Effects of Cover Crop and Nitrogen Rate on Corn Grain and Silage Yield, Nitrogen Loss in Tile Drainage and Soil Health.
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Introduction / Justification

Nitrogen is an essential input for profitable corn production. Previous research has shown subsurface tile drainage systems deliver nitrate-N to surface waters and thereby degrade water quality (Randall and Mulla, 2001, Dinnes et al., 2002). Row crop agriculture in the Midwest is under scrutiny to reduce nitrate 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 nitrate loads in tile drainage water. However, research in Minnesota has shown cover crop establishment can be difficult (Strock et al., 2004), often producing minimal cover crop growth (biomass) which results in less or inconsistent nitrate reduction in tile drainage water compared to other areas in the Midwest with longer growing seasons and milder winters (Kaspar et al., 2007).

There are cropping systems where cover crops could be more effective as nitrate scavengers and soil protectors. These cropping systems include following canning crops, like sweet corn and peas, small grains and when corn is harvested for silage in early September. In these systems there is considerably more time for cover crop establishment and growth in the fall before soils freeze in Minnesota. Furthermore, after silage corn a cover crop could protect the soil from erosion and potentially replenish carbon lost during the silage (biomass) harvest which would improve sustainability.

The species of cover crop, establishment date and termination date can affect its potential to sequester N and carbon (C). Cereal rye is effective at scavenging N when it’s established early and not terminated until spring. However, Vetsch et al. (unpublished) found cereal rye can negatively affect corn production and economics by decreasing yield or increasing input costs due to greater fertilizer N requirement, cover crop seed costs and herbicide costs for cover crop termination. A cover crop blend like oat, forage pea and radish are less expensive alternatives than cereal rye due to seed costs and no herbicide needed for termination. The potential of winter terminated cover crops to scavenge N and sequester C in a corn silage cropping system in Minnesota is not known. Furthermore, it’s not clear if nitrate loss in tile drainage is different between corn silage and corn grain systems.

Farmers are interested in the soil health benefits of cover crops, but also their potential to sequester carbon, especially in continuous corn systems with minimal or reduced tillage. The proposed study, which was initiated in 2021 on the tile drainage research facility in Waseca, provides an opportunity to simultaneously measure the effects of cover crops on corn production, nitrate loss in tile drainage and soil health metrics.

The objectives of this study are to quantify the effects and interactions of cover crops and N rates on corn production, nitrate-N concentration and loss in tile drainage, N uptake, NUE, economic return and soil health parameters.

Experimental Procedures

A research experiment was initiated in 2021 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 puts plots with the greatest historical flow all in the same block.

A total of 11 treatments were included in this study. Eight treatments were comprised from a partial factorial combination of three management factors: corn cropping system (corn for grain and corn silage), cover crop use and N rate. The three cover crop treatments included: no cover crop in both cropping systems (corn for grain and corn silage), cereal rye with spring termination or a blend of annuals (oat, forage pea and radish) with late fall or winter termination due to freezing. The four crop system treatments were corn for grain no cover crop (Gnc), corn for silage no cover crop (Snc), corn for silage with cereal rye cover (Srye) and corn for silage with annual blend cover (Sblend). These cover crop treatments were no-till drilled soon after corn silage harvest and only in the corn silage cropping system. Cover crop seeding rates were 60 lb/ac for cereal rye and 18, 8, and 1 lb/ac for oat, forage pea, and radish, respectively. Nitrogen rates of 180 and 220 lb N/ac for continuous corn were compared across all cropping systems and cover crop treatments. The 180-lb rate is near the maximum of the MRTN acceptable range for corn after corn in Minnesota at a 0.10 price ratio (N price / corn price). The 220-lb rate aids in determining a cover crops ability to sequester N thereby minimizing potential nitrate loss in tile drainage water. Three additional N rate treatments were included in the study. One was a “zero” N control, which received 4.6 lb N/ac from liquid starter fertilizer, and the others were 140 and 260 lb N/ac for corn grain production. These additional treatments help in determining the optimum N rate for corn grain production. The 140 and 260 lb N/ac treatments did not have tile drainage monitoring.

Nitrogen fertilizer treatments were split-applied with 20 lb N/ac at planting and the remainder applied at V2 as urea ammonium nitrate (UAN, 32-0-0) which was stream-injected about 10 inches from the row. Liquid starter fertilizer, ammonium poly phosphate (APP, 10-34-0 at 4 gal/ac; 4.6 lb N/ac + 16 lb/ac of P_2O_5), was applied in-furrow at planting to all plots. All treatments, except for the control, received 3 gal/ac of UAN (10.7 lb N/ac) and

3.5 gal/ac of ammonium thiosulfate (ATS, 12-0-0-26S; 4.7 lb N/ac + 10 lb S/ac) in a surface-dribbled band three inches from the corn row at planting. See table 1 for completion dates of each procedure and for each year. See Supplemental Materials Table S1 for products used, rates applied and other information.

Corn was planted at 34,000 seeds/ac in 30-inch rows. The cereal rye treatments received a broadcast-application of glyphosate to terminate the cover crop, a second application of glyphosate was required in 2022 due to unusually cold weather which reduced the effectiveness of the first application. Additional weed control included a pre and post emergence applications at full labeled rates (Table S1). Corn plant counts were taken from harvest rows. Relative leaf chlorophyll content (RLC) was calculated from Minolta SPAD meter measurements from the ear leaf (30 measurements per plot) at R1. Plot notes (corn height and greenness differences) were taken at the V8 and R3 corn growth stages. Corn silage yields were determined by hand harvesting two corn rows 10 ft in length. Plants were cut 8 inches above the soil surface (same as commercial harvesting). Whole plot samples were weighed wet, then four plants were chopped for a subsample to determine harvest moisture and this sample was dried at 140° F for 3 days, ground and submitted to a commercial lab to determine feed value (NDF, ADF, etc.) and nutrient content in corn silage. The remaining silage crop was removed with a custom harvester and cover crops were seeded with a no-till drill.

Corn grain yield from select treatments was harvested with a plot combine (two rows 33 ft in length). A grain sample was collected at harvest and this sample was dried at 140° F for 3 days, ground to and analyzed for nutrient content after microwave acid digestion at a commercial lab. Nitrogen removal in corn grain was calculated from grain 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 4.6 lb N/ac rate from starter fertilizer was assumed to be the zero N control.

Cover crop biomass yields were measured by cutting and collecting all material from two 20 by 30 inches (4.17 sq. ft) areas from each plot in the fall and prior to termination in spring. No biomass harvest was conducted in the fall of 2022 due to very little cover crop growth (Appendix Pic. 5). A very dry September and October contributed to the poor cover crop growth in 2022. Since the annual blend cover terminated during the winter, these plots were not sampled in spring. Biomass samples were dried at 140° F for 3 days, weighed, ground, and analyzed for C and N concentration at a commercial lab. A corn stover (residue) sample was collected from the corn grain production plots, these samples were dried at 140° F for 3 days, weighed, ground, and analyzed for C and N concentration.

Corn stalks were chopped (shredded) about 6 inches above the soil surface on corn grain plots prior to fall strip tillage. All plots were strip tilled to an 8-inch depth with a Redball™ Model 2000. A fertilizer blend of P-K-S (Table S1) was applied in the strip-till band.

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 of the flow is collected in containers. This insures some of the water sample comes from the entire period between sample collection. This technique is often referred to flow-weighted sampling (Dinnes et al., 2002). Tile water samples are taken from each plot once a week during normal tile flow and two times per week during heavy tile flow. Water samples are kept cool prior to collection and then frozen after collection.

Each year soil samples were taken from all plots in the spring prior to planting corn at 0- to 15, 15- to 30-, 30- to 60-, and 60- to 90-cm depths. Three 1.5-inch diameter (3.8 cm) cores are taken per plot. One core from a non-wheel track row is used to determine soil bulk density. The other cores are composited, immediately dried at 105º F, then ground and sieved to pass a 2-mm screen. Spring 0- to 15-cm samples were analyzed for Olsen P and exchangeable K using standard soil test methods for the North Central Region. All spring samples were analyzed for nitrate-N, ammonium-N, total N, total organic C, POXC and CO2 burst (min-C) using standard soil test methods for the North Central Region. In November, fall soil samples were collected from a 0- to 30-cm depth, immediately dried at 105º F, then ground and sieved to pass a 2-mm screen. These fall samples were analyzed for nitrate and ammonium-N. The POXC and CO2 burst tests were conducted in Dr. Anna Cates lab at the University of Minnesota. All other soil tests were conducted at commercial labs. These soil health tests allow us to assess microbial activity and food source. These C pools can be seen as early indicators of C sequestration and correlate with crop yields (Oldfield et al. 2021).

All data were statistically analyzed using ANOVA with Proc mixed in SAS® (SAS 9.4, SAS Institute Inc., 2014. Cary, North Carolina) after examination of residuals, outliers and normality assumptions using Proc univariate in SAS. A two-factor ANOVA with a split-plot arrangement of treatments compared the effects and interactions of crop system and cover crop treatments [grain corn, no cover crop; silage corn, no cover; silage corn, cereal rye with spring termination; and silage corn with annual blend with winter termination] and total N rate (180 and 220 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 row or column are significantly different.

Considerable variation in tile flow among individual plots is common in drainage research facilities. Managing it with blocking, statistical designs and replication is somewhat effective. Tile flow variability among treatments and among replications within a treatment often result in data that are not normally distributed and have non constant variance among treatments. These assumptions are often violated and statistical analyses with ANOVA is not recommended. Furthermore, variability in tile flow among plots greatly influences nitrate loss or load among individual plots and treatment means. Thus, nitrate loss data are also not normally distributed and have non constant variance. Adjusting or correcting these data for flow during a period of collection (three month or annual periods) often results in data that are normally distributed and have constant variance. These techniques were used in the analysis of the data in this study and will be discussed further in the results and discussion section.

