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Vegetative Cover Crops as a Nitrate Reduction Strategy for Tile Drainage Water
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Introduction / Justification

Nitrogen (N) is an essential input for profitable corn production. Previous research (Randall and Mulla, 2001, Dinnes et al., 2002) has shown subsurface tile drainage systems deliver nitrate-N to surface waters and thereby degrade water quality. Row crop agriculture in the Midwest is under scrutiny to reduce NO_3 concentrations and loads in tile drainage. The use of cover crops and applying appropriate rates of N for corn are potential management strategies to reduce NO_3 losses in tile drainage water (Dinnes et al., 2002). The species of cover crop, establishment date and termination date could greatly affect their potential to sequester N. Cereal rye is effective at scavenging N when it's established early and not terminated until spring. Generally, Minnesota farmers who use cover crops either use cereal rye in a no-till system or seed a blend of annuals like annual rye, crimson clover and radish. The annual covers are terminated either by cold temperatures or tillage. The potential of fall/winter terminated covers to scavenge N in a corn - soybean rotation in Minnesota is not well known.

The objective of this study was to measure the effects of vegetative covers (e.g. winter hardy and winter terminating cover crops) at various N rates on the following: 1) tile water flow, NO_3-N concentration and NO_3-N loss in tile drainage water and 2) corn and soybean yields, nitrogen uptake, and nitrogen use efficiency (NUE).

Experimental Procedures

A research experiment was initiated in 2016 at the Univ. of Minnesota Southern Research and Outreach Center drainage research facility on a poorly drained Canisteo-Webster clay loam soil complex. Thirty-six individual tile drainage plots were installed in 1976. Each plot, measures 20 ft. by 30 ft., has a separate drain outlet and is isolated from adjacent plots to minimize lateral flow. A single tile is placed four ft deep perpendicular to the rows. The plot spacing simulates a 50-ft. tile drain spacing. A randomized complete block design with 4 replications was used in this study. A restriction on randomization within blocks, based on previous tile flow history, helped balance variability in tile flow among the 36 plots. This restriction put plots with the greatest historical flow all in the same block.

Nine treatments were comprised from a factorial combination of two management factors, cover crop species (termination date) and N rate each at three levels. The three cover crop treatments include: no cover crop, a late summer seeded cover of cereal rye (rye) with spring termination and a late summer seeded cover as a blend (blend) of annuals (annual rye, crimson clover and radish) with late fall or winter termination due to freezing. Nitrogen rates for corn in 2017 were 3, 120 and 150 lb N/ac. The 3-lb rate was a control that received 3 lb N/ac from starter fertilizer. These control treatments allow for assessment of N contributions from the soil and cover crops. The 120-lb rate is near the current MRTN for Minnesota for a 0.10 price ratio (N price / corn price). The 150-lb rate or 125% of the MRTN allows us to test our hypothesis that the cereal rye cover terminated in spring may require a greater N rate to maximize corn production. Nitrogen fertilizer was band-applied during corn planting as ammonium poly phosphate (APP, 10-34-0) and UAN (28-0-0) and broadcast-applied at V4 as urea with a urease inhibitor (NBPT).

In 2016, soybeans (DeKalb 20-35) were planted on 9 May. Weeds were controlled with broadcast applications of glyphosate (24 oz/ac of PowerMax) on 3 and 28 June. Soil residual herbicides were not used to eliminate the potential of herbicide carryover affecting cover crop growth. Soybean seed yield and moisture were measured by combine harvesting four rows on 10 October. Fall strip tillage was performed and a subsurface band of 0-46-0 (50 lb P_2O_5/ac) and 0-0-60 (90 lb K_2O/ac) was placed 7-inches deep on 24 October.

In 2017, corn (NuTech 5L-503AMX) was planted at 36,000 seeds/ac on 7 May with 2.5 gal/ac of APP applied in-furrow. In addition to APP, the 120 and 150 lb N/ac treatments received 9 gal/ac of UAN surface-dribbled 3 inches from the corn row at planting for a total of 30 lb N/ac at planting. Weeds were controlled with broadcast applications of Liberty at 24 oz/ac on 31 May and 16 June. Stand counts were taken from the center six rows (harvest rows) on 1 June and plots were thinned to a uniform population on 23 June. On 10 June, urea with NBPT (Factor 3 qt/ton) was broadcast-applied at 90 and 120 lb N/ac to the 120 and 150 lb N/ac treatments, respectively. Relative leaf chlorophyll content (RLC) was calculated from Minolta SPAD meter measurements from the ear leaf at R1 on 19 July. At R6 on 28 Sep., six random plants were harvested to determine corn stover and cob yield and harvest index. Grain yield and moisture were measured by combine harvesting four rows on 25 October. On 2 Nov., 0-46-0 (25 lb P_2O_5/ac) and 0-0-60 (45 lb K_2O/ac) were broadcast-applied prior to strip tillage.

Grain samples were analyzed for protein with NIR and converted to grain N concentration by dividing grain protein by 6.25. Nitrogen removal in corn grain was calculated from grain and stover yield and N concentration data. Nitrogen use efficiency parameters: partial factor productivity, PFP (the ratio of the grain yield to the applied rate of N) and agronomic efficiency, (the ratio of the increase in grain yield over N-control plots to the applied rate of N) were calculated as described by Snyder and Bruulsema (2007). For these NUE calculations the 3 lb N/ac rate from starter fertilizer was assumed to be the zero N control.

During the growing season six whole corn plants were collected at V8 and VT to determine biomass yield, nutrient concentration, and nutrient uptake. These plants were weighed wet, chopped, subsampled, subsamples were weighed dry, ground, and analyzed for N and P concentration. Biomass yield and nutrient uptake were calculated after correcting for moisture and plant density.

Cover crops were broadcast seeded by hand (simulate aerial seeding) at R6 prior to leaf drop in soybean on 2 Sep. 2016 and at R5.5 in corn on 13 Sep. 2017. Seeding rates were 90 lb/ac for cereal rye and 12, 15, and 5 lb/ac for annual rye, crimson clover, and radish, respectively. Cover crop biomass yield was measured by cutting and collecting all material from 6.25 sq. ft. on 21 Oct. 2016, 17 Apr. 2017, and 1 Nov. 2017. Since the blend terminated during the winter, no biomass was collected in April of 2017. Biomass was dried, weighed, ground, and analyzed for total N and P content at a commercial lab.

Tile drainage is measured via an automated collection system. Tile water collects in drainage wells, then is pumped via a sump pump through water meters that measure flow volume. Flow volume is recorded on a datalogger hourly. These hourly flow data are examined for outliers prior to summarizing daily. The previous 24-hours of flow are summed at 8 am each day. Whenever the sump pump turns on and pressurizes the system, a portion (flow-weighted) of flow is collected in containers. Tile water samples are taken from each plot once a week during normal tile flow and two or three times per week during heavy tile flow. Water samples are kept cool prior to collection and then frozen after collection.

