Final Report to the Iowa Nutrient Research Center

Evaluation of Measurement Methods as Surrogates for Tile-Flow Nitrate-N Concentrations

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Introduction

Nitrate in surface and ground waters is a concern in Iowa and across the U.S. Midwest. Research attempts to minimize non-point nitrate loss from farm fields has remained a challenge after decades of research effort, although promising results have been obtained. An integrated set of long term in-field and edge-of-field soil and water management practices have been recommended to minimize nitrate loss. However, additional in-field practices are needed to provide farmers options as they work to fully meet nitrate-N water quality and nitrogen (N) loss goals within Iowa and the Mississippi river basin (Gulf of Mexico Hypoxia Task Force N reduction goal for the Gulf of Mexico).

Nitrogen management practice effects on nitrate loss to surface waters have been optimally determined through measurement of nitrate-N concentrations in tile water flow at specially designed water quality sites. These sites, however, are expensive to develop and maintain. In addition, the number of practices that can be compared is limited due to physical constraints on the number of experimental plots. With a common need to determine nitrate reduction practice effects with multi-year rotations, such as corn following soybean, the number of drainage plots available for practice evaluation becomes even more limited. Therefore, other nitrate-N measurement methods (surrogate methods) need to be developed that can evaluate N reduction practices. Such methods would allow more practices to be evaluated, and within agronomic research, evaluate effects on crop production and N use efficiency. If successful, surrogates could be utilized on land that is not suitable for tile drainage, but where groundwater recharge supplies water (and potential nitrate) to surface water systems.

Successful surrogate methods could substantially reduce the overhead cost of water quality research, broaden the scope of practices, reduce costs, and shorten the time for practice evaluation. The Iowa Nutrient Reduction Strategy mentions the desire to add innovative practices and new technology that are documented to have a positive effect on reducing nitrate loss to surface waters. Currently, the requirement for practice evaluation at tile drainage research sites stifles innovative practice development and implementation, and reduces the opportunity to reach drinking water nitrate and N loss goals.

This study was designed to investigate alternate nitrate measurement methods in lieu of nitrate in tile drainage flow. The objective was to determine if surrogate measurement methods would allow evaluation of in-field N management practices and provide reasonable estimate of nitrate-N concentrations comparable to tile flow drainage. This research included two measurement methods, nitrate-N in water collected with suction cup lysimeters and the soil profile.

Methods

The study was conducted at two water quality research sites in Iowa, the Agricultural Drainage Water Quality site (ADW, Gilmore City) and the Iowa State University Northwest Research Farm (NWRF, Sutherland). Each water quality research site is equipped with tile drainage that is monitored for drainage flow and nitrate-N concentration (Figures 1 and 2), with tile depth approximately three to three and one-half feet. Both sites have on-going water quality monitoring of in-field N management practices. Use of these sites allows direct comparison of surrogate measures to tile drainage water nitrate-N concentration. The study was conducted for two years in 2017 and 2018. The crop rotation was corn-soybean at each site, with both crops present each year and monitored for this study. Crop row spacing was 30-inch at both sites.

Two practices were chosen for study. At ADW the management practices were a winter cereal rye cover crop (RCC) or no rye cover crop (no RCC) in a no-till system, in both corn and soybean. At NWRF the management practices were late fall applied anhydrous ammonia (with nitrapyrin nitrification inhibitor) and spring preplant applied anhydrous ammonia (without nitrapyrin), each applied for corn only in a tilled system. At ADW, anhydrous ammonia was the N source, applied in the spring before planting corn in both the RCC and no RCC. The N rate at ADW was 150 lb N/acre and at NWRF 135 lb N/acre. The management practices were monitored in three replications at each site. Agronomic management at each site was consistent across the practices studied.

The surrogate nitrate-N measurement methods evaluated were ceramic suction cup lysimeters and soil profile sampling. Lysimeters were installed after crop planting at each site in early May, 2017 (total 98 lysimeters – SoilMoisture Equipment Co., model 1900, 1.9 inch diameter soil water sampler). Tension to the lysimeter was applied at 60 kPa (0.6 bar) with a vacuum pump. Water collection from the lysimeters began in late May in 2017 and late April in 2018, and continued approximately every two weeks until late fall (November or December) unless soil was too dry to obtain water in the lysimeters. At each lysimeter water collection time, soil profile samples were collected near one of the lysimeter locations (starting soil collection at least 24 inches from the nearest lysimeter), except no soil sampling in corn and soybean from approximately the corn mid-vegetative growth stage (early July each year) through the time of crop harvest. Tile flow water was collected on an on-going basis during the growing season, with nitrate-N concentrations used from sample dates within the lysimeter sampling period. In dry periods (especially in 2017 with overall low precipitation, Table 1), there were times when tile flow stopped or water could not be collected from the lysimeters. In addition, there were times each year and site when it was not possible to collect water in tile flow or lysimeters from all replicates. The total number of sample dates are provided in Table 2 for each year and measurement. Water samples were analyzed by an ISU water quality lab and soil samples by a commercial laboratory for nitrate-N concentration. Nitrate-N concentration results from tile water samples are presented without flow weighting.

Lysimeters were installed at two locations and two depths in each plot, total four lysimeters per plot (Figures 3 and 4). Two lysimeters (abbreviation CT) were placed in a crop row that was two rows away (approximately 45 inches) from the plot center tile (the tile monitored for water flow and nitrate-N) and two lysimeters (abbreviation FT) were placed in a crop row approximately mid-way between the center tile and the plot edge tile. The lysimeters were located approximately one-third of the plot length from the drainage collection well end of plots. For each lysimeter location (CT and FT), one lysimeter was at a 24-inch depth and the other at a 36-inch depth, separated along the crop row by a distance of 24 inches. At installation, 200-mesh silica sand flour was placed at the ceramic cup depth to enhance and maintain contact with soil. Bentonite clay was placed around the lysimeter PVC access tube at the soil surface to prevent water from flowing down the outside of the tube. The lysimeter access tube and water sampling tubing were covered at the soil surface with a short section of PVC pipe and cap for protection. In the second year, crop planting and anhydrous ammonia application was offset from the prior-year established lysimeter locations to avoid damaging installed lysimeters.

Two sets of eight profile soil cores (0.75 inch diameter) equally spaced across the corn inter-row width were collected near the FT lysimeter location (Figures 3 and 4) from each plot and composited for one sub-sample for each depth. There were two soil sample depths, 0-12 and 12-24 inch. The soil sample location was moved progressively away from the lysimeters each collection time. In the second year, soil sampling was moved to the opposite side of the lysimeters.