Results and Discussion

Weather

Weather data characterizing the 2021 growing season at Waseca are presented in Table 2 and Figure 1a. These data were taken from the SROC weather station (44.07064, -93.52645) located 0.3 miles from the drainage research site. The growing season was warm and dry as every month (April through September) had greater than normal mean temperatures and all months except August had considerably less than normal precipitation. An unusually dry period from April through mid-May (<0.9 inches of total precipitation), resulted in slow germination and uneven emergence of corn. The dry weather combined with liquid starter fertilizer injury of corn seedlings, a result of human error and equipment malfunction, required corn to be replanted on 24 May to minimize unevenness in corn stand and growth. Nitrogen loss due to leaching and denitrification would have been nearly zero during this droughty growing season as only two rainfall events of more than 1.0 inches occurred from April through September. Precipitation for the period from May through September totaled only 14.13 inches compared to the normal of 23.72 inches. Growing Degree Units (GDU) totaled 2,979 a record for Waseca and 470 more than normal. Despite the dry conditions, corn yields were near long-term averages in 2021 which is remarkable.

Weather data in 2022 are presented in Table 1 and Figure 1b. Spring started cool and wet but turned warm and dry as May through September had greater than normal mean temperatures and June, July and September had less than normal precipitation. The cool and wet April and early May delayed corn planting and other field operations. Precipitation for the period from May through September totaled 19.98 inches compared to the normal of 23.72 inches. While monthly rainfall was near normal (± 0.7 inches) in all months except September, rainfall distribution was irregular. Each month had a large rainfall event including 2.41 inches on May 11-12, 3.50 inches on June 13-14 (2.5 inches in 2 hours), 2.50 inches on July 24, 1.93 inches on August 7-8 and 1.98 inches on August 28 (Figure 1b). The May and June events resulted in significant runoff and ponding in low areas of fields. Nitrogen loss from leaching was likely minimal due to rainfall intensity and runoff; however, leaching and denitrification in ponded areas likely occurred during these May and June events. These large rainfall events contributed about half of the total rainfall for a month. Furthermore, June, July, August and September had long dry periods with minimal or no rainfall. Growing Degree Units (GDU) totaled 2,629, about 5% greater than normal. Despite this irregular weather, corn yields were only 10-15 bu less than average in 2022.

Cover crop biomass

Treatments significantly affected nutrient concentration and uptake in cover crops and the C:N ratio (Table 3a). For the 5 November 2021 sampling, biomass yields were numerically greater with rye (296 lb) than with blend (255 lb) but not significantly greater (*P* value = 0.114), when averaged across N rates for corn. The blend had greater N concentration in biomass and a lower C:N ratio than rye. Carbon concentration, N uptake and C uptake were not affected by treatments and no significant interactions among treatment effects were observed. When averaged across cover crop specie, the 170 lb N rate for corn in 2021 resulted in greater N concentration and uptake in biomass and lower C concentration and C:N ratio compared with the 140 lb N rate. These data suggest the 170 lb N/ac treatment had greater residual soil N (likely as NO_3^-) in the soil profile after harvest. However, the difference in N uptake in the cover crop biomass between the two N rates for corn was quite small, only 2 lb/ac.

Rye biomass yield averaged 296 lb/ac on 27 April 2022 compared with 276 lb/ac on 5 November 2021 (Table 3a). This small difference in biomass from fall to spring was not related to poor growth as rye height in April was about 2X greater than in November. The small increase in rye biomass from fall to spring was attributed to rye stand loss due to tractor wheel tracks and strip-tillage zones. Nitrogen rates for corn in 2021 had no effect on biomass yield and N and C concentration and uptake. However, C:N ratio was slightly less with 170 lb N/ac than with 140 lb N/ac.

Due to very poor growth during the dry fall of 2022 no cover crop biomass yields were taken in the fall of 2022. Rye biomass yields will be collected in the spring of 2023.

Corn grain production

Corn grain yield and moisture from 2021 (study setup year) are presented in Table 4a. Grain yields ranged from 111 bu/ac in the control (4.6 lb N/ac) to 167 bu/ac with 170 lb N/ac for corn following soybean. An ANOVA analysis showed yields were statistically equal among the 140, 170 and 200 lb N/ac treatments. Grain moisture ranged from 20.0 to 21.2 percent and only small differences were observed as the control treatment was slightly drier.

Corn grain yield, moisture, nutrient concentration and nutrient uptake in 2022 are presented in Table 4b. Grain yields ranged from 60 bu/ac in the control (4.6 lb N/ac) to 218 bu/ac with 260 lb N/ac for corn following corn. ANOVA showed yields were greatest with 260 lb N/ac but statistically equal among the 140, 180 and 220 lb N/ac treatments. Grain moisture ranged from 22.7 to 26.2 percent. Moisture was least with 180 and 220 lb N/ac and greatest with 260 lb N/ac suggesting the higher N rate enhanced plant stay green, which may have contributed to slightly greater yields in this relatively dry growing season. Grain N concentration was least with the control and was statistically equal among other N rates for corn. Nitrogen removal in grain increased with increasing N rate and was statistically similar between the 220 and 260 lb N/ac rates. Grain P concentration was greatest in the zero N control and numerically least with 260 lb N/ac. Grain K and S concentrations were also least with the zero N control treatment. Grain K and S concentrations among other N rates were generally not significantly different or were related to the zero N control. Grain P_2O_5 and K_2O removal was least with the zero N control and statistically equal among other N rate treatments. Grain S removal was least with the zero N control and slightly less with 140 lb N/ac compared with other higher N rates.

Corn silage yield, silage quality and nutrient uptake in silage

Corn silage yield, silage moisture and other corn production parameters for the 2021 setup year are presented in Table 5a. Since this was a setup year the cropping systems (corn for grain vs corn for silage) and cover crop treatments had not been established; therefore, the only true treatment effects would have been from the N rates applied for corn after the previous year's soybean. Silage yield at harvest moisture (wet) was numerically least with the control treatment (#1) but no significant differences among treatments were found (P value = 0.170). Wet silage yields in N fertilized treatments ranged from 22.7 to 24.9 ton/ac. Dry silage yields were less with the N control (7.47 ton/ac), however all other treatments had statistically equal yields ranging from 8.41 to 8.99 tons of dry matter per acre (TDM/ac). Silage moisture at harvest ranged was not affected by treatments and ranged from 61.6 to 63.8%. Plant population averaged slightly less than 30,000 and was not affected by N treatments. Relative leaf chlorophyll content calculated from SPAD readings were least with the N control, intermediate with 110 lb N/ac and statistically equal with all other treatments.

Corn silage yield, silage moisture and other corn production parameters in 2022 are presented in Table 5b. An ANOVA of all 11 treatments showed silage yields, SPAD and RLC were least with the N control and generally reduced with 140 lb N/ac compared to higher N rates. Silage moisture was greatest with the N control treatment and generally driest with silage treatments with cover crops. Plant populations ranged from 32,900 to 34,800 and were greater in the corn silage crop system. Residue cover after planting ranged from 15 to 67.5%. Residue cover was greatest with corn for grain at 140 and 260 lb N/ac, slightly less with corn for grain at other N rates and was considerably less with corn silage treatments which will be discussed in further detail below.

A split-plot statistical analysis of the main eight treatments can also be found in Table 5b. When averaged across the crop system treatments (main plots), N rates for corn (180 or 220 lb/ac) did not affect any of the silage yield and corn production parameters and there were no significant interactions among main plot and subplot factors. When averaged across N rates, crop systems did not affect wet silage yields but did affect dry silage yields. Dry silage yield was least in the corn grain system compared with all the corn silage systems. Silage moisture was less with Srye than with Gnc and Snc. Plant populations were about 1,000 plants/ac less with Gnc system than with silage systems, suggesting better soil tilth for germination and seedling growth in silage systems. SPAD readings were less with Gnc than with Snc and Sblend while Srye was intermediate. Interestingly, RLC trends were identical to SPAD as they should be, but no significant differences were observed (*P* value 0.104). Residue cover was least with Snc (16%) and Sblend (22%), intermediate with Srye (38%) and greatest with Gnc (54%). These data clearly show how the Snc system does not maintain adequate residue cover for erosion protection. The Sblend system is numerically better but still marginal; whereas, the Srye which was terminated in spring maintained >30% residue cover. In this strip-tillage system, the corn grain system had >50% residue cover after planting but also had lower silage yields (dry) and SPAD values.

Silage quality parameters, nutrient concentrations and removal in 2022 are presented in Table 6b. An ANOVA of all 11 treatments found crude protein (CP), starch and milk yield were least with the control and less with 140 lb N/ac compared to higher N rates. Generally, the control had greater acid detergent fiber (ADF), neutral detergent fiber (NDF) and total tract NDF digestibility (TTNDFD). Silage P concentration was not affected by the 11 treatments and ranged from 0.194 to 0.223% (% of DM). Silage K concentration ranged from 0.586 to 0.775% and was greatest with the control but most treatments were not significantly different. Silage S concentrations were least with the control (0.055%) and 140 lb N/ac (0.058%) and greatest with the Sblend at 220 lb N/ac treatment (0.074%). Nutrient removal in corn silage was always least with the control treatment and generally aligned with silage yield (Table 5b). With the control and 140 lb N/ac treatments excluded, nutrient removal in silage averaged 86, 136 and 12 lb/ac of P_2O_5, K_2O and S, respectively. When averaged across corn grain treatments at 180 and 220 lb N/ac (treatment #'s 2 and 3), nutrient removal in corn grain averaged 55, 38 and 9 lb/ac of P_2O_5, K_2O and S, respectively. These data are important when determining fertilizer rates for corn grain vs corn silage systems.

A split-plot statistical analysis of the main eight treatments is found in Table 6b. When averaged across the crop system treatments (main plots), N rates for corn (180 or 220 lb/ac) did not significantly affect any of the silage quality, nutrient concentration and nutrient removal parameters except for RumenS (*P*=0.095) and there were no significant interactions among main plot and subplot factors. When averaged across N rates, CP was greater with Sblend and Snc than with Gnc while ADF, NDF and undigestible detergent fiber (uNDF) were greatest with Srye. Milk yield was less with Srye than with Gnc, Snc and Sblend, when averaged across N rates. Gnc had slightly less P_2O_5 and S removal than did silage systems (Snc, Srye and Sblend). All other parameters (TTNDFD, starch, RumenS, P, K, S concentrations and K_20 removal) were not significantly affected by crop systems, when averaged across N rates. These data showed crop systems were more likely to affect quality parameters and nutrient concentrations and removal than were N rates. Furthermore, these data suggest that during the 2022 growing season, the 180 lb N/ac rate optimized yield, economic return, and forage quality.

