’ after each site name represents year 2020.

Sites	**EONR (lbs N a^{-1})**
BJC20	135
BJO20	108
DFO20	97
DHO20	26
DLD20	96
DLI20	83
SCA20	144

Soil microbial community structure

Soil microbial communities are important components of healthy soil because different microbes perform different tasks. Fungi are generally more efficient, have slower growth rates, higher C:N ratios, are more tolerant to dry soil and pH conditions, and have greater potential to immobilize N than bacteria (Rousk and Bååth, 2007; Rousk et al., 2009; de Vries, 2009). In addition, fungi do not fix N, however they do increase nutrient uptake through their hyphal network, produce glomalin that builds soil structure, have the ability to produce N_2O through denitrification, and are favored at lower temperatures (Seo and Delaune, 2010; de Vries, 2009; Pietikälainen et al., 2005). Selected bacteria have the capacity to fix N_2, release organic acids to solubilize nutrients, produce siderophores that chelate iron, convert ammonium to nitrate, and use nitrate as the final electron acceptor. In addition, several human activities might affect the microbial community structure, such as application of overdose of N fertilizer can suppress microbial biomass (Chen et al, 2015). Hence, microbial biomass and community structure can change at varying locations. Our analysis showed that there were large differences between the sites, that need to be explored further (Fig. 3).



Final Summary

After the completion of field research, we are processing the samples for laboratory analysis (after-harvest samples). Most of the data that has been collected was summarized in this report. Before the next field season, we will have complete data from year 1 and 2, which will be analyzed statistically to find possible influence of different parameters on yield. The results from year 1 were summarized and presented at 2020 ASA, CSSA, and SSSA Annual Virtual Conference and in North Central Soil Fertility Conference, 2020.

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Supplementary figures

Figure S1. Picture showing the corn patches because of mechanical issue at Dakota Lakes irrigated site.

Figure S2. Picture showing poor corn yield at Dennis Hoyle's site.

NREC – 2022
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Prepared by David Clay and Dwarika Bhattarai
Report – Work Progress
02/24/22

Research goal:

The goal of this project is to improve South Dakota N recommendation for reduced tillage systems. The objectives are to: 1) build a corn reduced tillage N recommendation algorithm for South Dakota; and 2) as recommended by the board, assess if similar changes are needed for P and K fertilizers.

Introduction:

Over the three-years of this experiment, research has been conducted on over 20 sites to determine the effects of soil health on N recommendations in no-tillage systems. Soil from these sites have been analyzed for plant and soil health characteristics and tissue samples have been analyzed for N and C. The next step in this project is to develop N recommendation algorithms that consider soil health.

We believe that the changes in soil health will improve nutrient efficiency for three reasons. First, higher soil organic matter contents and soil residue cover in reduced tillage systems increase precipitation and nutrient uptake efficiency. Second, higher soil organic matter contents and no-tillage leads to increased microbial diversity, which accelerates the movement of nutrients from less to more readily available forms. Third, increased fungal biomass increases the ability to take up both water and soil nutrients. No-tillage should increase fungal concentrations, which by itself should increase nutrient and water uptake.

Benefits from a diverse microbial community can be integrated into fertilizer recommendations through multiple mechanisms including creating system recommendations (for example, tillage-based recommendations in North Dakota) or basing the recommendation on changes in a measured soil property (carbon recommendation in Nebraska). We will explore both techniques in the creation of an algorithm that considers how interactions between management and soil biology affects N cycling. We believe that integrating soil health into the N recommendation will improve accuracy and reduce costs.

Site description and experimental design:

In years 1, 2, and 3 experiments were conducted at seven sites each year. Table 1 shows the list of farmers who provided their field to conduct our experiment. At this point, all sites have been harvested from year 3 and yields have been determined. Soil and plant samples are in the process of analysis. As discussed, these studies were conducted in a wide range of conditions, we will conduct a rigorous analysis of these data sets. The findings will be shared annually with the individual producers, neighbors, and agronomists. Blogs will be prepared and distributed through social media and non-technical guides published in the South Dakota Corn Best Management Practice Manual. The potential impacts include improved profitability resulting from more accurate recommendations, and findings that will determine if P and K recommendation warrant similar modifications.

Table 1. List of different farmer's field, their location, and year of experiment.