Results

In the first year, 2017, precipitation was well below normal in Northcentral to Northwest Iowa (Table 1), therefore the number of sample dates with tile flow and water collectable in lysimeters were limited (Table 2). In the second year, 2018, precipitation was above normal and therefore there were considerably more sample dates with tile flow and water collected in lysimeters. Ability to collect soil samples was not affected by dry moisture conditions.

Nitrate-N Concentration Trends

Time series graphs of nitrate-N concentrations for tile water, lysimeter water, and soil are presented in Figures 5-10. Those graphs include all data (arithmetic means) from all sample dates, even if there was only nitrate-N concentration data for one replicate for a practice within a measurement method. There were few sample dates in 2017 for tile or lysimeter water due to the dry conditions, although water was obtained more often in the lysimeters than tile flow. With above normal precipitation in 2018, water was obtained more often in tile flow and lysimeters than in 2017. However, in 2018 tile flow stopped at both sites and in both crops in the mid-to-late summer period, while water was still collected from the lysimeters during that period. The number of samples obtained in tile flow were greater than with lysimeter or soil sampling due to the planned frequency of sampling for each measurement method (every-other week interval for lysimeter and soil sampling versus capturing continual tile flow).

Nitrate-N concentrations in tile water were more consistent over time at both sites than either lysimeter water or soil. However, all measures had variation in nitrate-N concentration. For example, the standard deviation across samples for tile flow nitrate-N concentration at ADW in 2018 was 5.0 mg/L (corn phase) and 2.3 mg/L (soybean phase), while in lysimeter water was 16.2 mg/L (corn phase) and 8.6 mg/L (soybean phase). At NWRF in 2018, variation in nitrate-N concentration was lower than at ADW, with the standard deviation for tile flow nitrate-N concentration at 2.6 mg/L (corn phase) and 2.3 mg/L (soybean phase), while in lysimeter water at 8.3 mg/L (corn phase) and 6.8 mg/L (soybean phase). Fairly consistent flow-weighted nitrate-N concentrations have been found in the past at both sites. There was considerable variation in nitrate-N concentration between the individual lysimeters. Generally, the lysimeter water nitrate-N concentrations decreased into the crop growth and N uptake period, but not always. For an unexplained reason, the lysimeter water nitrate-N concentrations increased considerably at the ADW site in 2018, starting approximately the first of July and with considerable variation. It is not known why that occurred as the tile water and soil nitrate-N concentrations did not increase.

It could be possible that the lysimeters were measuring nitrate leaching from a band of anhydrous ammonia, but nitrate that had not yet reached the tile flow, or that nitrate was being averaged across the plot (from N bands and non-band areas) in tile drainage and thus not resulting in an increase in tile water concentration. Soil nitrate-N concentrations generally decreased with plant uptake, except at NWRF in 2018 corn. The decrease in concentration would be expected as crop uptake of nitrate increased with growth. Variation in profile soil nitrate-N could be a result of sampling across the anhydrous ammonia band. While two sets of eight soil cores were collected across the corn inter-row at each sampling, it is possible that more or less soil was collected from a high concentration of nitrate within the banded N.

Management Practice and Specific Measurement Analysis

To allow a practice and individual measurement method statistical analysis to be conducted across sample dates (including specific lysimeter placement and depth, and soil sample depth), sample dates within each measurement method were removed if that sample date did not have any replicate data for a particular measurement (data in corn and soybean phases both removed in such cases). That is, for a particular measurement method (tile, lysimeter, or soil) if there was a sample date with a practice that had no data for all of the three replicates, then that sample date was removed for both corn and soybean phases for that measurement method (dates remaining called useable in Table 2). Due to large nitrate-N concentration variation within and between sample dates within each specific measurement method, often there was no statistical significance for practice or interaction with sample date for measurement method or specific method placement and depth. Results presented in Figures 11-12 are only for those instances when practice or practice by sample date were significant. In those cases, the nitrate-N concentrations would be means across specific measurement lysimeter placement and depth, and soil depth. Other, non-significant statistical analyses are not presented.

At the ADW site, when the cover crop practice was statistically significant, RCC typically had lower nitrate-N concentrations in the tile water, lysimeter water, and soil than the no RCC (Figure 11); except for the soybean phase late in the season in 2018 where the RCC had higher lysimeter water nitrate-N concentrations. It is unknown why the lysimeter water concentrations were higher with the RCC in that instance as the tile water had lower nitrate-N concentrations with the RCC than no RCC. The amount of aboveground RCC biomass at termination varied each year and between the corn and soybean phases. In 2017, the RCC biomass dry matter was 500 lb/acre before corn and 1,120 lb/acre before soybean. In 2018, the RCC biomass was low before each crop phase, 380 lb/acre before corn and 250 lb/acre before soybean. The low RCC biomass in 2018 before each crop may have influenced the lack of difference in nitrate-N concentrations, and the opposite than expected difference in the lysimeter water late in the 2018 season (RCC higher than no RCC).

There were few differences in nitrate-N concentrations between fall and spring applied anhydrous ammonia at NWRF (Figure 12), especially in the tile water and soil. In the corn phase, when N timing was significant, fall application had higher nitrate-N concentrations than spring application. While a difference would not be expected in the soybean phase as no N is applied to soybean, there were two instances where lysimeter water nitrate-N concentrations were different between fall and spring application, but those were not consistent between years.

Correlation Analysis

By Site Restricted to Soil Sampling Periods

A correlation analysis was conducted for the relationship between the tile water, lysimeter water, and soil nitrate-N concentrations. For the analysis, lysimeter water or soil nitrate-N concentration at a specific sample date was compared to the nitrate-N concentration in the next occurring tile water sample date. This was done to help remove a time lag for water (and nitrate) to reach the drainage tile. Correlation was conducted using a combination of all individual plot data by site across crops and years; but initially restricted to the sample dates where there was soil sampling. Correlations were determined for each individual specific lysimeter and soil measurement (placement and depth), and for averages across measurement depths and/or placements within plots.