Tile drainage and nitrate concentrations and loss in 2022

Treatment means and standard errors (SE) for tile flow, flow-weighted (FW) NO_3-N concentration and NO_3-N loss or load in 2022 are presented in Table 7a. Tile flow began on 8 April 2022 and 99.8% of all tile flow occurred in April, May and June (Fig. 1). This late start for spring tile flow resulted from a dry growing season in 2021 that left the soil profile with a moisture deficit and a cool and relatively dry March and early April of 2022. Total annual flow averaged across treatments was 7.33 inches, which is less than normal. Total annual flow ranged from 4.8 (SE=1.13) inches with treatment #5 (silage with no cover at 220 lb N/ac) to 9.8 (2.77) inches with treatment #3 (grain corn with no cover at 220 lb N/ac). Except for treatment #'s 3, 5 and 7, mean tile flow among treatments was relatively uniform. Flow differences among treatments and among replications within a treatment often result in data that are not normally distributed and have non constant variance among treatments; therefore, only treatment means and standard errors (SE) are reported in Table 6a. Averaged across all 9 treatments tile flow was 0.9, 3.9 and 2.5 inches in April, May and June, respectively. Heavy rain during the morning of 13 June resulted in flooding of some drainage wells/culverts which restricted flow and contaminates sample collection. All drainage plots had returned to normal operation within 16 hours of the flooding.

In most treatments mean FW NO_3-N concentrations were least in April (ranged from 3.7 to 7.3 mg/L), increased in May (ranged from 2.9 to 9.9 mg/L) and were greatest in June (ranged from 4.1 to 13.8 mg/L, Table 7a). Averaged across months NO_3-N concentrations were least in the control (3.5 mg/L) and numerically greatest with the Snc at 220 lb N/ac treatment (10.5 mg/L). Both silage with rye cover treatments (#'s 6 & 7) had numerically lower FW NO_3-N concentrations compared with other fertilized crop system treatments. This was clearly evident in May when NO_3-N concentrations in other crop system treatments increased. These data suggest the cereal rye cover was an effective scavenger of NO_3 thereby reducing NO_3-N concentrations.

Averaged across all fertilized treatments NO_3-N losses were 1.1, 6.0 and 7.0 lb/ac in April, May and June, respectively (Table 7a). The total annual NO_3-N loss in 2022 ranged from 6.3 (3.9) lb/ac in the control to 22.7 (7.4) lb/ac with Gnc at 220 lb N/ac. The large SE (7.4) in the Gnc treatment resulted from considerable variability among replications within that treatment. Total annual NO_3-N loss in all other fertilized crop system treatments only ranged from 10.2 (3.0) to 14.8 (3.1) lb/ac.

Crop system, cover crop and N rate treatment effects on annual and three-month interval flow-adjusted NO_3-N concentration and annual flow-adjusted NO_3-N losses are presented in Table 8a. Due to 98.8% of the entire annual flow occurring during the April-June period, the April-June and annual average flow-adjusted NO_3-N concentration data and interpretation are almost identical. Therefore, only the April-June concentration data will be discussed here. An ANOVA of all 9 treatments showed flow-adjusted NO_3-N concentrations were least with the control (3.6 mg/L) followed by the Srye at 180 lb N/ac treatment (5.9 mg/L). The Srye at 180 lb N/ac treatment #6 had lower NO_3-N concentrations than treatment #'s 3, 4, and 5. The Snc at 220 lb N/ac treatment had greater flow-adjusted NO_3-N concentration than all other treatments except the Gnc at 220 lb N/ac. An

ANOVA of the 8 fertilized treatments found when averaged across N rates, flow-adjusted NO_3-N concentrations in April-June and the annual average were not significantly different. However, Srye had 27% lower NO_3-N concentrations than did Snc. This ANOVA found no significant differences among crop systems which contradicts the results from previous ANOVA of all 9 treatments. This may be a result of the split-plot statistical design not effectively blocking the variability and having greater power to find differences among sub-plots (N rates) and less power in finding differences among main-plots (crop systems). When averaged across crop systems, 220 lb N/ac had greater flow-adjusted NO_3-N concentrations than 180 lb N/ac (*P* value = 0.017).

Nitrate-N loss or load is calculated by multiplying tile flow (gal/ac/day) by a constant (8.34 lb/gal) and by the NO_3-N concentration in the sample for that period (a few days during heavy flow or a week or more during light tile flow). Flow-adjusted NO_3-N concentrations are calculated by summing the NO_3-N loss for a period of days (3 months or the annual total) and dividing by the sum of the flow and the constant for the same period. Flow-adjusted NO_3-N loss is calculated by dividing the annual sum of nitrate loss by the sum of the total annual flow (Eq. 1). Flow-adjusted NO_3-N concentration and loss data are normalized for variability in tile flow among individual plots and treatment means. This adjustment or correction minimizes variation and usually allows these data to be analyzed with ANOVA without violating the normality and constant variance assumptions.

Equation 1 $$total\ annual\ nitrate\ lost \div total\ annual\ flow\ = flow\ adjusted\ loss$$

Flow-adjusted NO_3-N losses ranged from 0.82 in the control to 2.82 lb NO_3-N/inch of drainage with Snc at 220 lb N/ac (Table 8a). Since the same parameters (total annual NO_3-N loss and total annual tile flow) are used in the calculation of flow-adjusted loss and concentration the values reported are derivatives of one another and therefore are numerically different but the statistical inferences and interpretation are nearly identical (see above) and will not be reiterated here. The 220 lb N/ac rate increased flow-adjusted NO_3-N loss 0.42 lb for every inch of tile drainage compared to the 180 lb N/ac rate (Table 8a) but 220 lb N/ac produced equal corn silage yields when compared to 180 lb N/ac (Table 5b).

Soil nitrogen

The effects of crop system, cover crops and N rates for corn in 2021 (setup year) on soil nitrogen were measured on 6 May 2022. Nitrate-N and total N (TN) at the 0- to 15- and 15- to 30-cm depths were not affected by treatments (Table 9a). An ANOVA of all 11 treatments found NO_3-N at the 30- to 60- and 60- to 90-cm depths was greatest with the grain system at 200 lb N/ac (treatment # 11). These data show how NO_3-N can accumulate in the soil profile at N rates greater than the economic optimum (EONR). A statistical analysis of the eight crop system treatments found when averaged across N rates, NO_3-N concentrations were greater with Snc and Sblend than with Srye at the 30- to 60-cm depth but no differences were found among other depths. Ammonium-N concentrations at the 0- to 15-cm depth were not affected by treatments. Some small differences were observed at the 15- to 30-cm depth with the 11 treatment ANOVA. However, the 8-treatment

ANOVA found no differences and model predicted means (Least Squares means, LS Means) were unusual and did not agree with trends observed in the data. Ammonium concentrations at 30- to 60- and 60- to 90-cm depths are not reported as many values were less than the laboratory minimum detection limit (MDL) of 0.5 mg/kg. These MDL values were assigned a value of 0.4 mg/kg for statistical analyses purpose. It's likely these "assigned" values are influencing the model predicted LS means. Total N concentrations were not affected by treatments in the 0- to 15- and 15- to 30-cm depths. At deeper depths TN was greater with Sblend than with Snc, when averaged across N rates. Crop system effects on TN at these deeper depths were not consistent among depths, which suggests these differences may not be related to cover crop treatments.

The effects of N rates for corn in 2021 on total residual soil NO_3-N (RSN) and NH_4-N remaining in the soil profile are shown in Figure 2. Nitrate-N increased at the 200 lb N/ac rate compared with other N rates in the corn grain cropping system. However, N rates had little effect on NH_4-N and NH_4-N was quite low (<18 lb/ac) in the 0- to 90-cm profile. The effects of cover crops and N rates on residual soil NO_3-N and NH_4-N remaining in the soil profile in the corn silage system is shown in Figure 3. Nitrate was least, only 16.6 lb/ac, with the rye cover at 140 lb N/ac and was greater with the annual blend cover. Greater N rates resulted in greater RSN in the soil profile with rye and blend covers. Oddly, the Snc at 140 lb N/ac rate had greater RSN than Snc at 170 lb N/ac. These data show the potential of the Srye system to scavenge RSN from the soil profile and thereby potentially reduce NO_3-N concentrations and losses in tile drainage water. Whereas, the Sblend system had similar RSN as the Snc system in early May of 2022.

The effects of crop system and N rates for corn in 2022 on soil inorganic N in the 0- to 30-cm depth were measured on 10 November 2022 (Table 10a). Nitrate-N concentrations ranged from 2.5 mg/kg in the control to 15.9 mg/kg with Srye at 220 lb N/ac. Nitrate-N concentrations were less with the corn grain system (Gnc), than with corn silage systems, when averaged across N rates. When averaged across crop systems, soil NO_3-N concentrations were greater with 220 lb N/ac than with 180 lb N/ac. Model predicted LS means did not agree with arithmetic means for the main effects of crop system (main plot); whereas, LS means did agree with arithmetic means with the main effect of N rate (sub-plots). These differences are likely caused by some skewness in the arithmetic mean data. No differences in NO_3-N concentrations were observed among the silage crop systems which means there was no affect of cover crops in the fall of 2022. Due to a very dry September and early October cover crop growth was extremely small, so a cover crops ability to scavenge NO_3-N would have been minimal. Crop systems and N rates for corn in 2022 had no affect on NH_4-N concentrations in the fall of 2022.

Soil physical and biological parameters

Soil bulk density (BD) was measured on 6 May 2022 (Table 9a). Soil was BD least in the surface soil depth (0- to 15-cm) and greater at deeper depths. An ANOVA of the eight treatments found no treatment effects on soil

BD. However, a 9-treatment ANOVA found BD was greater with the control at the 15- to 30-cm depth than with both of Snc treatments and with Srye at 220 lb N/ac and Sblend at 220 lb N/ac treatments.

Some of the soil health parameter data from the 6 May samples were only recently completed at the lab. These data will be tabulated, examined, statistically analyzed and interpreted in a later report.