Soil samples were taken from all plots in June (0- to 6-inch depth) and in the spring and fall (0- to 6-, 7- to 12-, 13- to 24-, and 25- to 36-inch depths). Samples were immediately dried at 105º F, then ground and sieved to pass a 2-mm screen. June samples were analyzed for pH, Olsen P, exchangeable K and soil organic matter using standard soil test methods for the North Central Region. Spring and fall samples were analyzed for nitrate and ammonium-N. All soil samples were analyzed at commercial labs.

All data were statistically analyzed using ANOVA with proc mixed in SAS® (SAS 9.2, SAS Institute Inc., 2008. Cary, North Carolina). A two-factor factorial ANOVA compared the effects and interactions of cover crop species and termination data [none, cereal rye (spring termination), and annual blend (winter termination)] and total N rate (3, 120, and 150 lb/ac). Mean separations were determined using the P Diffs procedure in SAS with alpha=0.10 level of significance. Treatments followed by different letters within a column are significantly different.

Results and Discussion

<u>Weather</u>

Weather in 2016 was extraordinary and record breaking (Table 1). March and April were warmer and drier than normal, which resulted in early spring field work and planting in southern Minnesota. May and June had near normal temperature and precipitation, nearly ideal for crop development. Precipitation in July, August and September was 202, 246 and 403 percent of normal, respectively. Each of these months had a 24-hour rainfall event that exceeded three inches. Extensive runoff and tile flow (Figure 1), water ponding, and saturated soil conditions were observed during these months, especially August and September. Growing season (April-September) rainfall totaled a record 45.88 inches or 21.21 inches (86%) more than normal. Total annual rainfall totaled 56.24 inches, a statewide record, and 157% of normal at Waseca. Near or slightly warmer than normal temperatures were observed throughout the 2016 growing season. Growing degree units (GDU) from 1 May through 9 October (first freeze) totaled 2,938 about 17% more than normal. Despite excessive rainfall in July, August and September, the 2016 growing season was a good one for crop production in south-central Minnesota.

Abundant and well distributed rainfall with moderate swings in temperatures describe the weather in 2017 (Table 1). The months of May, June, and October had significantly greater than normal precipitation; whereas, other months had near normal or less than normal precipitation. Growing season (April-September) rainfall totaled 24.56 inches only 0.11 inches less than normal. Daily rainfall exceeded 2.00 inches on just one day (10 July, Figure 3) in 2017; therefore, leaching and tile drainage was minimal compared to recent growing seasons. January and February were considerably warmer than normal all other months were near normal. Growing season GDU's totaled 2656 and were 3% more than normal.

Urea fertilizer with NBPT was broadcast-applied on 10 June, only 0.02 inches of rainfall was recorded the next two days and daily maximum air temperatures were in the 90's F. On 13 June, 1.73 inches of rainfall was recorded. Leaf burning due to ammonia volatilization from surface-applied unincorporated urea with NBPT was observed a few days after application; therefore, some of this fertilizer N was likely lost due to volatilization.

<u>Soybean production in 2016 (setup year)</u>

Soybean yields averaged 75 bu/ac in this extraordinarily wet growing season (Table 2). Yields were slightly greater without a cover crop than with either rye or blend. Due to the early September seeding date and plentiful rainfall, it's unlikely this yield difference was due to plant competition or soil moisture. It likely resulted from foot traffic in plots during cover crop seeding as some plants in this very dense canopy were trampled down during seeding.

<u>Cover crop biomass</u>

Cover crop biomass on 21 Oct. 2016 was 120% greater (194 lb/ac) with rye than with blend (88 lb/ac), when averaged across future N treatments (Table 3). This biomass yield difference resulted in greater N and P uptake with rye (5.9 lb N/ac) than blend (3.0 lb N/ac), despite a greater N concentration in the blend. Significant cover crop × N rate interactions showed biomass yield and N uptake were affected by the future N rate for corn with the blend cover but not with the rye cover. Moreover, the 120 lb N rate and blend cover had considerably greater biomass yield and subsequently greater N uptake. Since these N rates were not applied until spring 2017, it's unclear what these differences mean. They could be random in field variation or a remnant from the previous study on this plot. Whatever the reason, some annual blend plots had considerably greater biomass than others; whereas, the rye cover biomass was more consistent among plots within and across treatments. On 17 April 2017, rye biomass and N and P uptake was greater with the 150 lb N/ac rate (not yet applied) than with other N rates. By 17 April the blend cover had terminated and decomposed so much so it was difficult to locate which plots had blend without a plot plan (see appendix Pic. 5 and 6). On 17 April, N uptake in the rye biomass ranged from 5.7 to 10.9 lb/ac. The amount of sequestered N in this study is less than what is typically reported in the research literature.

<u>Corn production in 2017</u>

Corn biomass yield, N concentration, and N uptake at V8 and VT are presented in Table 4. When averaged across N rate, V8 corn biomass yield and N uptake was greatest with no cover, intermediate with blend, and least with rye. What is unclear is why the rye slowed early growth of corn. It could be due to less N availability and/or the extra residue from spring terminated rye (Pic. 6) kept the soil cooler thus slowing early growth. When averaged across cover crops, V8 biomass yield, N concentration, and N uptake were greater with 120 and 150 lb N/ac than with 3 lb N/ac (control). At the 3 lb N/ac rate, no cover had 82% greater biomass yield at V8 than rye. At VT, interaction between treatment main effects, cover crop and N rate, were found for biomass yield, N concentration, and N uptake. Generally, biomass yields were not different among cover crop treatments at 120 and 150 lb N/ac; whereas, biomass yields with the 3 lb N/ac control were greatest with no cover, intermediate with blend and least with rye. These data showed the cover crop treatments “caught up” to the no cover treatment by VT when fertilized with adequate N. This also suggests the reduction in growth with rye cover, when averaged across N rates, was most likely due to N deficiency. Nitrogen concentration and uptake at VT were not different among covers at 150 lb N/ac, but were less or trended less with no cover and rye at 120 lb N/ac. At 3 lb N/ac, N concentration with no cover was greater than blend and N uptake with no cover was greater than both blend and rye. These data showed in the control (3 lb N/ac) treatments, no cover had 10 and 17 lb/ac more N uptake at VT than the blend and rye, respectively. This suggests some of the N sequestered in the cover crops did not get released back to the corn crop by VT.

The effects of cover crop species and N rates on corn production parameters are presented in Table 5. Corn grain moisture was wettest with rye at 3 lb N/ac and driest with no cover at 3 lb N/ac. These data showed delayed maturation of corn with rye and accelerated maturation with no cover, but only with 3 lb N/ac control treatment. When averaged across N rates, stover N concentration and uptake were greater with no cover than with rye or blend. When averaged across cover crop treatments, stover and grain N concentration and stover N uptake increased with increasing N rate. No significant differences in final plant population due to treatments were observed in these data.