There were no statistically significant correlations at the ADW site between tile water and lysimeter water or soil nitrate-N concentrations (Table 3). Lack of correlation would mainly be due to the changes in lysimeter or soil nitrate-N concentrations over time versus the relative consistent tile water concentrations. Especially, due to the large increase in lysimeter water concentrations late in the season in both the 2018 corn and soybean phases at the ADW site. There were correlations between tile water and lysimeter nitrate-N concentrations at NWRF (Table 3). The correlation values were not high, but statistically significant. The best correlation was with the average of the four lysimeter concentrations per plot (average across the two depths and two placements). However, the average nitrate-N concentration of the two lysimeters (two depths) placed between the tile (FT) had similar correlation as with the four lysimeters. The highest correlation with the average of the two and four lysimeter concentrations indicates that for use of lysimeters to monitor N loss reduction practices there needs to be multiple lysimeters per plot, and probably multiple depths. Even with multiple lysimeters, there may not be good representation of actual nitrate-N concentrations in tile flow water. Correlation does not necessarily indicate good value prediction. This can be seen in Figure 13, where the lysimeter average nitrate-N concentration values at the NWRF site are considerably higher than the tile water values. The correlation/regression fit is there, but not a good estimation of actual tile water nitrate-N concentration.

At the NWRF site, the soil nitrate-N concentrations at the 12-24 inch depth were correlated to tile water concentrations, but the correlation was low (Table 3). There was significant correlation between the lysimeter and soil nitrate-N concentrations at both sites, especially for the 12-24 inch soil depth with the lysimeters placed between the tile (Table 4). That high correlation makes sense as the soil samples were collected near those between tile (FT) lysimeters, and thus both measuring similar nitrate in the soil system.

An additional correlation analysis was conducted to determine the relation between lysimeter and tile water nitrate-N, using the percent nitrate-N concentration change between management practices. This was an attempt to study the percent reduction from a nutrient practice (RCC vs. no RCC, and spring N vs. fall N). For both sites, the correlations using percent change were worse than using the concentrations, and all non-significant (data not shown).

By Site for All Lysimeter Sampling

Because there were more lysimeter water sample dates than soil sample dates, an additional correlation analysis was conducted with all of the lysimeter sample date data. Each specific lysimeter sample date was compared to the next occurring tile water sample date.

Correlations were also conducted by each site, year, and crop. In addition, the spring sampling period (initial sample each year to early July) was also investigated for each site.

For the ADW site in the soybean phase, there were no significant correlations between lysimeter water nitrate-N and tile water nitrate-N concentrations; for either the entire year or spring period only (data not shown). For the ADW corn phase in the 2017 entire year, the average of all four lysimeters was significantly correlated to tile nitrate-N concentrations; r = 0.53 and $P = 0.093$ (data not shown). However, the number of comparisons was low (n = 11) in that dry year. For the ADW corn phase in the 2018 entire year, there was a weak negative correlation ($P \leq 0.10$) between the lysimeter and tile water nitrate-N concentrations for the Lys-CT36, Lys-AvgCT, and Lys-Avg36 (correlation r range -0.23 to -0.26, with n=54) (data not shown). The negative correlation (and across years non-significant correlations) would be due to the different trend (large increase) in lysimeter water nitrate-N concentration versus the more consistent or decreasing tile water nitrate-N concentration in the late summer and fall in 2018 (Figures 5 and 6). However, within the spring period only, there were significant ($P \leq 0.10$), but low, correlations between the lysimeter and tile water nitrate-N concentrations for a few specific lysimeter placements (Table 5); Lys-FT36, Lys-Avg36, Lys-AvgFT, and Lys-Avg (correlation r range 0.33 to 0.48, with n = 29). These correlations were significant because there was not an increase in lysimeter water nitrate-N concentration with time like occurred in the later season.

For the NWRF site corn and soybean phases in 2017, there was only one lysimeter correlation with the tile nitrate-N concentrations statistically significant in each crop, and that was a same negative correlation for the entire year and the spring period only (Lys-CT24 corn and Lys-CT36 soybean phase, r = -0.83 and -0.81, with n = 5 and 6, respectively for corn and soybean phases, data not shown). For the NWRF site in 2018, in both the corn and soybean phases, there were many across-year significant correlations between the lysimeter and tile water nitrate-N concentrations (Table 6). The correlations generally were not improved when analyzed for the spring only period, and fewer specific lysimeter placements were significant in the spring period (Table 5). Having good correlation between lysimeter and tile water nitrate-N concentrations across the entire sampling year would be beneficial so as to capture practice effects within the entire crop phase, and possible effects from previous year practice implementation. These correlations using all of the lysimeter sample dates at the NWRF site are quite high. The average of the four lysimeters had the highest correlation in the corn phase, and nearly the highest correlation in the soybean phase. Several of the individual lysimeter placements had high correlation, but inconsistent. The average nitrate-N concentration of the two lysimeters (two depths) placed between the tile (FT) had similar correlation as with four lysimeters per plot. Using the expanded set of lysimeter sample dates produced better correlation with tile water nitrate-N concentrations than the set restricted to the soil sampling dates, and indicate that lysimeter soil water sampling can relate to tile flow nitrate concentrations. However, there still was considerable variation in the relationship between nitrate-N concentrations (Figure 14), and there was a trend for the lysimeter water nitrate-N concentrations to be greater than the tile water nitrate-N concentrations, especially in the corn phase (Figure 14). Therefore, specific predictability of tile water nitrate-N concentrations from lysimeter sampling has limitations, and considering the fact that at only one of two research sites was there a good and consistent correlation between lysimeter and tile water concentrations.

Across-Year Management Practice Comparisons

A data summary was compiled across the entire yearly sampling period for each site. This summary and analysis was conducted to simulate an across-year use of a measurement method for determining effects of management practices (comparison) on nitrate-N. Means were computed for each practice as a by-plot mean for all data across the sampling period each year and crop phase. Using the yearly means, a statistical analysis was conducted to determine management practice effect (separately by meaurement method) using tile water nitrate-N, lysimeter water nitrate-N, soil profile nitrate-N, and crop yield. For lysimeter and soil nitrate-N concentrations, the different collection depths and locations were summarized into one yearly mean – following the result where the highest and most consistent lysimeter correlation to tile water nitrate-N was with the average of all four lysimeters per plot. For each practice comparison, the percent change in nitrate-N concentration (nitrate-N reduction) was calculated for each measurement method. For the change calculation, the practices considered to be improved nitrate reduction practices were the RCC and spring applied N. Practice comparisons deemed statistically significant have the percentage presented in the regular font, and for the comparisons that are non-significant the percentage is in a light font (questionable if percent reduction should be compared as the differences were not significant).