Results Summary

A research study initiated in 2021 continued in 2022 the objectives are to quantify the effects and interactions of cover crops and N rates on corn production, nitrate-N concentration and loss in tile drainage, soil N, net return and soil health parameters. For the 5 November 2021 sampling, cover crop biomass yields were numerically greater with rye (296 lb) than with blend (255 lb) but not significantly greater (*P* value = 0.114). In spring prior to termination rye biomass was nearly equal to the previous fall. Grain yields ranged from 111 bu/ac in the control (4.6 lb N/ac) to 167 bu/ac with 170 lb N/ac for corn following soybean in 2021. An ANOVA analysis showed yields were statistically equal among the 140, 170 and 200 lb N/ac treatments. In 2022 grain yields ranged from 60 bu/ac in the control (4.6 lb N/ac) to 218 bu/ac with 260 lb N/ac for corn following corn. Silage yields in 2021 were only slightly less with the control than other N rates. In 2022 silage yields were less in corn grain production treatments than in corn silage treatments but were not different between the 180 and 220 lb N/ac rates. This could be the result of cooler soils due to greater residue cover in corn grain system or N rate interactions as grain yields increased with increasing N rate while silage yields were less affected by N rates except for the control which had considerably lower yields in 2022 than in 2021.

Tile drainage (tile flow) averaged across treatments was 7.3 inches in 2022. Nearly all drainage occurred during the months of April, May and June which is unusual especially in the last 20 years. Nitrate-N concentrations and flow-adjusted losses in tile drainage water were greater with 220 lb N/ac than with 180 lb N/ac. Averaged across N rates, flow-weighted nitrate-N concentrations were 9.0, 10.8, 6.8 and 8.6 mg/L with Gnc, Snc, Srye and Sblend, respectively and 3.6 mg/L in the control treatment. While flow-adjusted nitrate-N losses were 2.02, 2.42, 1.55 and 1.93 lb/inch with Gnc, Snc, Srye and Sblend, respectively and 0.82 lb/inch in the control treatment.

Soil data from May 2022 samples showed nitrate concentrations and total N were not affected by treatments at the 0- to 15- and 15- to 30-cm depths. However, Srye reduced soil nitrate-N concentration as the 30- to 60-cm depth while Sblend had the greater nitrate-N and total N concentration at this depth. Soil bulk density was not affected by treatments except for the 15- to 30-cm depth where small differences were found. Soil data from November of 2022 showed that nitrate-N concentrations were greater with 220 lb N/ac than with 180 lb N/ac and concentrations were considerably less with the grain cropping system (Gnc) than with silage cropping systems.

Outreach and Extension Activities

Some of the preliminary findings of this research project were presented at meetings on 10 August 2022 (Soil Health Nexus), 15 November 2022 (MASWCD Area V1 Meeting), and 6 December 2022 (AFREC Research Update).

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Table 1. Experimental methods and dates of completion (2021 was a setup year).

	Study year			
Experimental method or procedure	2021	2022	2023	2024
	-------------------- Month / day --------------------			
Previous crop	Soybean	Corn/silage	Corn/silage	Corn/silage
Collect spring soil samples	--	5/6		
Collect cover crop biomass samples	NA	4/27		
Cereal rye terminated with herbicide	NA	4/27, 5/18		
Corn planting & starter fertilizer	5/7, 5/26	5/19		
Residue measurements	NA	6/1		
Pre-emerge herbicide application	5/11	5/27		
V2 N application	6/14	6/9		
Corn plant stand counts	6/24	6/23		
Post-emerge herbicide application	7/1	6/24		
Take plot notes at V8 and R3	7/8 (V9)	7/6, 8/19		
SPAD measurements at R1	8/2	8/1		
Hand harvest silage plots	9/9	9/13		
Clean off remaining corn silage	9/14	9/16		
Seed cover crops	9/14	9/17		
Combine harvest corn grain	10/14	10/14		
Clean off remaining corn grain plots	10/16	10/21		
Collect cover crop biomass samples	10/27	10/31		
Collect corn stover (residue) samples	--	11/28		
Shred corn stalks on grain plots	11/3	10/31		
Strip till and apply P-K-S fertilizers	11/5	11/1		
Collect fall soil samples	11/24	11/10		

Table 2. 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	2021	1.04	1.27	19.2	13.2	-	-
Feb	2021	0.67	1.20	7.5	17.5	-	-
Mar	2021	2.41	2.25	38.2	30.7	-	-
Apr	2021	0.62	3.30	45.9	45.1	-	-
May	2021	2.66	4.47	58.1	57.9	344	320
Jun	2021	2.00	5.38	74.0	68.4	674	548
Jul	2021	2.73	4.93	71.9	71.4	666	652
Aug	2021	4.82	4.82	70.8	69.0	645	591
Sep	2021	1.92	4.12	63.7	61.6	452	374
Oct	2021	2.98	2.77	53.8	47.8	199	24
Nov	2021	0.64	1.89	34.9	32.9	-	-
Dec	2021	1.69	1.50	23.4	19.8	-	-
May-Sep	Total	14.13	23.72	66.8	65.7	2,629	2484
Annual	Total	24.18	37.90	46.8	44.6	2,979	2509
Jan	2022	1.13	1.27	6.5	13.2	-	-
Feb	2022	0.69	1.20	11.2	17.5	-	-
Mar	2022	1.62	2.25	30.2	30.7	-	-
Apr	2022	3.75	3.30	38.7	45.1	-	-
May	2022	4.74	4.47	59.1	57.9	336	320
Jun	2022	4.36	5.38	70.3	68.4	594	548
Jul	2022	4.60	4.93	72.5	71.4	691	652
Aug	2022	5.50	4.82	69.3	69.0	596	591
Sep	2022	0.78	4.12	62.8	61.6	412	374
Oct	2022	0.36	2.77	48.6	47.8	0	24
Nov	2022	1.84	1.89	33.2	32.9	-	-
Dec	2022	2.03	1.50	14.8	19.8	-	-
May-Sep	Total	19.98	23.72	66.8	65.7	2,629	2,484
Annual	Total	31.40	37.90	43.1	44.6	2,629	2,509
Jan	2023		1.27		13.2	-	-
Feb	2023		1.20		17.5	-	-
Mar	2023		2.25		30.7	-	-
Apr	2023		3.30		45.1	-	-
May	2023		4.47		57.9		320
Jun	2023		5.38		68.4		548
Jul	2023		4.93		71.4		652
Aug	2023		4.82		69.0		591
Sep	2023		4.12		61.6		374
Oct	2023		2.77		47.8		24
Nov	2023		1.89		32.9	-	-
Dec	2023		1.50		19.8	-	-
May-Sep	Total		23.72		65.7		2484
Annual	Total		37.90		44.6		2509

[†] 30-Yr normal, 1991-2020.

Table 3a. Cover crop dry matter yield, nutreint concentration and nutrient uptake as affected by cover crop specie and N rates for corn.

Treatments			Cover crop biomass on 5 Nov 2021						Cover crop biomass on 27 Apr 2022					
Trt	Cover crop	N rate	Yield	N conc.	C conc.	C:N ratio	N uptake	C uptake	Yield	N conc.	C conc.	C:N ratio	N uptake	C uptake
#		lb/ac	lb/ac	------------ % ------------			-------- lb/ac ---------		lb/ac	---------- % ----------			-------- lb/ac ---------	
6	Cereal rye	140	282	3.21	39.5	12.3	9.0	111	291	3.03	38.3	12.6	8.8	112
7	Cereal rye	170	311	3.89	41.1	10.6	12.1	128	301	3.11	38.4	12.3	9.4	116
8	Annual blend	140	254	3.89	41.4	10.8	10.0	105						
9	Annual blend	170	257	4.21	40.7	9.7	10.8	105						
Stats for RCB Design with a split-plot arrangement														
Cover crop (main plot)														
Cereal rye			296 A†	3.55 B	41.4 A	11.4 A	10.6 A	119 A						
Annual blend			255 A	4.05 A	41.1 A	10.2 B	10.4 A	105 A						
P > F:			0.114	0.042	0.401	0.059	0.868	0.134						
N rate for corn in 2021 (sub-plot)														
140			268 A	3.55 B	41.5 A	11.5 A	9.5 B	108 A	291 A	3.03 A	38.3 A	12.6 A	8.8 A	112 A
170			284 A	4.05 A	40.9 B	10.1 B	11.4 A	116 A	301 A	3.11 A	38.4 A	12.3 B	9.4 A	116 A
P > F:			0.418	0.014	0.067	0.009	0.072	0.300	0.871	0.227	0.982	0.092	0.738	0.856
Interaction (cover crop × N rate)														
P > F:			0.501	0.276	0.835	0.437	0.235	0.268						

† 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 4a. Corn grain yield and moisture, nutrient concentration and uptake in 2021.

Treatments						Grain nutrient concentration			Grain nutrient removal		
Trt	Corn for	Cover	'21 N rate	Yield	Moisture	Nitrogen	P	K	Nitrogen	P_2O_5	K_2O
#			lb/ac	bu/ac	-- % --						
1	Grain	None	4.6	111 c	20.0 b						
10	Grain	None	110	147 b	21.1 a						
2	Grain	None	140	160 ab	20.5 ab						
3	Grain	None	170	167 a	20.8 ab						
11	Grain	None	200	166 a	21.2 a						
Stats for RCB Design with a split-plot arrangement											
Nitrogen rate for corn in 2021											
P > F:				0.002	0.092						
LSD 0.10:				18	0.8						

Table 4b. Corn grain yield, moisture, nutrient concentration and nutrient removal in 2022.

Treatments						Grain nutrient concentration				Grain nutrient removal			
Trt	Corn for	Cover	'22 N rate	Yield	Moisture	Nitrogen	P	K	S	Nitrogen	P_2O_5	K_2O	S
#			lb/ac	bu/ac	-- % --	------------------- % -----------------				----------------- lb/ac ------------------			
1	Grain	None	4.6	60 c	24.1 bc	0.90 b	0.336 a	0.378 a	0.093 b	26 d	21.9 b	12.9 b	2.7 c
10	Grain	None	140	189 b	25.6 ab	1.07 a	0.243 bc	0.318 b	0.094 ab	96 c	50.4 a	34.3 a	8.4 b
2	Grain	None	180	194 b	22.7 c	1.16 a	0.264 b	0.348 ab	0.098 a	107 bc	55.5 a	38.3 a	9.0 a
3	Grain	None	220	201 b	23.9 c	1.17 a	0.247 bc	0.335 ab	0.095 ab	110 ab	54.5 a	38.5 a	9.0 a
11	Grain	None	260	218 a	26.2 a	1.18 a	0.196 c	0.273 c	0.086 c	121 a	46.4 a	33.7 a	8.9 a
Stats for RCB Design													
Nitrogen rate for corn in 2022													
P > F:				<0.001	0.020	0.003	0.017	0.013	0.014	<0.001	0.012	<0.001	<0.001
LSD 0.10:				15	1.7	0.11	0.059	0.044	0.005	12	15.3	6.9	0.5

Table 5a. Corn silage yield, plant population, leaf chlorophyll at R1 and residue cover after planting in 2021.

