Soil Drainage, Tillage, And Crop Residue Management Impacts On Corn N Use Efficiency And Soil Health

FINAL REPORT 2023 Growing Season

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BACKGROUND:

A research site with 720 (10 by 30-foot) plots was established in 2011 to evaluate the effect of soil drainage [drained (fully-open tile) and undrained (fully-closed tile)] conditions on soybean yield in a poorly-drained soils in south-central Minnesota in a corn-soybean cropping system. Starting in 2014, the effect of nitrogen rate and time of application on both corn and soybean was added as a variable. In 2017, tillage variables (conventional, strip-till, no-till) were added. More recently, in fall 2021 we added crop residue management variables [corn residue removed, cover crop planted in the fall/terminated in spring without residue removal, and traditional (residue left on the field)]. While both crops are present every year, this study evaluates N availability and corn response to N rates under the drainage, tillage, and crop residue variables described. We know all these variables impact soil health (soil carbon and total soil N) and can impact how much N is available to produce corn because they directly impact mineralization/immobilization and N loss (leaching and denitrification). However, little or no information is currently available in the Midwest to adjust N fertilization rates based on these conditions. Over the duration of this study, the variables established will allow us to evaluate corn N use efficiency and soil health.

GOALS AND OBJECTIVES

Some of the previous findings obtained from this research site clearly showed that corn yields are similar with drained and undrained conditions, but the N rate needed in undrained conditions is greater to achieve the economic optimum regardless of tillage conditions. We have also observed that pre-plant applications work as good as, or better than, split applications in drained soils, but split applications are often superior for undrained soils. We have also evaluated soybean yield and grain quality in response to drainage and tillage and with regard to direct N application or residual N from the previous corn crop. Based on what we have learned from previous studies in this site, under long-term drainage conditions (established in 2011) and tillage conditions (since 2017) we are now ready to evaluate new concepts to refine N management and quantify their influence on soil health parameters for Minnesota farmers.

The objectives of this study are to evaluate the effect of N rate and crop residue management [corn residue removed, cover crop planted in the fall/terminated in spring without removal of residue, and traditional (residue left on the field)] on 1) soil N availability for corn, and 2) corn grain yield and nitrogen use efficiency. Our goal is to refine N management accounting for soil conditions (drainage) and management practices (tillage and crop residue) normally encountered in Minnesota to improve N use efficiency, economic returns, environmental protection, and soil health and productivity.

METHODS/TIMETABLES

The study was conducted in a long-term research site established on a farmer's field near Wells in south-central Minnesota. Drainage conditions were established in 2011 with every plot having subsurface tile drains installed. The site was divided into eight blocks where four blocks were randomly assigned to be drained (D) (control drainage structures fully open) and four were randomly assigned to be undrained (UD) (control drainage structures completely closed). Each of these blocks was subdivided to accommodate both corn and soybean crops that rotate every year. In 2017, three tillage treatments were imposed: 1) conventional till (CT), 2) no-till (NT) and 3) strip-till (ST). Starting in fall 2021 three levels of residue management were added where soil cover from plant materials increased in the order (1<2<3): 1) corn residue removed, 2) traditional (residue left on the field), and 3 cover crop planted in the fall and terminated in spring without residue removal. Within each of these levels there are five 10x30 ft plots that receive 0, 130, or 260 lbs N/ac during the corn phase and the following year during the soybean phase they receive no nitrogen. The remaining two plots receive 130 lb N/ac during the corn phase and the following year during the soybean phase we are evaluating soybean seed treatment and plant population variables. Thus, the study has 360 10x30 foot plots in corn (2 drainage x 3 tillage x 3 residue management x 5 N rates x 4 replications= 360) and 360 plots in soybean for a total of 720 plots. The N rates in corn were selected to establish soil N supply (0N) and calculate N use efficiency for the 130N [near the economic optimum N rate (EONR)] and 2x the EONR (260N).

This report will only focus on the corn plots and will not discuss in detail the findings from the soybean crop or the data related to soil health, as those are objectives for a different research project. However, because all the treatments are followed by soybean and their residual effect will be measured in the corn plots we discuss the overall site management.