The across-year results are presented in Tables 7-10. In each table for relative comparison, the overall water quality site project management practice results are also presented for the tile flow-weighted nitrate-N concentrations. Those overall tile flow-weighted nitrate-N concentrations encompass an entire year summary, and encompass a time-period that is longer than the lysimeter/soil sampling period (possible tile water sampling before and after the lysimeter/soil sampling period). Generally, the magnitude of the mean nitrate-N concentrations, and difference between practices, are quite similar for the tile water measured in our study period (actual concentrations) and the tile flow-weighted nitrate-N concentrations from the overall project yearly period. For the lysimeter concentrations, in two instances the overall project tile flow-weighted nitrate-N concentrations had a significant difference between management practices (ADW 2017 corn and soybean phases), but lysimeter water nitrate-N concentrations were not different. And in three instances the management practice difference was significant for the lysimeter nitrate-N, but not for the overall project tile flow weighted nitrate-N concentrations (ADW 2018 corn phase, NWRF 2017 and 2018 corn phase). In other instances, the difference between practices were not significant for either the lysimeter water or overall project tile flow-weighted nitrate-N concentrations.

At the ADW site for the RCC and no RCC, the mean lysimeter water nitrate-N concentrations were higher than the tile water concentrations in the corn phase both years, especially in 2018. The mean lysimeter nitrate-N concentration in the corn phase was lower for the RCC compared to no RCC in 2018, but not 2017. In contrast, in the corn phase the mean tile nitrate-N concentrations were not different between the RCC and no RCC each year. In the soybean phase, the mean lysimeter water nitrate-N concentrations were similar to the tile concentrations in 2017, but higher in 2018. The mean lysimeter nitrate-N concentrations in the soybean phase were the same for the RCC and no RCC each year, the same result as for the tile concentrations. The across-year mean soil nitrate-N concentrations were low and generally showed no difference between with or without the RCC, likely due to the decrease in soil nitrate-N concentration with crop uptake. There was no difference in crop yields due to the RCC or no RCC.

At the NWRF site for the fall and spring anhydrous ammonia application timing, the mean lysimeter water nitrate-N concentrations were similar to the mean tile water concentrations both years and crop phases. In the corn phase each year, the mean lysimeter water nitrate-N concentration was higher with the fall N application. This was the same result for the tile water nitrate-N concentration in 2018, but there was no difference in 2017. There were no N timing differences for lysimeter or tile water nitrate-N concentrations in the soybean phase. Soil nitrate-N concentrations were low and generally had inconsistent differences between fall and spring N application; higher mean soil nitrate-N concentration with fall N in 2017 corn phase, lower with fall N in 2018 soybean phase, and no difference in 2017 soybean or 2018 corn phases. There was no difference in crop yields due to N application timing.

An issue with the study design was use of only two management practices and three replications, which limited the statistical degrees of freedom for these across-year practice comparisons; and thus limited the potential to determine management practice statistical differences. In future research of N reduction practices, additional replication and perhaps more reduction practices would be useful when evaluating practices with surrogate measurement methods.

Summary

This study was a unique opportunity to investigate different nitrate-N measurement methods (surrogate to tile drainage water nitrate-N – suction cup lysimeter water and soil profile nitrate-N) at two on-going water quality research sites utilizing tile drainage monitoring. And, the opportunity to study two different in-field nitrate loss reduction management practices, rye cover crop (with and without RCC) and fertilizer N application timing (fall and spring anhydrous ammonia). Following is a summary of the study findings.

- Lysimeter water nitrate-N concentrations were quite variable in time and space.
- Soil nitrate-N concentrations were variable and decreased with crop N uptake.
- Dry conditions limited lysimeter water sample collection, but not soil sample collection.
- There can be no estimate of discharge flow (nitrate-N load) with lysimeter or soil sampling.
- Cannot flow-weight lysimeter or soil nitrate-N concentrations across time.
- Lysimeter water nitrate-N concentrations, when restricted to the soil sampling dates, correlated to tile water nitrate-N concentrations, but only at one of the two water quality sites (NWRF only).
    - Correlations were low ($r \leq 0.42$).
    - Best correlation to tile water nitrate-N concentrations was with the mean of the four lysimeters per plot; two placements relative to tile and two depths ($r = 0.42$).
    - Between tile lysimeter placement (average of the two lysimeter depths) had better correlation than placement near the monitored drain tile ($r = 0.40$ vs. 0.33), and similar but lower than the average of four lysimeters.
    - Lysimeter water nitrate-N at 24 and 36 inch collection depths (average of placement) had similar correlation.
- Correlations improved when all lysimeter sample dates were included and separated by each crop phase (but again only for NWRF site in 2018).
    - Correlations up to $r = 0.78$.
    - Better correlation when lysimeters placed between tile lines than near the monitored drain tile.

    - More consistent correlation with the mean of the four lysimeters per plot; two placements relative to tile and two depths (r = 0.61 in corn and r = 0.67 in soybean phases).
- The often low correlation of lysimeter nitrate-N concentrations with tile water nitrate-N concentrations is partially explained by the relatively consistent tile water nitrate-N concentrations across time but the varying and sometimes much higher lysimeter water nitrate-N concentrations.
    - High lysimeter concentrations especially occurred at the ADW site in the late season 2018 corn phase, and there were negative correlations when analyzed across that entire year.
    - However, limiting the lysimeter correlation to the 2018 year spring period at ADW in the corn phase resulted in a significant but low correlation (r = 0.35 for the four lysimeter average).
- Predictability of tile water nitrate-N concentrations is limited because of the trend for lysimeter nitrate-N concentrations to be higher than in the tile water, and more variable.
- Soil profile nitrate-N concentrations correlated (but poorly) to tile water nitrate-N concentrations, but only at one of two water quality sites and only one sample depth (only NWRF, r = 0.23 for the 12-24 inch depth).
- Soil nitrate-N concentrations correlated with lysimeter water nitrate-N concentrations at both water quality sites and both depths.
    - r = 0.27 to 0.63.
    - Correlation highest for the 12-24 inch soil depth with the 24 inch lysimeter depth (r = 0.62 and 0.63).
    - Correlation because the soil samples were collected near the between-tile lysimeter placement.
- Across measurement-year summary of lysimeter water nitrate-N concentrations indicated similar management practice trends as tile water nitrate-N concentrations in many but not all cases, but not the same concentration levels.
- Using only two N management practices for comparison per site limited ability to determine practice effects; more replications would be helpful and possibly more management practices studied.
- Banded N fertilizer (in this study anhydrous ammonia at both water quality sites) increases small-scale within-plot spatial variation and thus likely variation issues with use of lysimeters for sampling soil water for nitrate-N concentration and determination of N management practice effects.
    - Similar issue with soil sampling.
- Nitrogen reduction practice effects on water quality (nitrate) would be best determined with monitoring of tile drainage flow.
    - Integrates entire soil volume being drained.
    - Integrates across time scales.
    - Integrates across small scale spatial variation caused by some N management practices (example banded N).
    - Allows computation of nitrate-N load.