	Treatments			Corn silage yield		Silage			
Trt	Corn for	Cover	'21 N rate	Wet tons	Dry tons	Moisture	Plant pop.	SPAD	RLC
#			lb/ac	ton/ac	ton/ac	%	pl/ac × 10^3		%
1	Grain	NA	4.6	20.4	7.47 b	63.2	29.5	45.0 d	78.2 d
2	Grain	NA	140	23.2	8.58 a	63.0	29.1	55.7 ab	97.0 abc
3	Grain	NA	170	23.1	8.62 a	62.6	29.1	55.4 abc	96.4 abc
4	Silage	NA	140	24.3	8.86 a	63.4	29.6	55.1 abc	96.0 abc
5	Silage	NA	170	24.9	8.99 a	63.8	29.6	55.8 ab	97.2 ab
6	Silage	NA	140	22.8	8.57 a	62.4	29.6	55.9 ab	97.3 ab
7	Silage	NA	170	24.4	8.93 a	63.4	29.6	55.4 abc	96.4 abc
8	Silage	NA	140	22.9	8.45 a	63.1	29.3	54.6 bc	95.2 bc
9	Silage	NA	170	23.5	8.58 a	63.5	29.6	55.4 abc	96.4 abc
10	Grain	NA	110	22.7	8.41 a	63.4	no data	53.9 c	94.3 c
11	Grain	NA	200	23.3	8.93 a	61.6	no data	56.3 a	98.0 a
Stats for RCB Design all 11 treatments									
Treatment									
P > F:				0.170	0.039	0.397	0.172	<0.001	<0.001
LSD 0.10:				NS	0.62	NS	NS	1.5	2.7

Table 5b. Corn silage yield, plant population, leaf chlorophyll at R1 and residue cover after planting in 2022.

	Treatments			Corn silage yield		Silage				Residue
Trt	Corn for	Cover	'22 N rate	Wet tons	Dry tons	Moisture	Plant pop.	SPAD	RLC	Cover
#			lb/ac	ton/ac	ton/ac	%	pl/ac × 10^3		%	%
1	Grain	None	4.6	11.4 d	3.63 d	68.3 a	33.6 bcd	36.2 e	61.9 e	50.0 b
2	Grain	None	180	23.3 bc	8.17 bc	65.0 bc	33.2 cd	55.8 cd	95.5 cd	55.5 b
3	Grain	None	220	23.3 bc	8.45 abc	63.8 cde	33.5 bcd	55.9 cd	95.6 cd	52.0 b
4	Silage	None	180	25.6 a	9.03 a	64.8 bc	34.8 a	57.1 abc	97.6 abc	15.0 e
5	Silage	None	220	24.9 ab	8.89 ab	64.3 cde	33.8 bcd	57.5 ab	98.3 ab	17.0 e
6	Silage	Rye	180	25.1 ab	9.11 a	63.7 cde	34.4 ab	56.9 abcd	97.3 abcd	35.5 c
7	Silage	Rye	220	24.2 abc	8.95 a	63.1 e	34.2 abc	56.2 bcd	96.2 bcd	40.5 c
8	Silage	Blend	180	24.8 ab	9.09 a	63.3 de	34.0 abc	57.5 ab	98.4 ab	18.5 de
9	Silage	Blend	220	25.0 ab	9.07 a	63.7 cde	34.8 a	58.2 a	99.5 a	25.0 d
10	Grain	None	140	22.3 c	7.85 c	64.7 bcd	33.3 cd	55.5 d	94.9 d	67.5 a
11	Grain	None	260	25.8 a	8.82 ab	65.9 b	32.9 d	56.5 bcd	96.6 bcd	64.5 a

Stats for RCB Design all 11 treatments

	Wet tons	Dry tons	Moisture	Plant pop.	SPAD	RLC	Residue Cover
Treatment							
P > F:	<0.001	<0.001	<0.001	0.025	<0.001	<0.001	<0.001
LSD 0.10:	2.0	0.74	1.5	1.0	1.4	2.5	7.8

Stats for RCB Design with a split-plot arrangement for treatments 2 through 9

	Wet tons	Dry tons	Moisture	Plant pop.	SPAD	RLC	Residue Cover
Crop and cover crop system							
Grain corn, no cover crop	23.3 A	8.31 A	65.1 A	33.4 B	55.8 C	95.5 A	53.8 A
Silage corn, no cover crop	25.3 A	8.96 A	65.0 A	34.3 A	57.3 AB	97.9 A	16.0 C
Silage corn, cereal rye	24.7 A	9.03 A	62.8 B	34.3 A	56.5 BC	96.8 A	38.0 B
Silage corn, annual blend	24.9 A	9.08 A	63.3 AB	34.4 A	57.8 A	98.9 A	21.8 C
P > F:	0.124	0.084	0.089	0.051	0.030	0.104	<0.001
Nitrogen rate for corn in 2022							
180 lb/ac	24.7 A	8.85 A	64.3 A	34.1 A	56.8 A	97.2 A	31.1 A
220 lb/ac	24.4 A	8.84 A	63.9 A	34.1 A	56.9 A	97.4 A	33.6 A
P > F:	0.546	0.954	0.294	0.965	0.795	0.858	0.371
Interaction (crop system × N rate)							
P > F:	0.901	0.893	0.607	0.163	0.761	0.857	0.590

Table 6b. Corn silage quality parameters, silage nutrient concentrations and nutrient removal in silage as affected by cropping system and nitrogen rates in 2022 (all means are LS means).

	Treatments			Silage quality parameters^								Nutirent concentratoin in silage			Nutirent removal in silage		
Trt	Corn for	Cover	'22 N rate	CP	ADF	NDF	uNDF	TTNDFD	Starch	RumenS	Milk Yield†	P	K	S	P2O5	K2O	S
#			lb/ac	% of DM	% of DM	% of DM	% of NDF	% of NDF	% of DM	% of starcl	lb/ton	---------------	% of DM	---------------	---------------	lb/ac	---------------
1	Grain	None	4.6	4.32 c	26.3 a	44.2 a	12.9 ab	45.1 a	28.6 d	75.6 a	2740 f	0.216 a	0.775 a	0.055 c	36.2 e	68 d	4.0 e
2	Grain	None	180	6.76 a	20.0 cd	35.6 def	10.3 e	44.8 ab	39.3 abc	70.9 bc	3259 abc	0.209 a	0.630 bc	0.068 b	78.1 cd	123 c	11.1 cd
3	Grain	None	220	6.77 a	18.4 d	35.9 def	10.5 de	44.2 ab	38.9 abc	71.1 bc	3250 abc	0.209 a	0.651 bc	0.067 b	81.1 abcd	132 abc	11.3 bc
4	Silage	None	180	7.07 a	20.6 bcd	37.2 cde	10.4 de	43.2 bcd	38.0 abc	69.8 bc	3239 abcd	0.223 a	0.630 bc	0.069 ab	91.9 a	136 abc	12.5 abc
5	Silage	None	220	7.22 a	19.4 cd	33.6 f	9.5 e	43.8 abc	41.3 a	65.8 d	3340 a	0.207 a	0.586 c	0.071 ab	84.4 abcd	125 c	12.6 abc
6	Silage	Rye	180	6.81 a	21.0 bc	38.4 cd	12.2 bc	43.4 abc	36.2 c	71.6 b	3128 cd	0.216 a	0.675 bc	0.069 ab	89.9 ab	148 ab	12.6 abc
7	Silage	Rye	220	6.82 a	22.7 b	39.5 bc	12.4 abc	42.1 cd	35.5 c	70.4 bc	3103 d	0.196 a	0.595 c	0.071 ab	80.4 bcd	128 bc	12.7 ab
8	Silage	Blend	180	7.13 a	21.1 bc	37.4 cde	11.5 cd	43.3 bc	37.9 abc	70.6 bc	3170 bcd	0.221 a	0.634 bc	0.071 ab	91.8 a	138 abc	12.9 ab
9	Silage	Blend	220	7.25 a	19.0 cd	34.6 ef	10.6 de	44.5 ab	40.3 ab	68.4 cd	3287 ab	0.220 a	0.663 bc	0.074 a	91.2 ab	144 abc	13.4 a
10	Grain	None	140	5.66 b	25.2 a	42.7 ab	13.6 a	41.3 d	31.2 d	71.8 b	2923 e	0.194 a	0.663 bc	0.058 c	73.1 d	131 abc	9.5 d
11	Grain	None	260	7.03 a	20.9 bc	37.8 cd	11.8 bc	44.8 ab	36.7 bc	72.4 b	3177 bcd	0.222 a	0.711 ab	0.071 ab	89.4 abc	150 a	12.5 abc
<u>Stats for RCB Design all 11 treatments</u>																	
Treatment																	
P > F:				<0.001	<0.001	<0.001	<0.001	0.04	<0.001	0	<0.001	0.261	0.068	<0.001	<0.001	<0.001	<0.001
LSD 0.10:				0.50	2.3	3.3	1.2	1.8	3.9	3.1	148	NS	0.090	0.005	11.4	22	1.6
<u>Stats for RCB Design with a split-plot arrangement for treatments 2 through 9</u>																	
Crop and cover crop system																	
Grain corn, no cover crop				6.76 C	19.3 B	35.0 B	10.4 BC	44.5 A	39.7 A	71.0 A	3255 A	0.217 A	0.656 A	0.067 A	80.8 B	129 A	11.2 B
Silage corn, no cover crop				7.14 AB	20.0 B	34.7 B	9.9 C	43.5 A	40.3 A	67.8 A	3290 A	0.223 A	0.623 A	0.070 A	89.3 A	132 A	12.5 A
Silage corn, cereal rye				6.82 BC	21.9 A	38.3 A	12.3 A	42.7 A	36.5 A	71.1 A	3115 B	0.214 A	0.650 A	0.070 A	86.3 AB	139 A	12.7 A
Silage corn, annual blend				7.19 A	20.1 B	35.3 B	11.1 B	43.9 A	39.7 A	69.5 A	3229 A	0.228 A	0.664 A	0.072 A	92.6 A	142 A	13.1 A
P > F:				0.078	0.095	0.065	<0.001	0.292	0.126	0.118	0.040	0.296	0.683	0.184	0.053	0.274	0.061
Nitrogen rate for corn in 2022																	
180 lb/ac				6.94 A	20.7 A	36.5 A	11.1 A	43.7 A	38.5 A	70.8 A	3199 A	0.225 A	0.657 A	0.069 A	89.1 A	137 A	12.3 A
220 lb/ac				7.01 A	19.9 A	35.2 A	10.8 A	43.6 A	39.6 A	69.0 B	3245 A	0.216 A	0.639 A	0.071 A	85.4 A	133 A	12.5 A
P > F:				0.612	0.302	0.210	0.317	0.969	0.346	0.095	0.280	0.122	0.474	0.327	0.221	0.462	0.618
Interaction (crop system × N rate)																	
P > F:				0.971	0.263	0.270	0.459	0.517	0.561	0.551	0.513	0.518	0.375	0.798	0.405	0.198	0.992