In the fall after harvest, tillage and residue management treatments were established. In the spring, the plots with cover crop were chemically terminated on May 31, 2023 Corn was planted on May 4, 2023 and N rate treatments were applied May 23 as a broadcast application of Agrotain. The plans is to apply N before crop emergence, but wet conditions prevented the operation. Substantial rain over a short period resulted in emergence problems in Undrained soils and corn was replanted at the end of May in the undrained blocks.

At physiological maturity (R6 development stage) corn plants were collected and partitioned into cobs and the rest of the plant. Dry biomass was calculated for each sample. The vegetative tissues were ground and analyzed for total N content. Corn plots were harvested on October 30, 2023 and grain yields were calculated. A grain subsample was ground and analyzed for total N content. After harvest, soil samples were collected from the corn plots in 1-ft increment down to 3-ft.

Soil fertility (other than N rates) and agronomic practices followed University of Minnesota guidelines to optimize agronomic productivity.

Data were statistically analyzed, and this report will present the preliminary results for the year of the report.

Results and Discussion

During the 2023 growing season precipitation amounts were on average 6.9 inches below the normal (Table 1). Most of the growing season (April to September) was drier than normal except May which was similar to normal precipitation.

Corn grain yield was affected by nitrogen rate in the 2023 growing season (Table 2). Average yields were low (less than 180 bu/ac) indicating that water was a limiting factor. Drainage, tillage and residue management had no effect on corn response. This again likely illustrates that water was a greater limiting factor than these variables. However, some of the trends we observed are similar to what we have seen in other growing seasons. The average yield average across variables was 179 bu/ac for drained and 174 bu/ac for undrained conditions. There was a trend of increasing yield with greater tillage intensity from no-till to conventional. Similarly, there was a trend for increasing yield with increasing crop residue present from residue removal to cover crop without residue removal, though residue removal is a direct treatment effect for the soybean crop and indirect for corn (soybean residue is not removed). It is possible that over time, the presence of more residue is improving the physical characteristics of the soil, which might have helped retain water more effectively for the crop during a droughty year. Evaluation of soil physical properties is an objective that will be evaluated from samples taken at the end of the project.

Residual soil total inorganic N (TIN) at 0-36 inches showed a significant 4-way interaction (Table 2, Fig. 1). Though the focus should be on the highest level of significant interaction, simpler levels of interaction can be helpful to interpret more complicated interactions. For this reason, Figure 2 shows the only significant 3-way interaction Drainage by Tillage by Nitrogen rate. This interaction was explained by greater residual N with the highest N rate for CT and ST in Drained soils compared to others. Also, while residual N increased with N rate regardless of drainage or tillage, this increase was only a trend for NT soils. Three and four way interactions are often complicated to explain, but in this case, ultimately, the significant main effects explain the more meaningful results. Soil TIN decreased as the amount of tillage decreased from conventional tillage (76 lb N/ac) to strip-tillage (70 lb N/ac) to no-till (64 lb N/ac) and soil TIN increased as N rate increased (Table 2). These results follow the differences (or at least trends) observed for corn yield. Typically, conditions that increase corn yield are the conditions that increase soil N mineralization. Greater residual N with more intensive tillage could reflect better conditions for N mineralization

Soybean yield was affected by tillage and nitrogen rate in the 2023 growing season, but drainage, and residue management had no effect on corn response (Table 4 and 5), though there was a significant 3-way interaction that included residue management as a significant variable along with tillage and N rate (Table 5 and Fig. 3). The 3-way interaction was explained by the residue removal increasing yield when no N was applied in the no-till system, but these differences did not exist in the other tillage systems where the yield was consistently greater than no-till. The no-till and 0N combination was probably one of the most challenging conditions for soybean. Having less residue present likely ameliorated some of these negative conditions by minimizing N immobilization and likely improving soil conditions for soybean growth, such as warmer soil temperatures and more N mineralization. Exploring the significant main variables also showed that soybean yield was similar for CT and ST but greater than NT. Soybean yields were greater for the 0-N rate than 130 and 260-N rate (Table 4). It is possible that greater corn residue with the higher N rates might have resulted in more N immobilization, which negatively influenced soybean growth.