Suction cup lysimeters have potential use for determining nitrate-N reduction practice effects, especially for practices with large effects on nitrate-N. Relating to (predicting) tile water nitrate-N concentrations has limitations, including larger variation and differences in relative concentrations. Use of lysimeters will require multiple and perhaps specific within plot locations, multiple depths, frequent and many sample water collection times, and measurement in multiple years. Especially, when N is banded into concentrated zones. Sampling for soil profile nitrate-N has limited potential as a surrogate measure as related to tile water nitrate-N. Soil sampling has potential for determining differences between management practices, but sampling would likely need to be limited to the springtime before crop uptake becomes rapid and influences nitrate-N levels in soil or a management practice supplies nitrate back to the soil system (such as a cover crop).

There was a quite different level of lysimeter surrogate measure success between the two sites studied, with the reasons not fully understood. As discussed, several aspects of surrogate measures need to be understood and carefully considered if implemented as a method to determine potential water quality effect of various in-field N reduction practices.

Acknowledgements

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Figure 1. Tile flow sampling diagram for a plot at the Agricultural Drainage Water Quality (ADW) site, Gilmore City, IA. Not to scale.

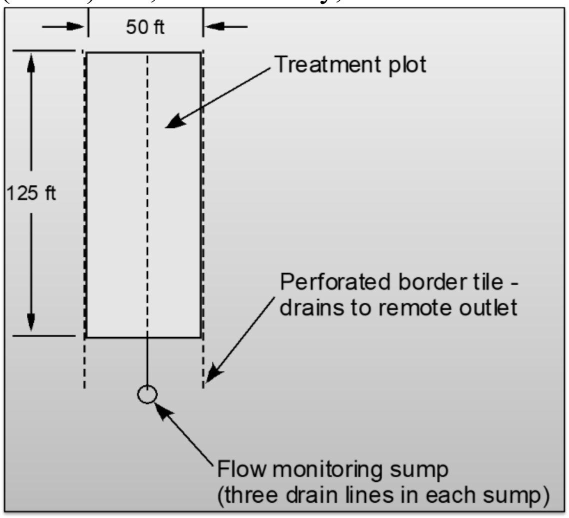

Figure 2. Tile flow sampling diagram for plots at the Northwest Research Farm (NWRF) water quality site, Sutherland, IA. Not to scale.

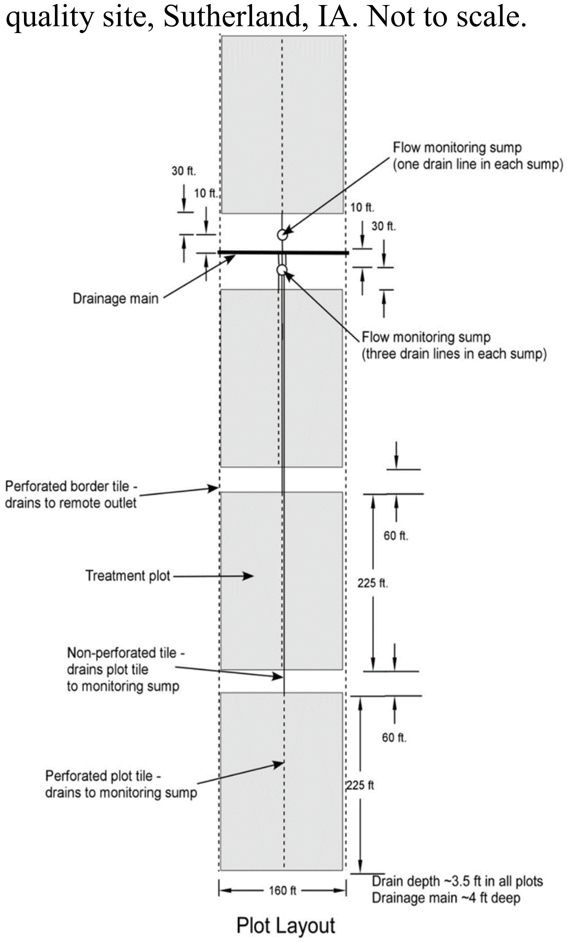

Figure 3. Suction cup lysimeter and soil profile sampling locations within a plot at the Agricultural Drainage Water Quality (ADW) site, Gilmore City, IA. The black and blue circles represent lysimeter locations. The small dots represent soil sample core location. The CT abbreviation means near monitored drain tile and FT means between tiles. Not to scale.

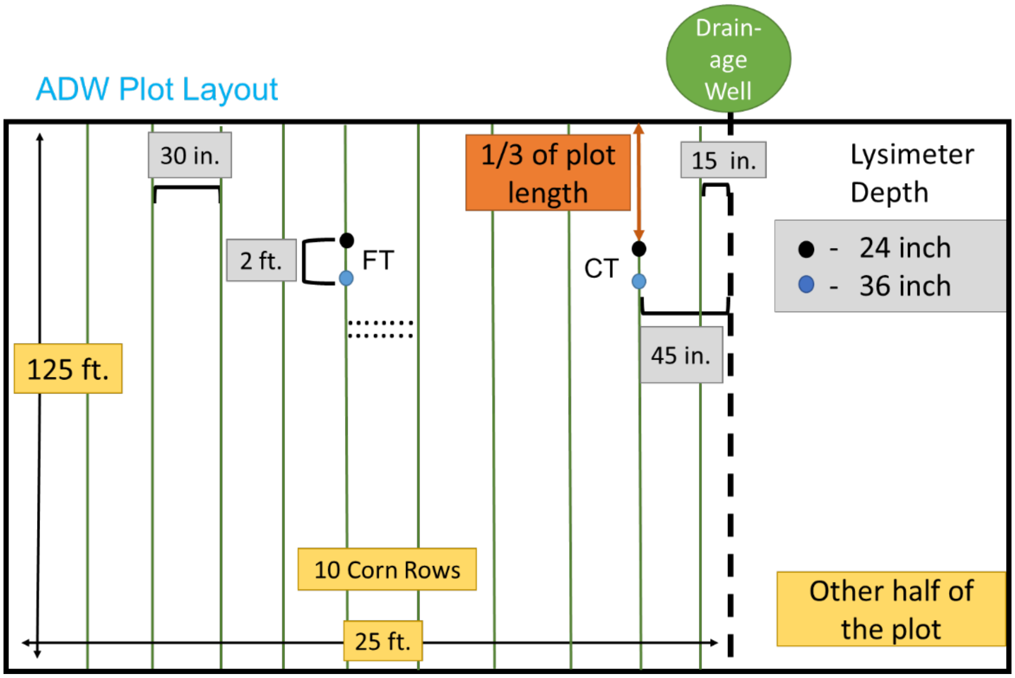

Figure 4. Suction cup lysimeter and soil profile sampling locations within a plot at the Northwest Research Farm (NWRF) water quality site, Sutherland, IA. The black and blue circles represent lysimeter locations. The small dots represent soil sample core location. The CT abbreviation means near monitored drain tile and FT means between tiles. Not to scale.