^ CP, crude protein; ADF, acid detergent fiber; NDF, neutral detergent fiber; uNDF, undigestible NDF at 240 hour; TTNDFD, total tract NDF digestibility; RumenS, in-situ rumen degradable starch at 7 hour.

† Milk yield, milk production estimated using the MILK2006 model developed by the Univ. of Wisconsin.

Table 7a. Monthly mean tile flow, flow-wieghted (FW) nitrate-N concentration and nitrate-N loss as affected by treatments in 2022.

	Corn	Cover	Total	Tile drain flow								FW nitrate-N concentration								Nitrate-N loss or load							
Trt	for	Crop	N Rate	April		May		June		Total		April		May		June		Average		April		May		June		Total	
#			lb/ac	inch	SE	inch	SE	inch	SE	inch	SE	mg/L	SE	mg/L	SE	mg/L	SE	mg/L	SE	lb/ac	SE	lb/ac	SE	lb/ac	SE	lb/ac	SE
1	Grain	None	4.6	0.8	0.56	2.7	1.15	2.5	0.49	6.2	2.24	3.7	0.6	2.9	1.2	4.1	1.1	3.5	1.1	0.8	0.7	2.8	2.1	2.7	1.1	6.3	3.9
2	Grain	None	180	0.6	0.11	3.3	0.67	2.9	0.61	6.8	1.26	4.4	0.9	4.9	1.3	10.0	1.1	6.3	1.1	0.6	0.1	3.6	0.2	7.1	1.6	11.4	1.6
3	Grain	None	220	1.4	0.51	5.0	1.52	3.3	0.81	9.8	2.77	6.1	0.6	7.2	0.3	12.0	0.6	8.2	0.2	2.1	0.8	9.8	3.6	10.8	3.3	22.7	7.4
4	Silage	None	180	0.7	0.26	3.7	0.33	2.1	0.16	6.6	0.55	6.2	0.2	6.8	0.3	11.3	0.6	8.3	0.2	1.0	0.4	6.4	0.6	5.8	1.0	13.2	0.6
5	Silage	None	220	0.4	0.23	2.7	0.71	1.6	0.24	4.8	1.13	7.3	1.2	9.9	1.6	13.8	1.7	10.5	1.6	0.5	0.2	5.9	0.7	5.8	1.0	12.2	1.5
6	Silage	Rye	180	1.1	0.27	4.2	1.11	2.2	0.48	7.4	1.85	4.5	0.7	3.9	0.5	8.5	0.6	5.3	0.3	1.0	0.4	4.4	1.6	4.8	1.1	10.2	3.0
7	Silage	Rye	220	1.2	0.52	4.6	1.33	3.0	0.47	8.9	2.11	4.3	0.5	5.3	0.3	9.7	1.2	6.1	0.4	1.4	0.6	5.8	1.7	7.6	1.6	14.8	3.1
8	Silage	Blend	180	0.9	0.39	4.4	1.26	2.5	0.56	7.8	2.20	5.2	0.5	5.7	0.8	11.0	1.5	7.4	0.8	1.1	0.4	5.6	1.2	7.0	2.2	13.7	3.7
9	Silage	Blend	220	0.9	0.35	4.4	0.84	2.4	0.35	7.7	1.48	5.5	0.3	6.2	0.5	12.3	0.4	7.9	0.4	1.1	0.4	6.6	1.1	6.9	0.9	14.6	2.3
All treatment mean:				0.9		3.9		2.5		7.3		5.2		5.9		10.3		7.0		1.1		5.7		6.5		13.2	
Fertilized treatment mean:				0.9		4.0		2.5		7.5		5.4		6.2		11.1		7.5		1.1		6.0		7.0		14.1	

Table 8a. Treatment effects on 3-month flow-adjusted nitrate-N concentration and annaul loss in 2022.

	Corn	Cover	Total	3-month flow-adjusted nitrate-N concentration					Flow adj.
Trt	for	Crop	N Rate	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Average	NO_3 loss
#			lb/ac	------------- mg/L -------------					lb/inch
1	Grain	None	4.6	no data	3.6 d	no data	no data	3.6 d	0.82 d
2	Grain	None	180		7.9 bc			7.9 bc	1.80 bc
3	Grain	None	220		10.0 ab			10.0 ab	2.25 ab
4	Silage	None	180		9.0 b			9.0 b	2.03 b
5	Silage	None	220		12.5 a			12.4 a	2.82 a
6	Silage	Rye	180		5.9 cd			5.9 cd	1.35 cd
7	Silage	Rye	220		7.7 bc			7.7 bc	1.75 bc
8	Silage	Blend	180		8.5 bc			8.5 bc	1.91 bc
9	Silage	Blend	220		8.6 b			8.6 b	1.95 b
Stats for RCB Design all 9 treatments									
Treatment									
P > F:					0.001			0.001	0.001
LSD 0.10:					2.6			2.6	0.59
Stats for RCB Design with a split-plot arrangement for treatments 2 through 9									
Crop and cover crop system									
Grain corn, no cover crop					8.7 A			8.7 A	1.98 A
Silage corn, no cover crop					8.5 A			8.5 A	1.90 A
Silage corn, cereal rye					6.2 A			6.2 A	1.41 A
Silage corn, annual blend					7.7 A			7.7 A	1.76 A
P > F:					0.488			0.487	0.519
N rate for corn in 2022									
180 lb/ac					6.8 B			6.8 B	1.55 B
220 lb/ac					8.7 A			8.7 A	1.97 A
P > F:					0.017			0.017	0.017
Interaction (crop system × N rate)									
P > F:					0.449			0.447	0.455

Table 9a. Spring (6 May 2022) soil nitrate, ammonium, total N and bulk density by depth as affected by crop system treatments and N rates for corn in 2021.

Treatments				Nitrate-N by depth (cm)				Ammonium-N by depth (cm)				Total N by depth (cm)				Soil bulk density by depth (cm)			
Trt	Corn for	Cover	'21 N rate	0-15 cm	15-30	30-60	60-90	0-15 cm	15-30	30-60	60-90	0-15 cm	15-30	30-60	60-90	0-15 cm	15-30	30-60	60-90
#			lb/ac	--------------------- mg/kg -------------------				--------------------- mg/kg -------------------				--------------------- % -------------------				--------------------- g/cc -------------------			
1	Grain	None	4.6	2.0 a	2.1 a	2.4 cd	1.2 c	3.8 a	2.8 a	most data < MDL		0.23 a	0.22 a	0.083 a	0.050 d	1.13 a	1.43 a	1.50 a	1.50 a
2	Grain	None	140	3.0 a	2.8 a	2.5 cd	1.6 bc	3.0 a	2.1 ab	of 0.5 mg/kg		0.27 a	0.22 a	0.085 a	0.073 ab	1.11 a	1.36 abcd	1.47 a	1.45 a
3	Grain	None	170	2.6 a	1.9 a	3.2 bcd	1.5 bc	2.9 a	0.4 d			0.26 a	0.21 a	0.077 a	0.060 bcd	1.12 a	1.37 abcd	1.46 a	1.35 a
4	Silage	None	140	3.7 a	3.6 a	3.7 bc	2.8 ab	3.2 a	0.8 cd			0.27 a	0.17 a	0.083 a	0.060 bcd	0.99 a	1.30 d	1.47 a	1.50 a
5	Silage	None	170	2.8 a	3.5 a	3.0 bcd	1.2 c	2.8 a	1.2 bcd			0.26 a	0.20 a	0.073 a	0.058 bcd	1.10 a	1.32 cd	1.44 a	1.53 a
6	Silage	Rye	140	2.4 a	1.9 a	1.6 d	1.0 c	3.3 a	1.6 bc			0.28 a	0.23 a	0.093 a	0.055 cd	1.08 a	1.38 abc	1.48 a	1.45 a
7	Silage	Rye	170	2.8 a	3.0 a	2.9 bcd	1.4 c	4.6 a	1.3 bcd			0.28 a	0.22 a	0.095 a	0.058 bcd	1.20 a	1.30 d	1.48 a	1.49 a
8	Silage	Blend	140	2.6 a	3.6 a	4.0 bc	2.0 bc	3.3 a	0.9 cd			0.27 a	0.21 a	0.103 a	0.088 a	1.13 a	1.38 abcd	1.49 a	1.43 a
9	Silage	Blend	170	3.8 a	4.5 a	4.6 ab	2.0 bc	3.1 a	0.9 cd			0.27 a	0.19 a	0.088 a	0.073 ab	1.04 a	1.34 bcd	1.46 a	1.44 a
10	Grain	None	110	1.3 a	1.4 a	3.2 bcd	2.1 bc	3.8 a	1.2 bcd			0.27 a	0.19 a	0.083 a	0.065 bcd				
11	Grain	None	200	2.8 a	2.7 a	6.7 a	3.9 a	4.5 a	0.9 cd			0.28 a	0.16 a	0.070 a	0.070 bc				
Stats for RCB Design of all 11 treatments																			
Treatment																			
P > F:				0.120	0.168	0.031	0.026	0.520	0.007			0.174	0.357	0.136	0.016	0.485	0.066	0.993	0.128
Stats for RCB Design with a split-plot arrangement for treatments 2 through 9																			
Crop and cover crop system																			
Grain corn, no cover crop				3.0 A	2.4 A	2.8 BC	1.5 A	4.5 A	1.5 A			0.27 A	0.21 A	0.081 BC	0.072 B	1.03 A	1.37 A	1.42 A	1.32 A
Silage corn, no cover crop				3.4 A	3.5 A	3.4 AB	2.0 A	4.3 A	1.5 A			0.27 A	0.19 A	0.078 C	0.064 BC	0.96 A	1.31 A	1.55 A	1.43 A
Silage corn, cereal rye				2.8 A	2.5 A	2.2 C	1.2 A	2.4 A	0.4 A			0.29 A	0.22 A	0.094 AB	0.062 C	1.06 A	1.34 A	1.44 A	1.40 A
Silage corn, annual blend				3.3 A	4.0 A	4.3 A	2.0 A	2.7 A	0.8 A			0.27 A	0.20 A	0.095 A	0.085 A	1.00 A	1.36 A	1.43 A	1.35 A
P > F:				0.618	0.152	0.026	0.264	0.212	0.393			0.499	0.353	0.066	0.001	0.487	0.398	0.151	0.110
Nitrogen rate for corn in 2021																			
140 lb/ac				3.1 A	3.0 A	3.0 A	1.8 A	3.4 A	1.2 A			0.28 A	0.21 A	0.091 A	0.074 A	0.99 A	1.35 A	1.47 A	1.38 A
170 lb/ac				3.2 A	3.2 A	3.4 A	1.5 A	3.6 A	0.9 A			0.27 A	0.20 A	0.083 A	0.067 A	1.03 A	1.33 A	1.45 A	1.37 A
P > F:				0.813	0.672	0.317	0.407	0.634	0.126			0.450	0.733	0.165	0.103	0.434	0.371	0.268	0.815
Interaction (crop system × N rate)																			
P > F:				0.290	0.565	0.494	0.177	0.433	0.033			0.921	0.590	0.690	0.371	0.350	0.543	0.897	0.294