Table 1. Monthly cumulative precipitation and monthly mean air temperature for the 30-yr normal, the 2023 growing season and calculated departure from the normal for the 2023 season.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
							Inch						
Normal	0.7	0.7	1.6	3.4	4.5	5.6	4.9	4.2	3.8	2.7	1.4	1.1	34.6
2023	2.22	2.45	1.62	2.78	4.76	2.44	2.02	2.56	1.93	3.19	0.2	1.57	27.7
Departure	1.5	1.8	0.0	-0.6	0.3	-3.2	-2.9	-1.6	-1.9	0.5	-1.2	0.5	-6.9
							°F						
Normal	14.3	18.5	31.7	45.5	58.2	68.5	72.3	69.6	62.5	48.8	34.0	20.8	45.4
2023	18.6	18.6	28.3	45.6	61.7	71.5	70	72	67	51.8	36.7	32.5	47.9
Departure	4.3	0.1	-3.4	0.1	3.5	3.0	-2.3	2.4	4.5	3	2.7	11.7	2.5

Normal precipitation is for 1990 to 2019, temperature is for 1993 to 2019 as there is no earlier record. The weather information was collected from Wells MN. https://www.dnr.state.mn.us/

Table 2. Statistical analysis of main (fixed effects) and their interactions and probability level for corn grain yield and residual soil TIN (total inorganic N) for the 2023 growing season.

Main Variable	Corn Grain Yield (bu/ac)	Residual Soil TIN 0-36” (lb/ac)
Drainage		
Drained (D)	179	70
Undrained (UD)	174	70
Tillage		
Conventional tillage (CT)	182	76 a
No-tillage (NT)	170	64 b
Strip-tillage (ST)	176	70 ab
Residue management		
Cover crop	181	71
Residue removal	171	-
No residue removal	177	70
N rate		
0 N	156 c	58 c
130 N	180 b	69 b
260 N	193 a	84 a

Within main effect, means followed by the same letter are not significantly different at p=0.05.

Table 3. Statistical analysis of main (fixed effects) and their interactions and probability level for corn grain yield and residual total inorganic (ammonium and nitrate) soil N (TIN).

Type III Tests of Fixed Effects			
	Corn Yield	**Grain N**	**Residual soil TIN**
Effect		**Pr > F**	
Drainage (D)	0.4973		0.9669
Tillage (T)	0.2021		0.0175
D x T	0.6655		0.5356
Residue management (R)	0.1751		0.6601
D x R	0.7753		0.6182
T x R	0.4489		0.4038
D x T x T	0.3554		0.5121
N rate (N)	<.0001		<.0001
D x N	0.7131		0.0017
T x N	0.9756		0.0044
D x T x N	0.3777		0.0192
R x N	0.8123		0.0428
D x R x N	0.5603		0.3652
T x R x N	0.3058		0.1979
D x T x R x N	0.9735		0.0355

Table 4. Soybean yield in response to main variables.

Main Variable	Soybean Grain Yield (bu/ac)
Drainage	
Drained (D)	71
Undrained (UD)	72
Tillage	
Conventional tillage (CT)	76 a
No-tillage (NT)	64 b
Strip-tillage (ST)	74 a
Residue management	
Cover crop	71
Residue removed	72
No residue removed	71
N rate	
0 N	73.3 a
130 N	70.9 b
260 N	69.8 b

Within main effect, means followed by the same letter are not significantly different at p=0.05.

Table 5. Statistical analysis of main (fixed effects) and their interactions and probability level for soybean yield.