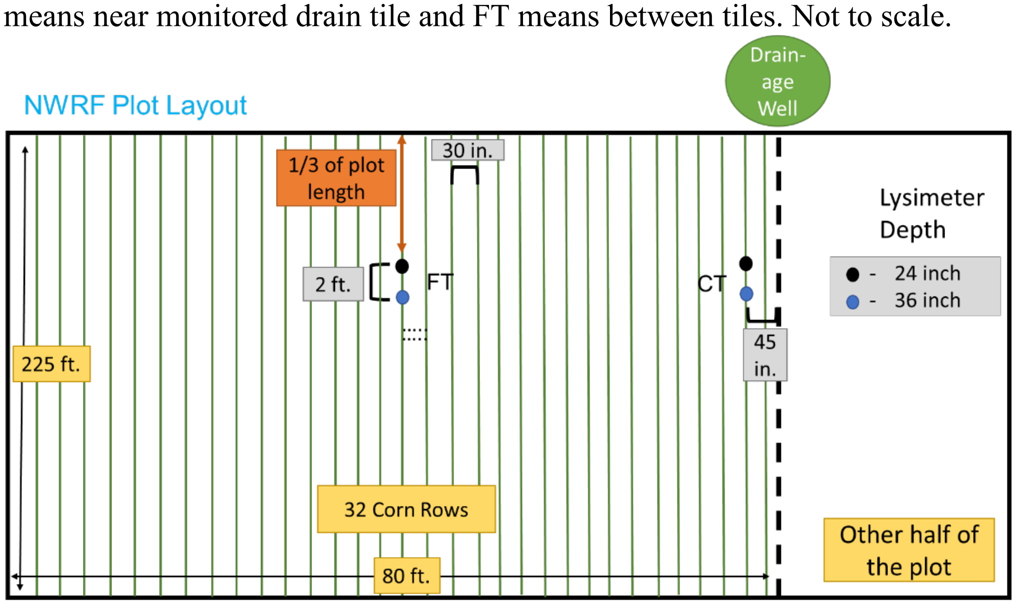

Figure 5. Time series graphs for nitrate-N concentration in tile water at the Agricultural Drainage Water Quality (ADW) site, all samples collected. Rye cover crop (RCC).

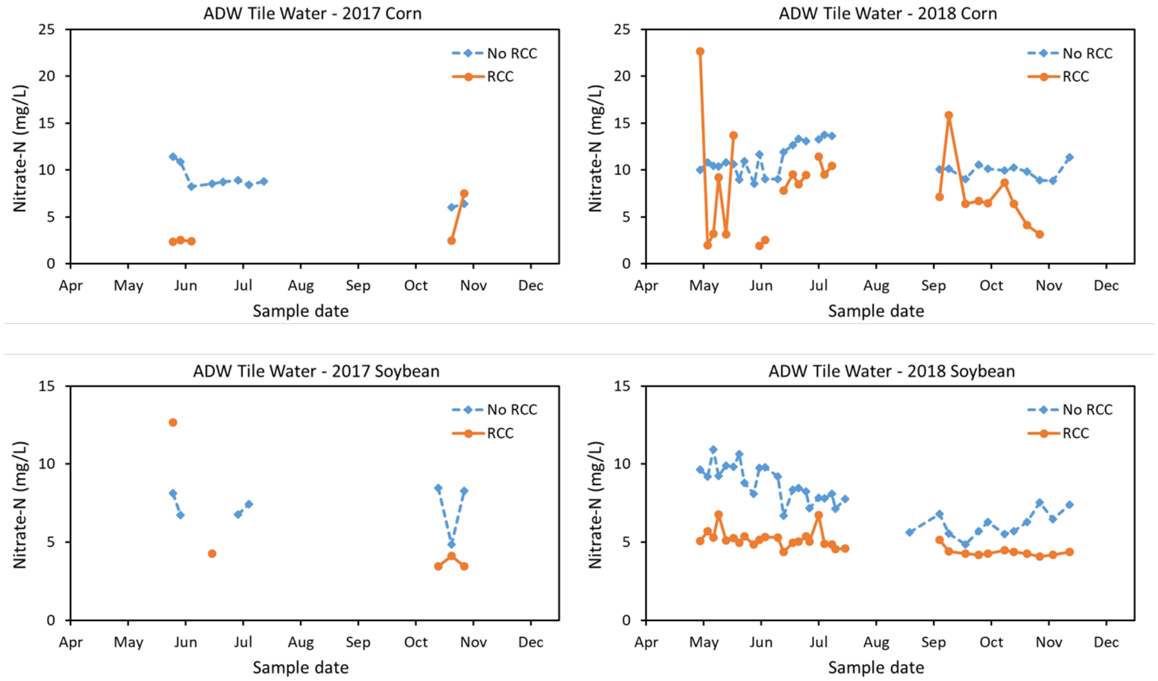

Figure 6. Time series graphs for nitrate-N concentration in lysimeter water at the Agricultural Drainage Water Quality (ADW) site, all samples collected. Rye cover crop (RCC). See Table 3 footnote for lysimeter placement codes.