Significant interaction between treatment main effects was observed for corn grain, cob, stover, and silage yield, grain N uptake, total N uptake, and RLC (Table 5). At 150 lb N/ac grain yields were not statistically different among the three cover crop treatments; however, at 120 lb N/ac grain yields were reduced compared with 150 lb N/ac for both no cover and rye cover. At 3 lb N/ac grain yields were greatest (150 bu/ac) with no cover, intermediate (120 bu/ac) with blend, and least (108 bu/ac) with rye. This 42 bu/ac spread in grain yield was expected as research (Badger and Kaiser, 2017) has shown corn yields can be reduced at less than optimum N rates when following cereal rye covers; therefore, corn grown following rye requires more N fertilizer to optimize production. Cob yields were not affected by cover crop treatments at 150 lb N/ac; however, at 3 lb N/ac cob yields ranked no cover > blend > rye. Corn stover yields were similar among cover crop treatments at both 120 and 150 lb N/ac. At 3 lb N/ac stover yield was greater with no cover than with rye and blend covers. The silage yield response to treatments was nearly identical to corn grain yield.

Both cover crops reduced grain N uptake compared with no cover at 3 lb N/ac (Table 5). Rye cover reduced grain N uptake at 120 lb N/ac; however, no significant differences in grain N uptake were found among cover crop treatments at 150 lb N/ac. Total N uptake was greater with no cover than with rye at all N rates. Total N uptake was greater with no cover than with blend at 3 and 150 lb N/ac. Nitrogen uptake was generally less with cereal rye compared with no cover. This suggests some of the N sequestered by cereal rye was either lost, likely through gaseous N compounds, and/or still immobilized in soil organic matter.

At VT/R1, RLC was similar among cover crop treatments at both 120 and 150 lb N/ac; whereas, at 3 lb N/ac RLC was greater with no cover and the blend than with rye (Table 5). At VT/R1, RLC data predicted no N deficiencies in corn at 120 lb N/ac; however, N deficiency symptoms were evident at R5 and yields were reduced in both no cover and rye cover treatments at the 120 lb N/ac rate (Appendix Pic. 7). These data suggest a considerable amount of N was taken up after VT/R1 and that N deficiency this late can reduce yield.

<u>Tile drainage and nitrate concentrations and loads</u>

Tile drainage and nitrate concentrations in drainage water were measured during the 2016 growing season. The goal during this setup year of the study was to flush out residual NO_3-N from the previous research study and thereby remove any legacy effects in the tile drainage system. Over 17 inches of tile drainage was recorded in this record wet 2016 growing season (Fig. 1). This amount is twice as much as a typical growing season and therefore ideal for flushing out the system. The majority, nearly 13 inches, of drainage was recorded in August and September, which is very unusual. Nitrate-N concentrations in June ranged from 8 to 10 mg/L and modest differences due to legacy effects of previous study were observed (Fig. 2). By September 2016, NO_3-N concentrations had declined to about 4.5 mg/L and variability among the newly seeded cover crop treatments was minimal.

The effects of cover crop species and N rates for corn on tile flow, flow-weighted NO_3-N concentrations, NO_3-N loss (load), and flow adjusted loss in 2017 are presented in Table 6. Tile flow began in February and some tile flow occurred in every month except January and December in 2017 (Fig. 3). Total annual flow averaged across treatments was only 4.2 inches, which is less than normal. Due to the lack of consistent flow in many months the flow data have been pooled into two periods, pre-N application (Pre) and post N application (Post). The first N treatments were applied at planting on 7 May; therefore, Pre was from 15 Feb to 7 May and Post was from 8 May to 16 November. Tile flow was not affected by treatment main effects, cover crop species and N rate for corn, or by interaction of these main effects. Some numeric differences were observed, these could be a result of treatment effects, seasonal flow variability (low flow year), and/or random variability.

When averaged across N rates, flow-weighted NO_3-N concentrations were greatest with no cover, intermediate with blend, and least with rye (Table 6). These concentration differences were consistent for Pre and Post periods and the annual average. When compared to cereal rye, annual average NO_3-N concentrations were 3.4 times greater with no cover and 2.6 times greater with blend. When averaged across cover crops, NO_3-N concentrations were not significantly affected by N rates for corn although some small numeric differences were observed. NO_3-N loss or load to surface waters during the Post period was greatest with no cover, intermediate with blend, and least with rye, when averaged across N rates for corn. There were no significant differences for NO_3-N load during Pre period or for the annual total. Flow-adjusted NO_3-N loss was greatest with no cover (1.9 lb/inch), intermediate with the blend (1.5 lb/inch), and least with cereal rye (0.6 lb/inch), when averaged across N rates for corn.

$$total\ nitrate\ lost \div total\ flow\ = flow\ adjusted\ loss$$

In these one-year data with less than normal tile drainage a cereal rye cover crop terminated in the spring, three weeks before planting corn, dramatically reduced NO_3-N concentration and load. A blend of annual covers terminated in late fall also reduced NO_3-N concentration and load compared to no cover, but not nearly as much as cereal rye.

Soil inorganic nitrogen

The effects of cover crops and N rates on soil NO_3-N at four soil depths are presented in Table 7. For the fall 2016 sampling (21 Oct.), soil NO_3-N was not significantly affected by treatment main effects at any depth. At the 0- to 6-inch depth NO_3-N ranged from 10.6 to 16.3 lb/ac among treatments and was numerically less with cereal rye (11.2 lb/ac) and blend (12.0 lb/ac) compared with no cover (14.5 lb/ac). For the spring 2017 sampling (17 Apr.) soil NO_3-N was affected by cover crops at all depths. At 0- to 6-inch depth, soil NO_3-N was greatest with no cover, intermediate with blend and least with rye, when averaged across N rates for corn in 2017 (not applied until May/June). At the 7- to 12-, 13- to 24-, and 25- to 36-inch depths, cereal rye had significantly less soil NO_3-N than no cover and the blend. The 0- to 36-inch total soil NO_3-N was 51.2, 26.2, and 42.5 lb/ac for the no, rye, and blend cover crop treatments, respectively. These data showed cereal rye, which was terminated on 17 April, effectively sequestered soil N and thereby reduced the amount of NO_3-N that could be leached via tile drainage in the spring. Only one depth (7- to 12-inch) had significant differences among treatments for the fall 2017 sampling (26 Oct.). Soil NO_3-N was less with no cover at 3 lb N/ac compared with rye and blend covers at 3 lb N/ac. Soil NO_3-N was greater in the fall of 2017 than in fall of 2016 and spring of 2017, which could affect NO_3-N losses in tile drainage in the spring of 2018.

The effects of cover crops and N rates on total inorganic N (TIN) in soil at four soil depths are presented in Table 8. For fall 2016 sampling, TIN was not significantly affected by treatment main effects at any depth and only small numeric differences were observed among cover crop treatments, when averaged across N rates. For spring 2017 sampling, soil TIN was affected by cover crops at the 0- to 6- and 7- to 12-inch depths. At 0- to 6-inch depth, TIN was greater with no cover than with blend and rye, when averaged across N rates. At the 7- to 12-inch depths, cereal rye had significantly less TIN than no cover and the blend. The 0- to 36-inch total for soil TIN was 78.3, 62.4, and 73.1 lb/ac for the none, rye, and blend cover crop treatments, respectively. Soil TIN was not affected by treatments at any depth for the fall 2017 sampling.