All means are LS means

Table 10a. Soil nitrate-N and ammonium-N from 0- to 30-cm depth as affected by crop system and nitrogen rates for corn.

	Fall 2021					Fall 2022					Fall 2023				
	4.6†	140	170	Mean^	LSmean	4.6	180	220	Mean	LSmean	4.6	180	220	Mean	LSmean
	---------- NO_3-N, mg/kg ----------														
Cropping system															
Grain, none						2.5	3.2	4.3	3.8	3.1B‡					
Silage, none							9.8	13.5	11.7	7.7AB					
Silage, rye							6.8	15.9	11.4	15.7A					
Silage, blend							10.6	13.5	12.1	12.7A					
Mean^:							7.6	11.8							
LS Mean:							7.7B	11.9A							
	---------- NH_4-N, mg/kg ----------														
Cropping system															
Grain, none						3.4	4.6	3.2	3.9	3.9A					
Silage, none							3.9	4.5	4.2	2.8A					
Silage, rye							4.4	5.0	4.7	5.1A					
Silage, blend							4.6	4.6	4.6	3.2A					
Mean:							4.4	4.3							
LS Mean:							3.8A	3.7A							

† Control treatment received 4.6 lb N/ac as starter fertilizer.

‡ 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.

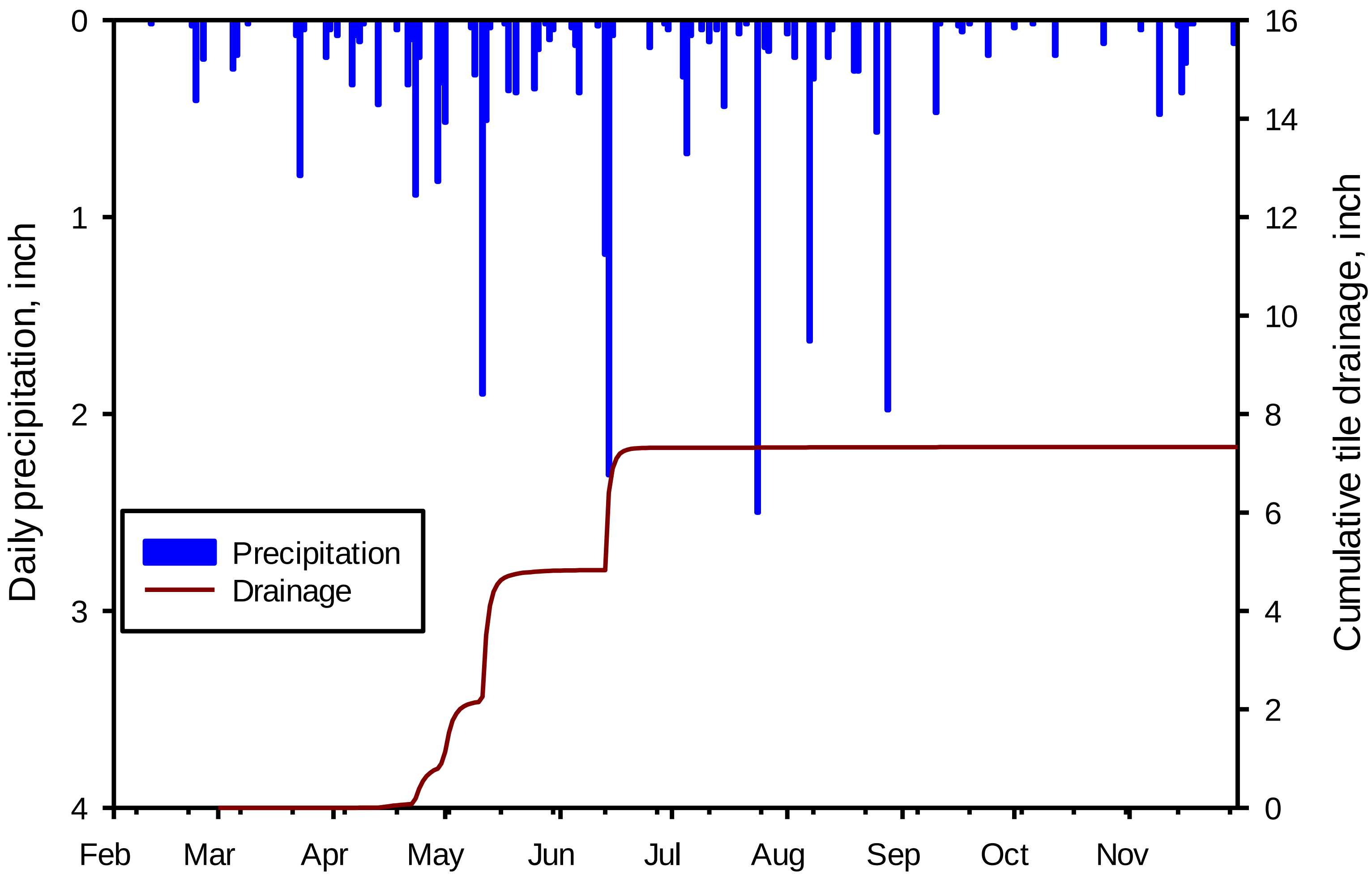


Figure 1. Daily precipitation and cumulative tile drainage in 2022.

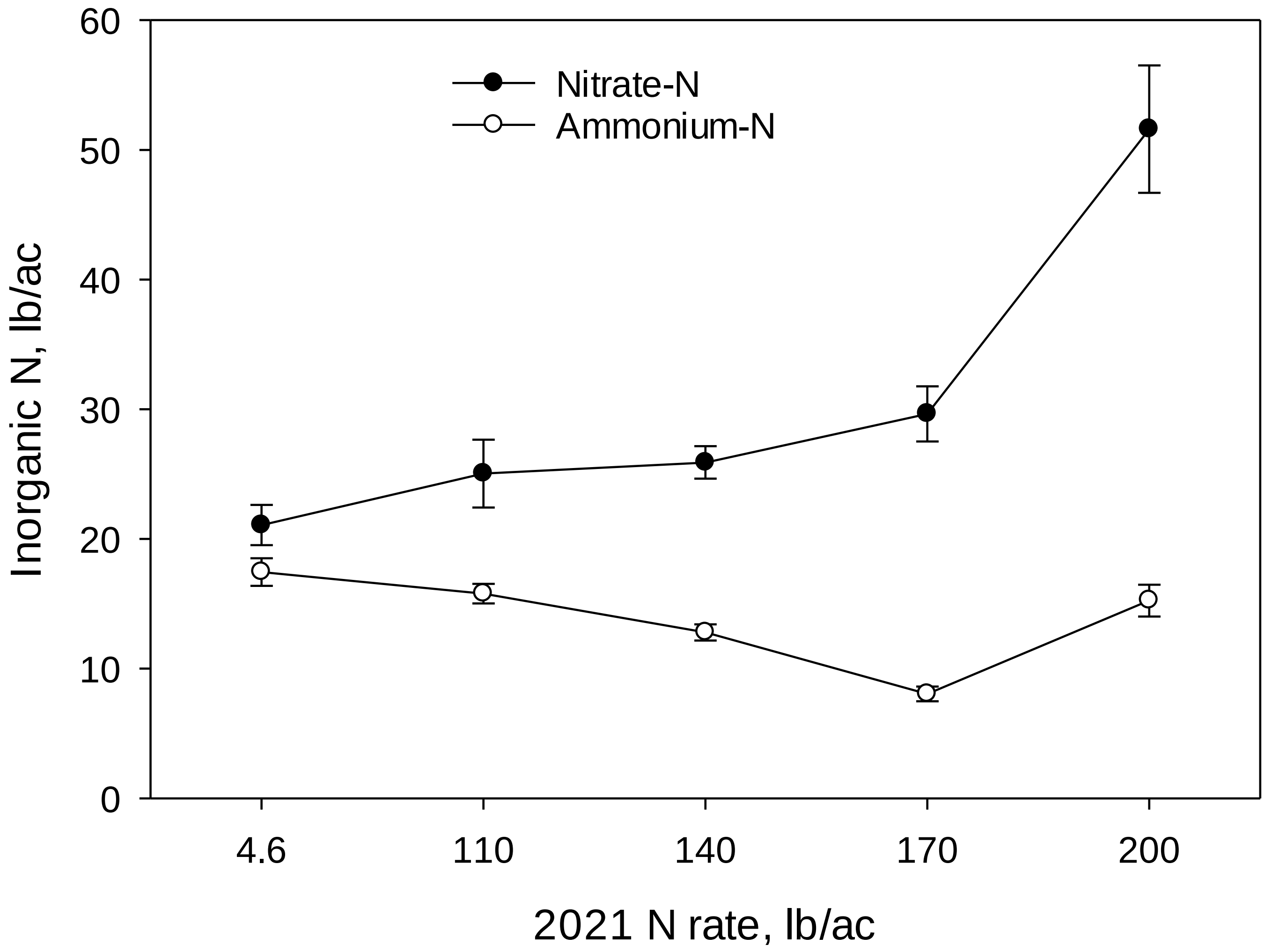


Figure 2. Inorganic nitrogen in the 0- to 90-cm soil profile on 6 May 2022 as affected by nitrogen rate for corn in 2021.