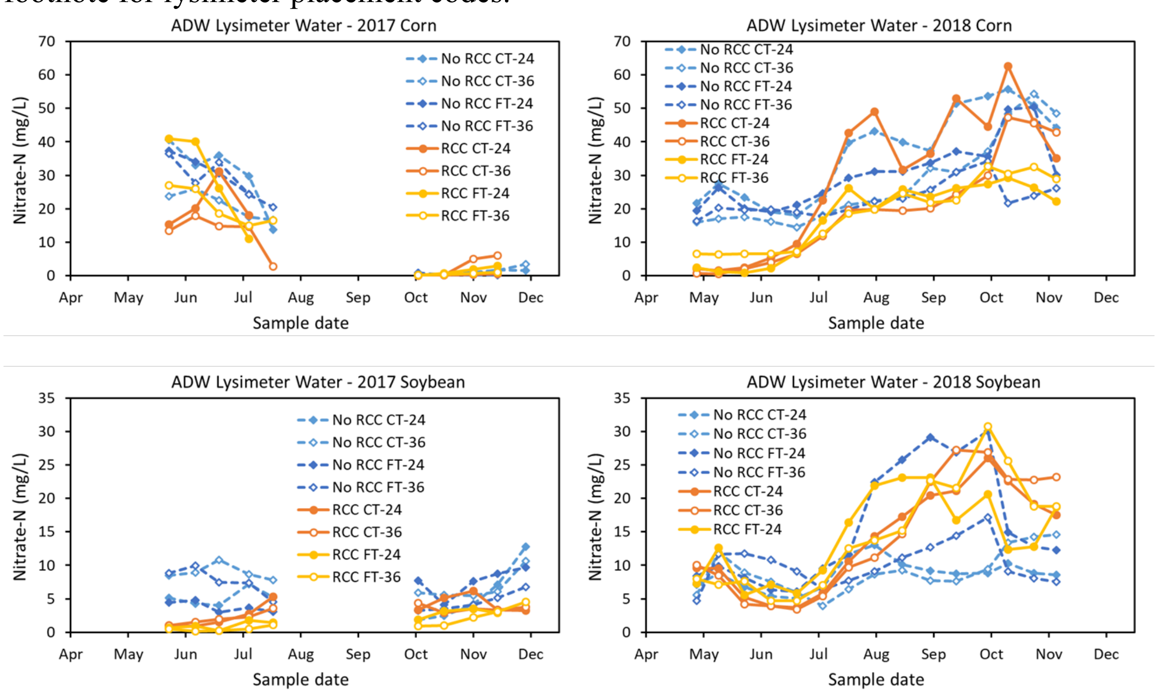

Figure 7. Time series graphs for nitrate-N concentration in soil at the Agricultural Drainage Water Quality (ADW) site, all samples collected. Rye cover crop (RCC). See Table 3 footnote for soil depth codes.

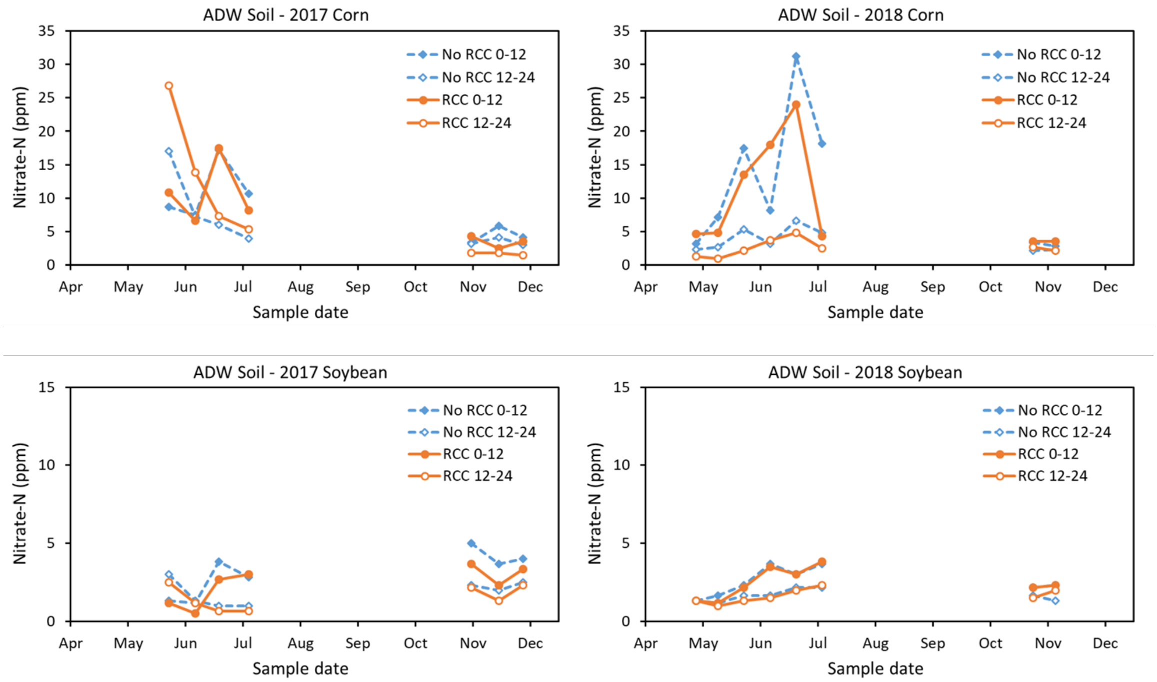

Figure 8. Time series graphs for nitrate-N concentration in tile water at the Northwest Research Farm (NWRF) site, all samples collected. Fall applied N (F) and spring preplant N (S)

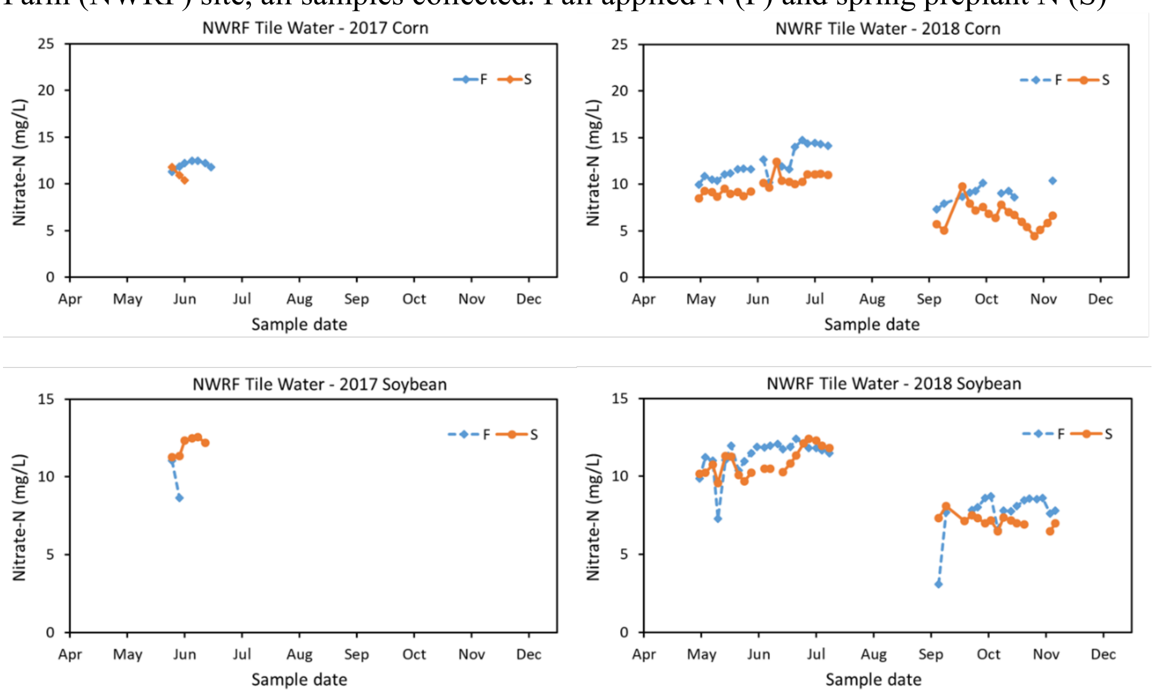

Figure 9. Time series graphs for nitrate-N concentration in lysimeter water at the Northwest Research Farm (NWRF) site, all samples collected. Fall applied N (F) and spring preplant N (S). See Table 3 footnote for lysimeter placement codes.