Summary

A research experiment initiated in 2016 continued in 2017. The objective of this research was to measure the effects of vegetative covers (e.g. winter hardy and winter terminating) at various N rates on the following: 1) tile water flow, NO_3-N concentration, and NO_3-N loss in tile drainage water and 2) corn and soybean yields, nitrogen uptake and NUE. Cover crops seeded in September of 2016 reduced NO_3-N concentration, and NO_3-N loads in tile drainage water in 2017, especially the cereal rye cover that was terminated in April before planting corn. At the greatest N rate (150 lb N/ac) corn grain yields were statistically the same among the three cover crop treatments; however, at the U of M MRTN rate for corn following soybean (120 lb N/ac) grain yields were reduced compared with 150 lb N/ac for both the no cover and cereal rye treatments. Even though the cereal rye cover crop averaged only 234 lb/ac of biomass, it was effective at scavenging residual soil nitrate and reducing nitrate losses in tile drainage water in 2017.

Outreach and Extension Activities

This research information was presented at three meetings in 2017: The Ag Expo on 25 January, the SROC Agronomy tour on 20 June, and MCR&PC research update in Shakopee on 7 September.

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Table 1. Monthly total precipitation, mean air temperature, and growing degree units (GDU, base 50/86) as compared to 30-year normal values at Waseca.

		Precipitation		Mean Air Temp.		GDUs	
Month	Year	Observed	Normal†	Observed	Normal†	Observed	Normal†
		----- inches -----		------ ºF ------			
Jan	2017	1.43	1.25	19.4	13.2	-	-
Feb	2017	1.56	1.00	29.4	18.5	-	-
Mar	2017	1.50	2.49	31.6	31.2	-	-
Apr	2017	2.84	3.21	49.1	46.1	-	-
May	2017	5.10	3.93	57.8	58.7	310	332
Jun	2017	4.14	4.69	70.1	68.5	578	538
Jul	2017	6.56	4.42	73.6	72.0	716	655
Aug	2017	3.90	4.75	66.3	69.8	505	597
Sep	2017	2.02	3.67	63.9	61.3	446	348
Oct	2017	4.14	2.67	49.6	48.2	100	20
Nov	2017	0.17	2.16	31.4	32.7	-	-
Dec	2017	0.90	1.48	16.9	17.8	-	-
Apr-Sep	Total	24.56	24.67			2556	2470
Annual	Total	34.28	35.72			2656	2490

† 30-Yr normal, 1981-2010.

Table 2. Soybean seed yields in 2016 (setup year).

	Nitrogen rate for corn in '17			
Cover crop	3	120	150	Mean†
None	78.4	75.9	76.3	76.9 A
Cereal rye	73.7	73.0	75.4	74.1 B
Annual blend	72.9	74.2	74.7	73.9 B
Mean:	75.0	74.4	75.5	

† Within each row or column letters following numbers indicate treatment significance at *P*<0.10.

Table 3. Cover croop biomass yield, nutrient concentration, and uptake as affected by treatments.

Treatments			Cover Crop Biomass on 21 Oct. 2016					Cover Crop Biomass on 17 Apr. 2017				
Trt	Cover crop	N rate	Yield	N conc.	P conc.	N uptake	P uptake	Yield	N conc.	P conc.	N uptake	P uptake
#		lb/ac	lb/ac	------------ %	------------	--------- lb/ac	---------	lb/ac	----------- %	-----------	--------- lb/ac	---------
4	Cereal rye	3	173 ab	3.11 bc	0.37	5.4 a	0.63	195	3.64	0.33	6.9	0.66
5	Cereal rye	120	185 ab	3.18 bc	0.38	5.9 a	0.70	170	3.34	0.39	5.7	0.69
6	Cereal rye	150	224 a	2.94 c	0.41	6.5 a	0.96	337	3.30	0.42	10.9	1.42
7	Annual blend	3	77 c	3.40 b	0.38	2.6 b	0.29					
8	Annual blend	120	140 b	3.40 b	0.45	4.8 a	0.68					
9	Annual blend	150	46 c	3.83 a	0.40	1.7 b	0.19					
Stats for RCB Design with a two-factor factorial arrangement												
Cover crop												
Cereal rye			194 A	3.08 B	0.39	5.9 A	0.77 A	234	3.43	0.38	7.8	0.93
Annual blend			88 B	3.54 A	0.41	3.0 B	0.39 B					
P > F:			<0.001	0.001	0.565	<0.001	0.015					
N rate for corn in 2017												
3			125	3.25	0.37	4.0	0.46	195 B	3.64	0.33	6.9 B	0.66 B
120			163	3.29	0.41	5.3	0.69	170 B	3.34	0.39	5.7 B	0.69 B
150			135	3.38	0.41	4.1	0.58	337 A	3.30	0.42	10.9 A	1.42 A
P > F:			0.300	0.617	0.690	0.210	0.421	0.048	0.155	0.351	0.022	0.078
Interaction (cover crop × N rate)												
P > F:			0.046	0.043	0.659	0.091	0.116					

Table 4. Corn dry matter yield and N uptake as affected by cover crops and N rates in 2017.

Treatments			V8 Corn Dry Matter Yield			VT-R1 Corn Dry Matter Yield		
Trt	Cover crop	N rate	Yield	N conc.	N uptake	Yield	N conc.	N uptake
#		lb/ac	lb/ac	%	lb/ac	lb/ac	%	lb/ac
1	None	3	1105	2.28	25.3	5715 c^	1.11 d	63.3 d
2	None	120	1296	3.71	47.9	6720 ab	1.40 c	93.8 c
3	None	150	1252	3.75	46.9	7056 ab	1.58 ab	111.6 ab
4	Cereal rye	3	607	2.20	13.4	3653 e	0.98 de	35.9 e
5	Cereal rye	120	933	3.77	35.1	6405 bc	1.51 bc	95.8 bc
6	Cereal rye	150	923	3.86	35.6	7254 ab	1.57 ab	115.7 a
7	Annual blend	3	820	2.17	18.2	4502 d	0.95 e	42.9 e
8	Annual blend	120	1230	3.69	45.2	7357 a	1.55 ab	114.7 a
9	Annual blend	150	1077	3.68	39.6	6990 ab	1.67 a	116.8 a
Statistical significance of treatment main effects for a two-factor factorial arrangement								
Cover crop								
No cover			1217 A	3.25	40.0 A	6497 A	1.36	89.6
Cereal rye			821 C	3.27	28.0 C	5771 B	1.35	82.5
Annual blend			1042 B	3.18	34.4 B	6283 AB	1.39	91.5
P > F:			0.005	0.259	0.007	0.089	0.785	0.341
N rate for corn								
3			844 B	2.22 B	19.0 B	4623 B	1.01 C	47.4 C
120			1153 A	3.72 A	42.7 A	6827 A	1.49 B	101.4 B
150			1084 A	3.76 A	40.7 A	7100 A	1.61 A	114.7 A
P > F:			0.012	<0.001	<0.001	<0.001	<0.001	<0.001
Interaction (cover crop × N rate)								
P > F:			0.709	0.500	0.838	0.026	0.100	0.004

^ Numbers followed by different letters are significantly different at α = 0.10 level. Capital letters signify differences in main effects and small letters are differences due to interaction between main effects.