SN	Farmer's name	# Of field	Years of experiment	Location
1	Bryan Jorgensen	3	2019-2021	Ideal
2	Bob Speck	2	2019 and 2021	St. Lawrence
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6	Dakota Lakes Irrigated	3	2019-2021	Pierre
7	Scott Carlson	3	2019-2021	Badger

The experiment has six different N treatments (0, 40, 80, 120, 160 and 200 lbs. N acre^{-1}), only four treatments in 2019, replicated four times and arranged in RCB design. Urea (46:0:0) fertilizer (treated with urease inhibitor) were broadcasted as the source of N before corn V4 growth stage. Each site was applied with recommended rate of P and K fertilizers based on soil test results.

Soil samples from four depths (0-2", 2-6", 6-12", and 12-24") were collected from each block prior to the application of fertilizers and from each plot after corn harvest. These samples were analyzed for 24-hr microbial respiration (0-2"), soil nitrate-N and ammonium-N (all depths), soil pH and EC (all depths), total N and total C analysis (all depths). In addition, soil samples (0-2") were taken from each block before planting corn and from each plot at various corn growth stages for phospholipid fatty acid (PLFA) analysis. The respiration test was performed using Solvita test kit. Soil nitrate-N and ammonium-N is extracted with 1M KCl (10:1). Soil PLFA is extracted following a modified Buyer and Sasser (2012) protocol.

Climatic information:

Across the years, weather was never similar. The first year of our experiment, 2019, was a wet year followed by a normal wet year in 2020. The last year, 2021, was extremely dry year and resulted in poor corn yield in several locations. According to Applied Climate Information System (ACIS), in 2021, the cumulative rainfall during the corn growing season (May-October) ranged from around 4 inches to 16 inches across sites; precipitation during September and October covers more than 50% of the total rainfall during the season.

Preliminary N analysis on corn yield

Corn yield and corn N response across the experimental sites and years were different that might be because of various locations and weather conditions across years. For example, corn yield in 2020 ranged between 61 to 282 bu a^{-1} whereas in 2021 the range was between 41 and 236 bu a^{-1}. This information will be re-analyzed using strong machine learning algorithms to determine the corn N response.

Analysis between measured values.

Initial analysis of data collected in 2019, which was a high rainfall fall year showed that infiltration rate was very important (Table 2). Site with high infiltration had high yields. This data set also showed that sites with high electrical conductivity had low yields. The high correlation between yields and water infiltration during the high rainfall year was expected. It will be interesting to compare these results with different climatic conditions.

Table 2. Correlation coefficients between the different measurement

	Microbial biomass	NO_3-N	NH_4-N	pH	EC	Water infiltration	Solvita CO_2
Yield	-0.23	-0.15	-0.23	-0.55	-0.67	0.82	-0.37

Update on microbial community analysis

Soil microbial communities are important components of healthy soil because different microbes perform different tasks. A comparison on spring 2021 soil microbial biomass data from consecutive weeks (last week of April and first week of May) showed reduced fungal and mycorrhizal biomass in the later week whereas the bacterial biomass slightly increased (Figure 1). This implies that as the soil temperature increases, bacterial population starts increasing and thus improves mineralization. Fungi are known to improve nutrients uptake through their hyphal network and are favored at lower temperatures.