Type III Tests of Fixed Effects	
	Soybean Yield
Effect	**Pr > F**
Drainage (D)	0.8406
Tillage (T)	<.0001
D x T	0.6342
Residue management (R)	0.9541
D x R	0.2683
T x R	0.2369
D x T x T	0.231
N rate (N)	<.0001
D x N	0.204
T x N	0.8443
D x T x N	0.742
R x N	0.983
D x R x N	0.4728
T x R x N	0.0064
D x T x R x N	0.692

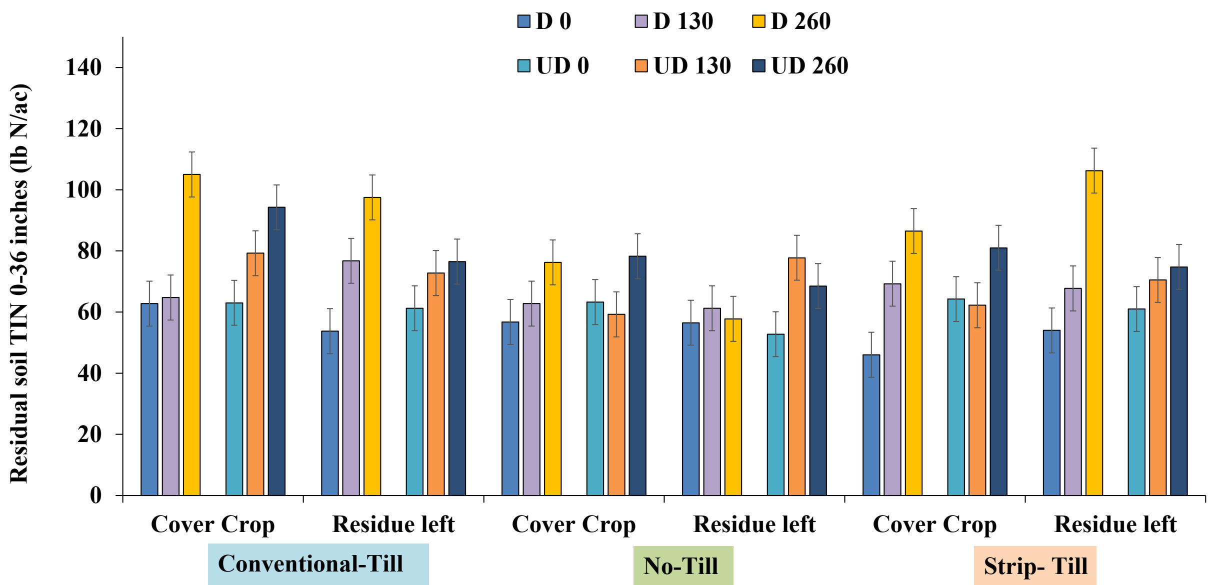

Figure 1. Residual total inorganic (ammonium and nitrate) soil N (TIN) at 0-36 inches depth response exploring the significant 4-way interaction. Error bars represent standard error of the mean.