Table 5. Corn production and nitrogen use efficiency parameters as affected by cover crops and N rates in 2017.

Trt	Treatments: Cover crop	Treatments: N rate	Grain H_2O	Grain Yield	Relative Grain Yield	Cob Yield	Stover Yield	Silage Yield	Stover [N]	Grain [N]	Nitrogen uptake: Stover	Nitrogen uptake: Grain	Nitrogen uptake: Total	Relative Leaf Chlor.	Final Plant Pop.	NUE PFP	NUE AE
#		lb/ac	%	bu/ac	%	----------- tdm/a -----------			%	%	--------- lb N/ac ---------			%	pl*10^3/ac	bushel/lb N	
1	None	3	17.5 d^	154 d	60.5 d	0.48 c	2.80 b	6.92 d	0.30	0.97	16.8	70 d	87 e	72.7 c	33.8		
2	None	120	18.0 cd	240 b	94.6 b	0.61 b	3.41 a	9.70 bc	0.45	1.16	30.9	132 b	163 bc	99.0 ab	34.1	2.00	0.72
3	None	150	18.4 bc	254 a	100.0 a	0.66 a	3.50 a	10.17 a	0.51	1.20	35.4	144 a	179 a	99.0 ab	33.8	1.69	0.67
4	Cereal rye	3	19.3 a	108 f	42.5 f	0.36 e	2.08 c	5.00 f	0.27	0.95	11.1	49 e	60 f	67.1 d	33.9		
5	Cereal rye	120	18.8 ab	226 c	89.1 c	0.62 b	3.45 a	9.43 c	0.40	1.12	27.5	120 c	147 d	97.6 b	33.9	1.89	0.99
6	Cereal rye	150	18.5 bc	247 ab	97.2 ab	0.64 ab	3.35 a	9.84 ab	0.45	1.19	30.3	139 ab	169 bc	98.7 ab	33.5	1.65	0.93
7	Annual blend	3	18.6 bc	120 e	47.1 e	0.41 d	2.16 c	5.40 e	0.30	0.98	13.1	55 e	69 f	71.9 c	34.0		
8	Annual blend	120	18.5 bc	244 b	95.9 b	0.64 ab	3.41 a	9.81 abc	0.39	1.16	26.2	133 b	159 c	98.7 ab	33.9	2.03	1.03
9	Annual blend	150	18.4 bc	247 ab	97.3 ab	0.62 ab	3.35 a	9.83 ab	0.46	1.17	30.8	137 ab	168 b	100.0 a	33.9	1.65	0.85
Statistical significance of treatment main effects for a two-factor factorial arrangement																	
Cover crop																	
No cover			18.0 B	216 A	85.0 A	0.58 A	3.24 A	8.93 A	0.42 A	1.11	27.7 A	115 A	143 A	90.2 A	33.9	1.85	0.69
Cereal rye			18.9 A	194 C	76.3 C	0.54 B	2.96 B	8.09 B	0.37 B	1.08	23.0 B	102 B	125 B	87.8 B	33.8	1.77	0.96
Annual blend			18.5 A	203 B	80.1 B	0.56 AB	2.98 B	8.35 B	0.38 B	1.10	23.4 B	109 AB	132 B	90.2 A	34.0	1.84	0.94
P > F:			0.008	0.008	0.008	0.070	0.007	0.007	0.059	0.491	0.014	0.047	0.030	0.011	0.563		
N rate for corn																	
3			18.5	127 C	50.1 C	0.42 B	2.35 B	5.77 C	0.29 C	0.97 C	13.7 C	58 C	72 C	70.6 B	33.9		
120			18.4	237 B	93.2 B	0.62 A	3.42 A	9.64 B	0.41 B	1.14 B	28.2 B	128 B	156 B	98.4 A	33.9	1.97	0.91
150			18.4	249 A	98.2 A	0.64 A	3.40 A	9.94 A	0.47 A	1.19 A	32.1 A	140 A	172 A	99.2 A	33.7	1.66	0.81
P > F:			0.964	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.492		
Interaction (cover crop × N rate)																	
P > F:			0.017	<0.001	<0.001	0.002	<0.001	<0.001	0.500	0.193	0.840	0.003	0.023	0.003	0.612		

^ Numbers followed by different letters are significantly different at α = 0.10 level. Capital letters signify differences in main effects and small letters are differences due to interaction between main effects.

Table 6. Tile flow, flow-wieghted NO_3-N concentration, NO_3-N loss, and flow-adjusted loss as affected by treatments in 2017.

Trt	Cover Crop	N application Planting	N application V4	Tile flow Pre	Tile flow Post	Tile flow Total	Flow-weighted NO_3-N Pre	Flow-weighted NO_3-N Post	Flow-weighted NO_3-N Average	NO_3-N lost Pre	NO_3-N lost Post	NO_3-N lost Total	Flow adj. NO_3 loss
#		---- lb/ac ----		------	inch	------	------	mg/L	------	------	lb/ac	------	lb/inch
1	None	3	0	1.0	2.8	3.8	6.4	8.8	8.4	1.4	5.5	6.9	1.8
2	None	30	90	1.3	3.5	4.8	8.3	9.5	9.3	2.4	7.2	9.5	2.0
3	None	30	120	0.5	1.8	2.3	7.3	9.1	8.8	0.8	3.7	4.4	1.9
4	Rye	3	0	1.6	3.9	5.5	2.8	2.7	2.8	1.0	2.7	3.7	0.7
5	Rye	30	90	1.0	3.1	4.1	2.7	2.5	2.5	0.5	1.7	2.2	0.5
6	Rye	30	120	1.6	3.5	5.1	3.0	2.3	2.4	0.8	1.8	2.6	0.5
7	Blend	3	0	1.0	3.0	4.1	5.8	5.8	5.8	1.2	3.7	4.8	1.2
8	Blend	30	90	1.4	3.2	4.6	6.4	8.3	7.8	2.2	5.7	7.9	1.7
9	Blend	30	120	0.8	2.4	3.2	5.8	7.2	6.9	1.0	3.9	4.9	1.5
Stats for RCB Design with a two-factor factorial arrangement													
Cover crop													
No cover				0.9	2.7	3.6	7.3 A^	9.1 A	8.8 A	1.5	5.4 A	6.9	1.9 A
Cereal rye				1.4	3.5	4.9	2.8 C	2.5 C	2.6 C	0.8	2.1 B	2.8	0.6 C
Annual blend				1.1	2.9	4.0	6.0 B	7.1 B	6.8 B	1.5	4.4 AB	5.9	1.5 B
P > F:				0.352	0.405	0.378	0.001	<0.001	<0.001	0.343	0.093	0.130	<0.001
N rate for corn													
3				1.2	3.3	4.4	5.0	5.8	5.7	1.2	4.0	5.1	1.2
120				1.2	3.2	4.5	5.8	6.8	6.5	1.7	4.9	6.6	1.4
150				1.0	2.6	3.6	5.4	6.2	6.0	0.9	3.1	4.0	1.3
P > F:				0.786	0.615	0.666	0.318	0.115	0.198	0.507	0.451	0.463	0.194
Interaction (cover crop × N rate)													
P > F:				0.365	0.704	0.586	0.591	0.147	0.292	0.379	0.534	0.476	0.291

^ Numbers followed by different letters are significantly different at α = 0.10 level. Capital letters signify differences in main effects and small letters are differences due to interaction between main effects.