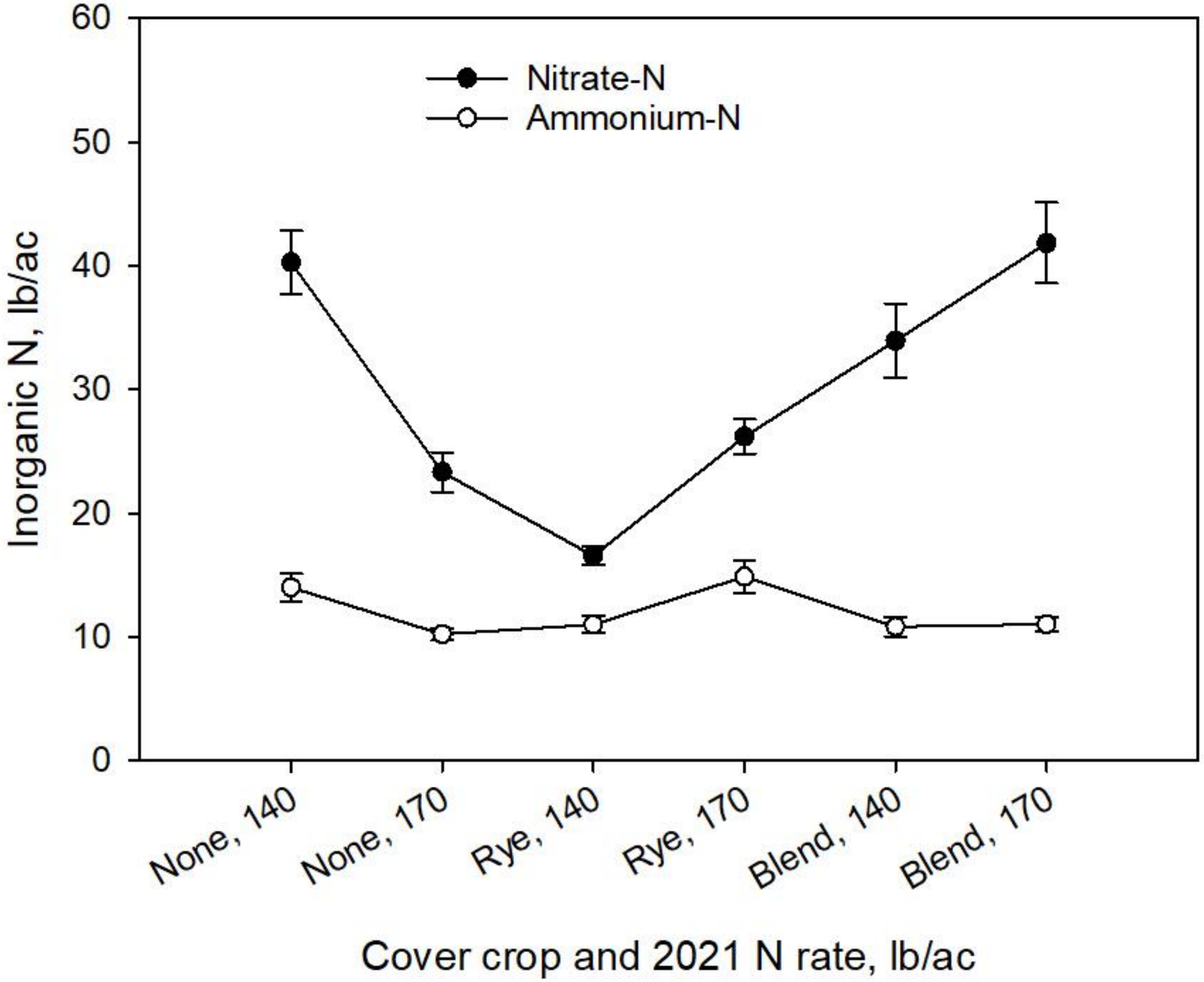


Figure 3. Inorganic nitrogen in the 0- to 90-cm soil profile on 6 May 2022 as affected by cover crops and N rate for corn in 2021.

Supplemental Materials

Supp. table 1. Experimental methods, products and rates (2021 was a setup year).

Experimental method or procedure	Study year 2021	2022	2023	2024
	------ Month / day ------			
Previous crop	Soybean	Corn/silage	Corn/silage	Corn/silage
Total N rates, lb/ac	4.6, 110, 140, 170, 200	4.6, 140, 180, 220, 260		
Termination herbicides	NA	Roundup PowerMax 24 & 32 oz/ac, Deliver 1 qt/ac		
Corn hybrid	DeKalb 50-08GENSS RIB	Dairyland HIDF 3802Q		
Pre-emerge herbicides	SureStart 2.5 qt/ac, Roundup WeatherMax 24 oz/ac, Deliver 1 qt/ac	SureStart 2.5 qt/ac		
Post-emerge herbicides	Liberty 22 oz/ac, Deliver 1 qt/ac	Liberty 32 oz/ac, Class Act Flex (2%)		
P-K-S fertilizers sources	TSP[1], MOP, Elemental S	TSP, MOP, gypsum		
P-K-S fertilizer rates, lb/ac	45 lb P_2O_5, 90 lb K_2O/ac, 15 lb S	45 lb P_2O_5, 90 lb K_2O/ac, 15 lb S		

1 TSP, triple super phosphate (0-46-0); MOP, muriate of potash (0-0-60), elemental S (90%); gypsum (17% S)

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.

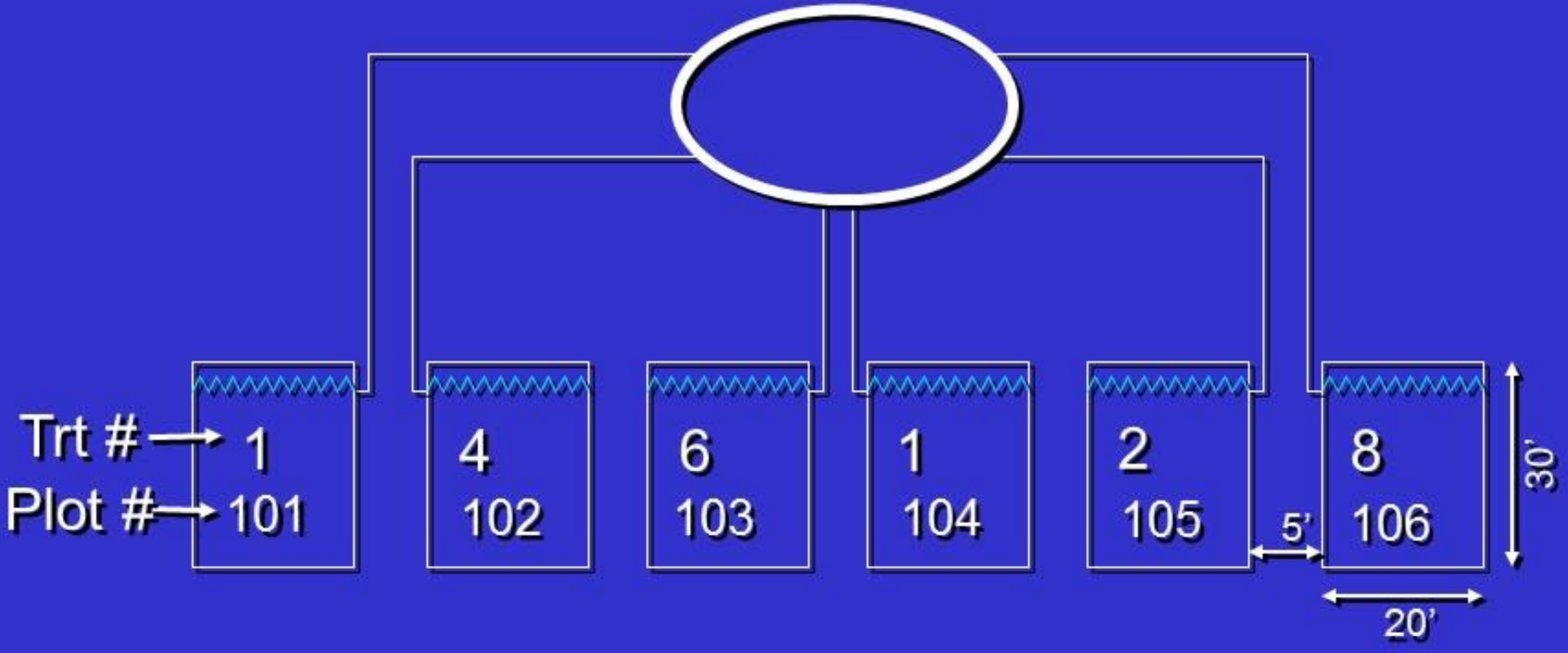
Pic. 3. Plumbing inside culvert: sump well, pump, and water meters.

Pic. 4. Silage harvest, cover crop planting (14 September 2021), cover crop growth (November 2021).

Pic. 5. Corn planting on 19 May 2022.

Pic 6. Sidedress UAN application 9 June 2022.

Drainage Research Facility at Waseca, SROC




Great Plains
3P608NT


N+S
10-34-0