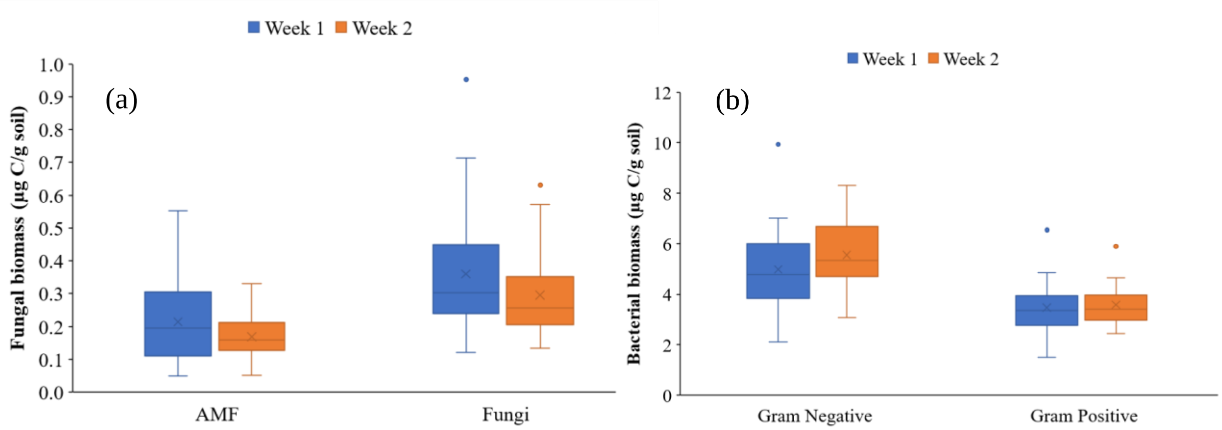

Figure 1. Boxplots showing the biomass of (a) Arbuscular Mycorrhizal Fungi (AMF), and Fungi, and (b) gram-positive and gram-negative bacteria (µg C/g soil) from the experiment sites in Spring 2021 before planting corn. In the figure, blue box represents the first sampling week (last week of April), and the orange box represents the second sampling week (first week of May). The data is averaged across experimental sites.

We have extracted soil DNA from one of our baseline samples from spring 2021. We have used DNA extraction kits from MP Bio company (Cat.NO.116560200, MP Biomedicals, Solon, Ohio). Microbial biomass determined using PLFA method had fair positive correlation (0.29) with the DNA yield. However, the DNA yield was highly correlated with the biomass of AMF (0.57) and fungi (0.4) (Figure 2).

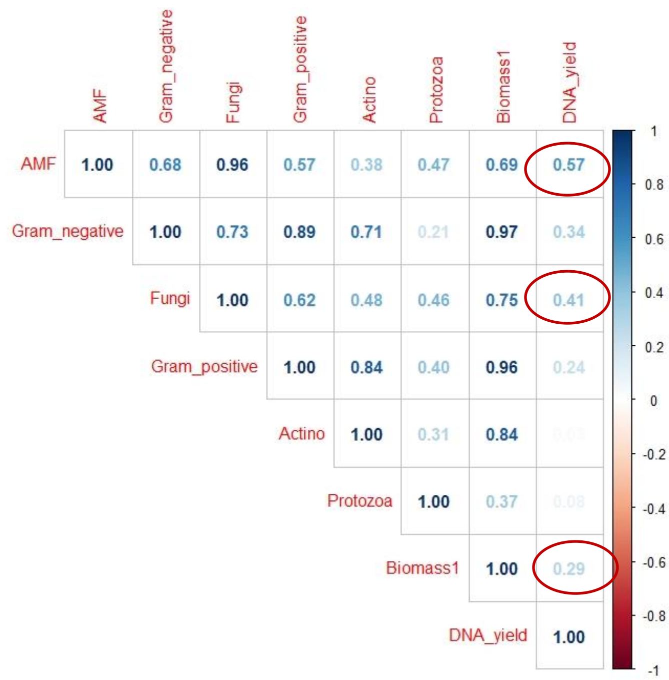

Figure 2. Correlation matrix showing the correlation coefficients across various soil microbial biomass and soil DNA yield.

Our previous results from Figure 1 have shown that the fungal biomass is higher in spring samples, which could have resulted in greater DNA from fungi and AMF. This information gives insight into determining the gene expression from the extracted DNA that will determine the proportion of different genes.

Summary

In this project, research was conducted for 3 site years with 7 sites each year. Each site year has very different soil and climatic conditions. The laboratory analysis has been completed for the first two years and we are in the process of completing the analysis for year 3. We had some delays due to problems associated with moving from Ag Hall to the Raven Precision Farming building. At this point, these problems have been minimized. We have found differences in corn yield and corn N response across sites. We performed preliminary data analysis from the first two years of data, which showed that soil health had a large effect on corn yields. We have extracted soil DNA from baseline samples, in addition to the PLFA analysis. Analyzing gene expression might make it easier to interpret the microbial activities, which will be completed in March 2022. By the end of this year, our goal is to complete this analysis and publish the findings at appropriate locations.