Table 7. Soil nitrate-N by depth as affected by cover crop species, nitrogen rate for corn, and sampling date.

	Fall 2016				Spring 2017				Fall 2017				Spring 2018			
	3^	120	150	Mean	3	120	150	Mean	3	120	150	Mean	3	120	150	Mean
	--- NO_3-N, lb/ac ---															
	0- to 6-inch depth															
Cover crop																
None	14.1	16.3	13.2	14.5	13.8	10.7	11.7	12.0A	14.6	17.4	20.4	17.5				
Cereal rye	11.8	10.6	11.0	11.2	7.1	5.6	5.2	6.0C	13.9	19.6	16.8	16.8				
Blend	13.0	12.0	10.8	12.0	9.0	9.7	9.6	9.5B	14.9	16.5	21.8	17.7				
Mean:	13.0	13.0	11.7		10.0	8.6	8.9		14.5	17.8	19.7					
	7- to 12-inch depth															
None	12.0	13.5	14.8	13.4	12.2	10.6	12.5	11.8A	10.0b	16.0a	19.0a	15.0				
Cereal rye	11.6	10.9	11.3	11.3	5.9	6.0	5.1	5.7B	16.9a	17.9a	13.9ab	16.2				
Blend	13.4	12.3	12.7	12.8	10.5	10.7	10.8	10.6A	15.6a	16.8a	14.9ab	15.7				
Mean:	12.3	12.2	12.9		9.5	9.1	9.5		14.2	16.9	16.0					
	13- to 24-inch depth															
None	14.8	16.9	16.7	16.1	16.3	14.7	15.8	15.6A	24.2	28.1	36.4	29.6				
Cereal rye	16.2	17.6	15.8	16.5	11.6	6.9	5.6	8.0B	27.5	27.3	26.5	27.1				
Blend	16.0	14.8	15.2	15.4	13.4	11.7	12.5	12.6A	27.5	26.3	30.6	28.1				
Mean:	15.7	16.5	15.9		13.8	11.1	11.3		26.4	27.2	31.2					
	25- to 36-inch depth															
None	13.9	14.9	15.8	14.9	12.0	11.5	11.8	11.8A	20.8	24.2	24.0	23.0				
Cereal rye	16.2	12.7	14.1	14.4	6.9	5.9	6.7	6.5B	26.0	27.5	24.3	25.9				
Blend	14.1	13.7	14.4	14.1	11.1	10.4	7.8	9.8A	26.5	16.0	19.8	20.8				
Mean:	14.8	13.8	14.8		10.0	9.3	8.7		24.4	22.5	22.7					

^ Nitrogen fertilizer rate for corn in 2017, lb N/ac.

† Numbers followed by different letters are significantly different at α=0.10 level. Capital letters signify differences in main effects and small letters are differences due to interaction between main effects.

Table 8. Soil total inorganic-N by depth as affected by cover crop species, nitrogen rate for corn, and sampling date.

	Fall 2016				Spring 2017				Fall 2017				Spring 2018			
	3^	120	150	Mean	3	120	150	Mean	3	120	150	Mean	3	120	150	Mean
	---------- Total inorganic-N, lb/ac ----------															
	0- to 6-inch depth															
Cover crop																
None	21.3	27.2	21.9	23.5	20.8	19.4	20.4	20.2A	21.2	26.2	26.6	24.7				
Cereal rye	24.0	20.8	20.8	21.8	17.4	16.0	13.2	15.5B	21.2	30.7	25.8	25.9				
Blend	23.1	21.0	19.8	21.3	17.4	17.1	17.9	17.4AB	23.6	23.7	30.0	25.7				
Mean:	22.8	23.0	20.8		18.5	17.5	17.2		22.0	26.9	27.4					
	7- to 12-inch depth															
None	18.4	20.9	23.7	21.0	17.1	15.9	17.2	16.8A	13.8	21.4	24.0	19.7				
Cereal rye	19.5	18.1	15.7	17.8	11.8	14.7	9.9	12.1B	21.4	22.8	17.3	20.5				
Blend	20.8	19.2	18.8	19.6	17.0	18.4	15.2	16.9A	19.9	20.2	18.7	19.6				
Mean:	19.6	19.4	19.4		15.3	16.4	14.1		18.4	21.4	20.0					
	13- to 24-inch depth															
None	23.3	30.0	26.9	26.7	20.4	22.7	21.8	21.6	28.3	33.4	41.6	34.4				
Cereal rye	27.6	28.5	26.3	27.5	24.3	16.4	13.5	18.1	35.9	35.4	31.9	34.4				
Blend	27.1	26.2	26.1	26.5	22.0	18.6	17.4	19.4	33.2	32.2	35.9	33.8				
Mean:	26.0	28.2	26.4		22.3	19.2	17.6		32.5	33.7	36.5					
	25- to 36-inch depth															
None	26.6	26.1	27.0	26.6	16.8	22.8	17.6	19.7	26.3	28.6	30.4	28.4				
Cereal rye	29.0	27.3	23.7	26.7	18.2	19.4	12.6	16.7	34.4	35.0	29.5	33.0				
Blend	26.9	25.1	27.3	26.4	19.2	21.0	18.1	19.4	33.4	22.0	25.2	26.8				
Mean:	27.5	26.2	26.0		18.7	21.1	16.1		31.4	28.5	28.4					

^ Nitrogen fertilizer rate for corn in 2017, lb N/ac.

† Numbers followed by different letters are significantly different at α=0.10 level. Capital letters signify differences in main effects and small letters are differences due to interaction between main effects.