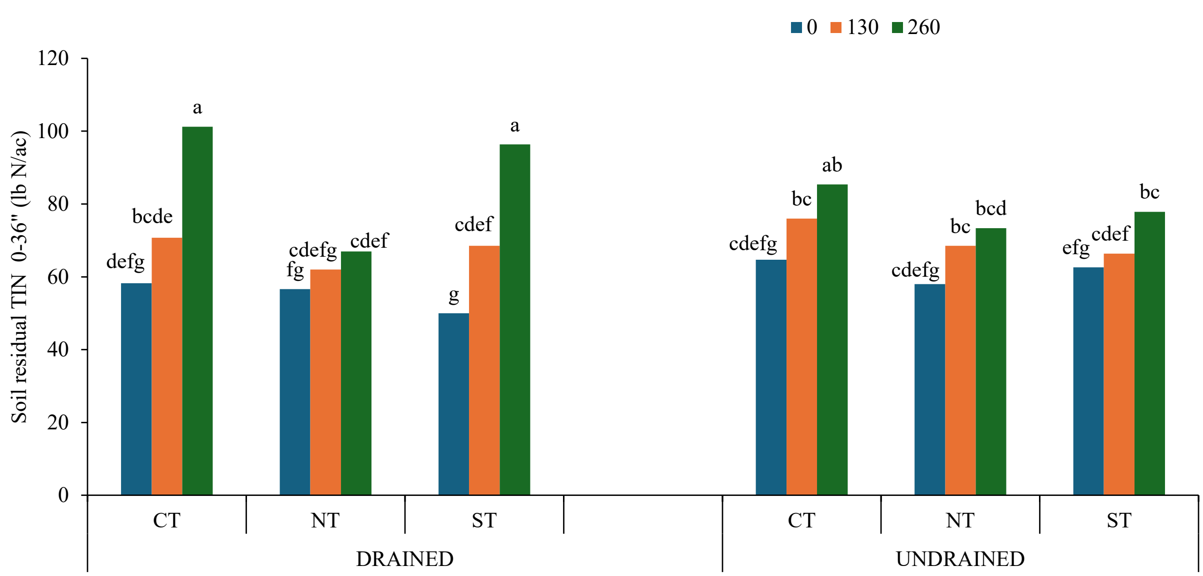

Figure 2. Residual total inorganic (ammonium and nitrate) soil N (TIN) at 0-36 inches depth response exploring the significant 3-way interaction. Error bars represent standard error of the mean.

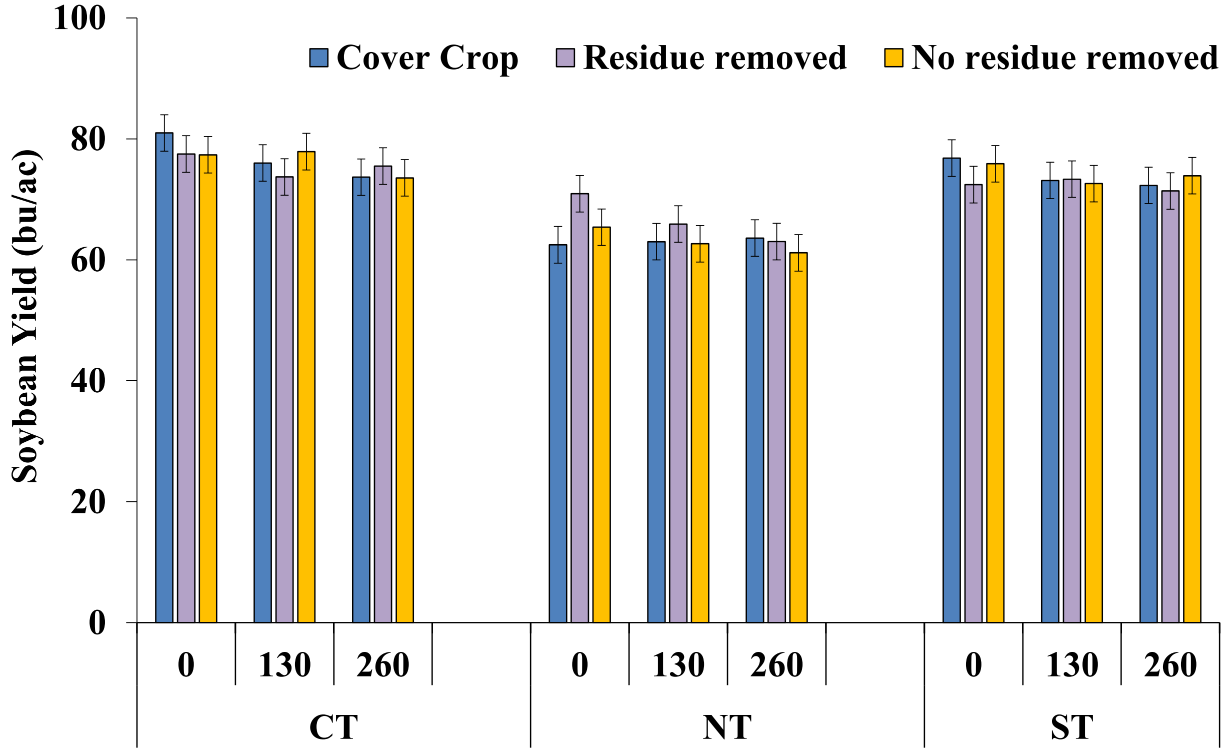

Figure 3. Soybean yield response exploring the significant 3-way interaction. Error bars represent standard error of the mean.