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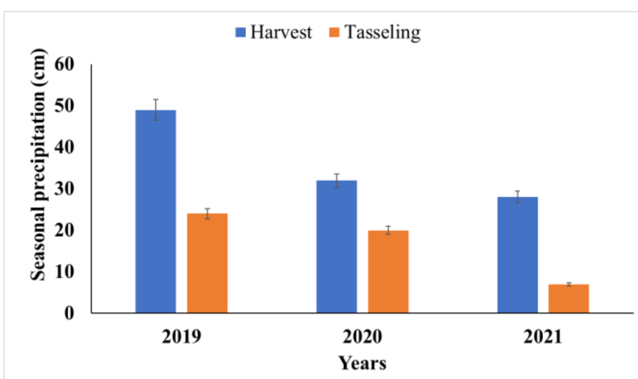

Figure 1. Bar diagram showing the seasonal precipitation (cm), at tasseling and harvest stages, across the experiment years.

Nitrogen analysis on corn yield

Corn yield and corn N response across the experimental sites and years were different that might be because of various locations and weather conditions across years. For example, corn yield in 2020 ranged between 61 to 282 bu a^{-1} whereas in 2021 the range was between 41 and 236 bu a^{-1}.

Our analysis showed that there were sites which were non-responsive to fertilizer-N. Corn yield at these non-responsive sites were more strongly correlated with evapotranspiration (0.86) and seasonal precipitation use efficiency (0.64) compared to fertilizer-N responsive sites. Moreover, the current SD corn N recommendation model was highly correlated with the economic optimum N rate (0.83) in non-responsive sites as compared to that in responsive sites (0.25). This information will be re-analyzed using strong machine learning algorithms to determine the corn N response.

Analysis between measured values.

Initial analysis of data collected in 2019, which was a high rainfall fall year showed that infiltration rate was very important (Table 2). Site with high infiltration had high yields. This data set also showed that sites with high electrical conductivity had low yields. The high correlation between yields and water infiltration during the high rainfall year was expected. It will be interesting to compare these results with different climatic conditions.

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Soil microbial communities are important components of healthy soil because different microbes perform different tasks. A comparison on spring 2021 soil microbial biomass data from consecutive weeks (last week of April and first week of May) showed reduced fungal and mycorrhizal biomass in the later week whereas the bacterial biomass slightly increased. This implies that bacterial population increased with temperature which increased mineralization.

Using the PLFA technique, it was not possible to identify the enzymatic activities as well as other soil transformations driven by soil microbes. This technique worked well to assess the soil microbial biomass and compare the temporal and spatial changes. Soil DNA sequencing method could be helpful to overcome the issues. We have extracted soil DNA from one of our baseline samples from spring 2021. We have used DNA extraction kits from MP Bio company (Cat.NO.116560200, MP Biomedicals, Solon, Ohio). Microbial biomass determined using PLFA method had fair positive correlation (0.29) with the DNA yield. However, the DNA yield was highly correlated with the biomass of AMF (0.57) and fungi (0.40).

The amount of nitrite reductase genes, *nirK and nirS*, across different sites were analyzed using qPCR techniques. The number of *nirK* and *nirS* genes were 1.46 million and 12,027 copies, respectively, across sites. These gene copies were obtained from the baseline soil samples. Since we were able to troubleshoot the issues related to qPCR analysis, soil samples from various growth stages, including the treatment application time, will be analyzed for different nitrifying and denitrifying genes. This information will be useful to understand the role of soil microbes in mineralization.

Summary

In this project, research was conducted for 3 site years with 7 sites each year. Each site year has very different soil and climatic conditions. The laboratory analysis has been completed for all the sites, except for microbial analysis. We have found differences in corn yield and corn N response across sites. We performed preliminary data analysis, which showed that soil health and climate had large effect on corn yields. We have extracted soil DNA from baseline samples, in addition to the PLFA analysis. We are, now, processing the soil samples for qPCR that provides the information regarding the quantities of various genes involved in N-cycle.

Our first paper is ready for submission to publish. We are working on the second chapter that includes the results from soil microbial community structure and analysis using machine learning approaches. By the end of this year, our goal is to publish the findings at appropriate locations.

Conferences and workshops:

Last year, we presented our work at the following regional, national, and international conferences.

- **First place**, oral presentation, Prediction of no-till corn N requirement using machine learning algorithm, ASA, CSSA, and SSSA international annual meeting, 6-9 November 2022, Baltimore, MD.
- **Poster presentation**, Prediction of no-till corn N requirement that considers soil health, Bayer poster competition, Nitrogen Use Efficiency Workshop organized by The University of Nebraska-Lincoln, August 1-3, 2022.