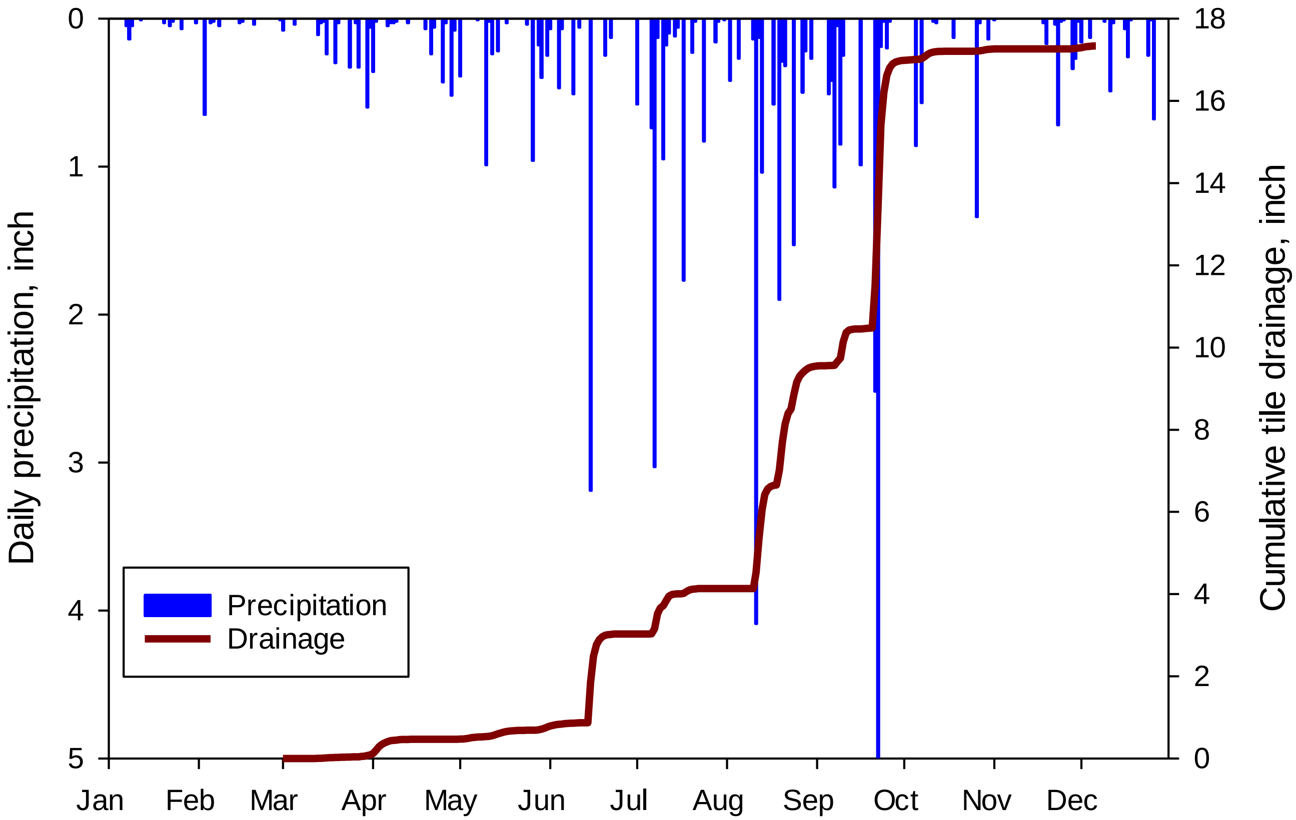


Figure 1. Daily precipitation and cumulative tile drainage in 2016.

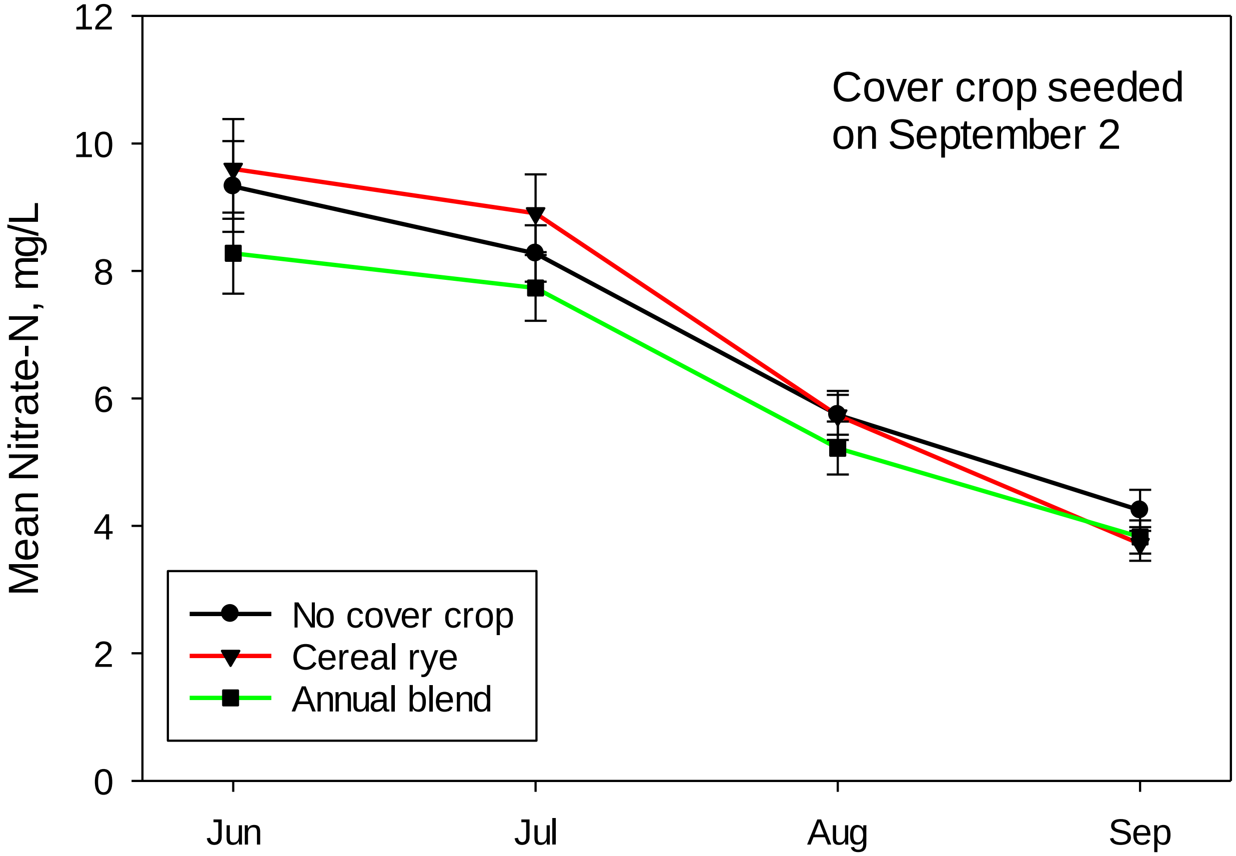


Figure 2. Nitrate-N concentration in tile drainage as affected by cover crop treatments in 2016 (setup year).

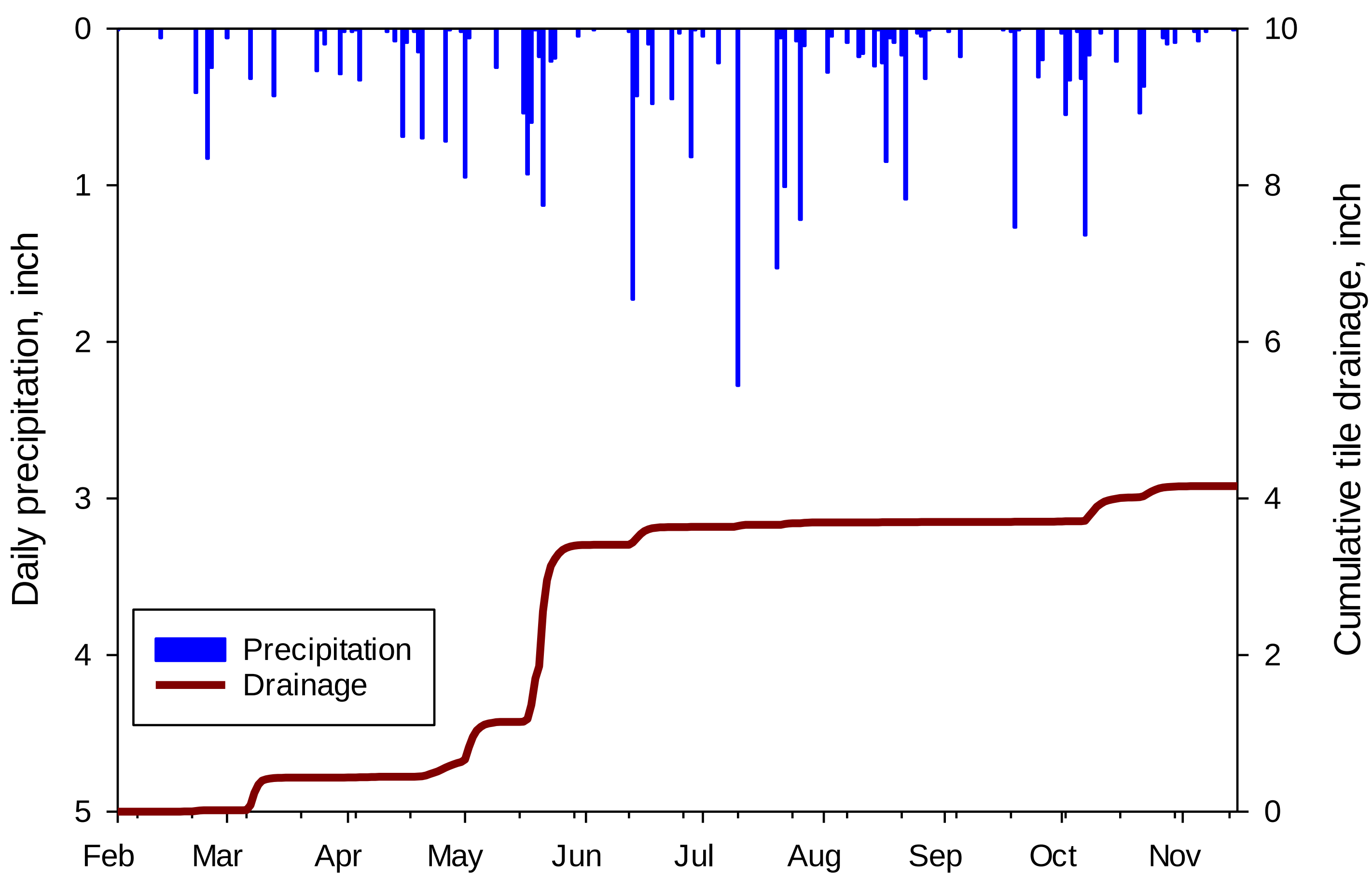


Figure 3. Daily precipitation and cumulative tile drainage in 2017.

Appendix Pictures

Pic. 1. Schematic diagram of tile drainage system.

Pic. 2. Tile drainage well access culvert, data logger, and coolers for holding water sample collection bottles.

Pic. 3. Plumbing inside culvert: sump well, pump, and water meters.

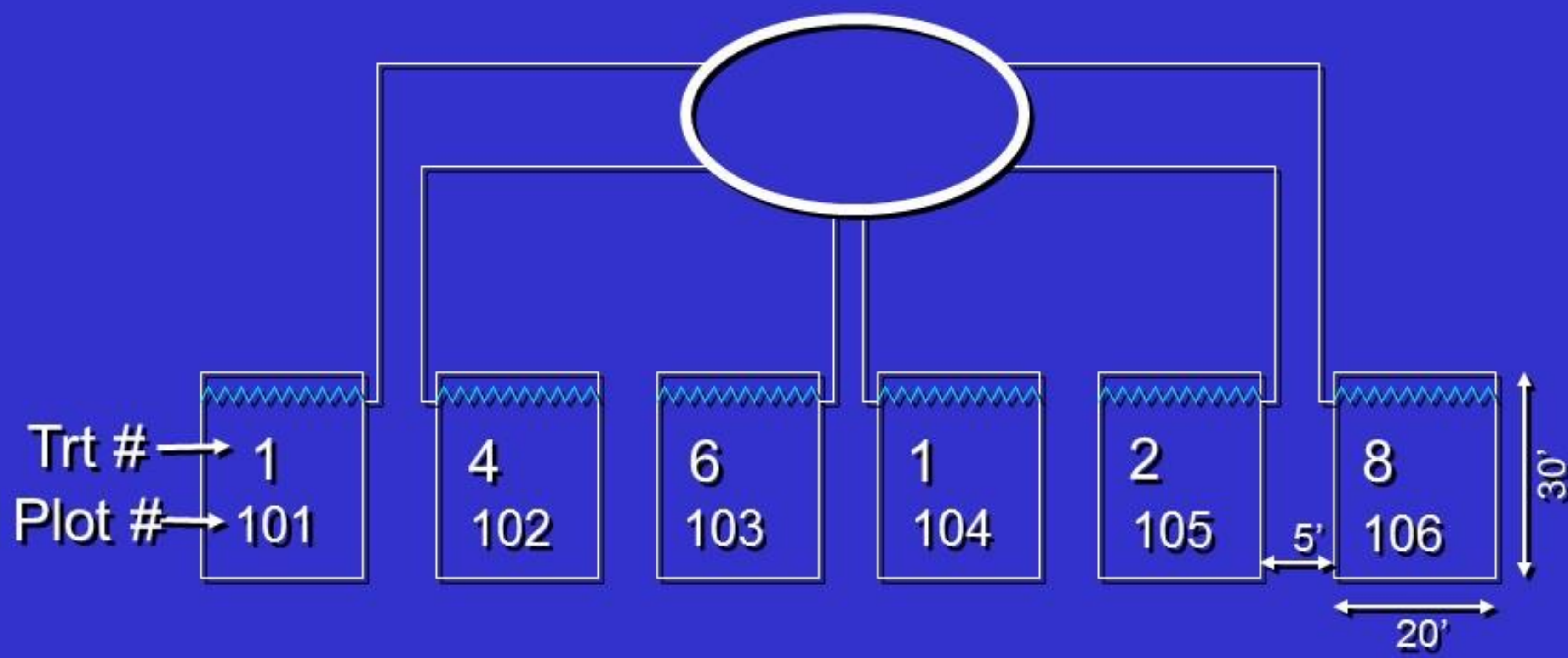
Pic. 4. Strip tillage on 24 October 2016, injecting P and K fertilizer at time of tillage.

Pic. 5. Spraying cereal rye with glyphosate on 17 April 2017 to terminate it prior to planting corn.

Pic. 6. Planting corn into strip-till bands on 7 May 2017. Applying liquid starter fertilizer (10-34-0 and UAN) at planting.

Pic. 7. Nitrogen deficiency on lower leaves at R5 (6 September) with 120 lb N/ac and cereal rye cover crop.

Drainage Research Facility at Waseca, SROC




Oct. 24, 2016
Orbit-Air


April 17, 2017


May 7, 2017


120 lb N/ac w/cereal rye
150 lb w/cereal rye, Sept. 6