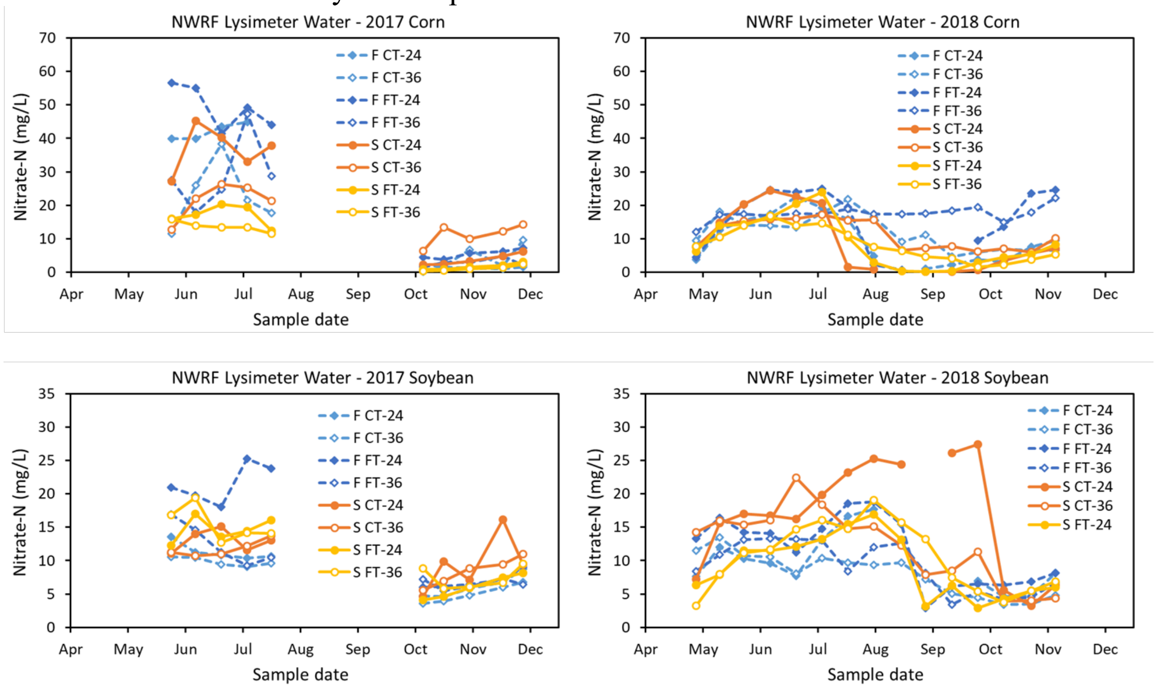

Figure 10. Time series graphs for nitrate-N concentration in soil at the Northwest Research Farm (NWRF) site, all samples collected. Fall applied N (F) and spring preplant N (S). See Table 3 footnote for soil depth codes.

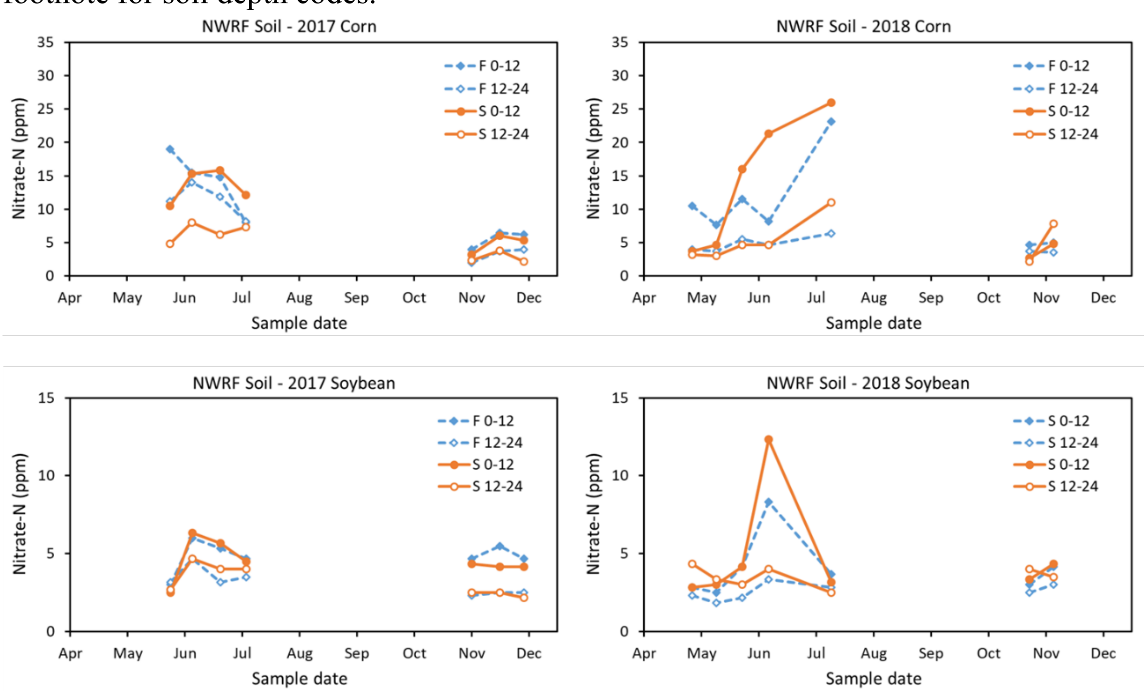

Figure 11. Time series graphs for nitrate-N concentration at the Agricultural Drainage Water Quality (ADW) site, with significant management practice and/or sample date interaction. Black dots represent significant difference at a sample date or mean ($P = 0.10$). Rye cover crop (RCC). See Table 3 footnote for lysimeter placement codes.

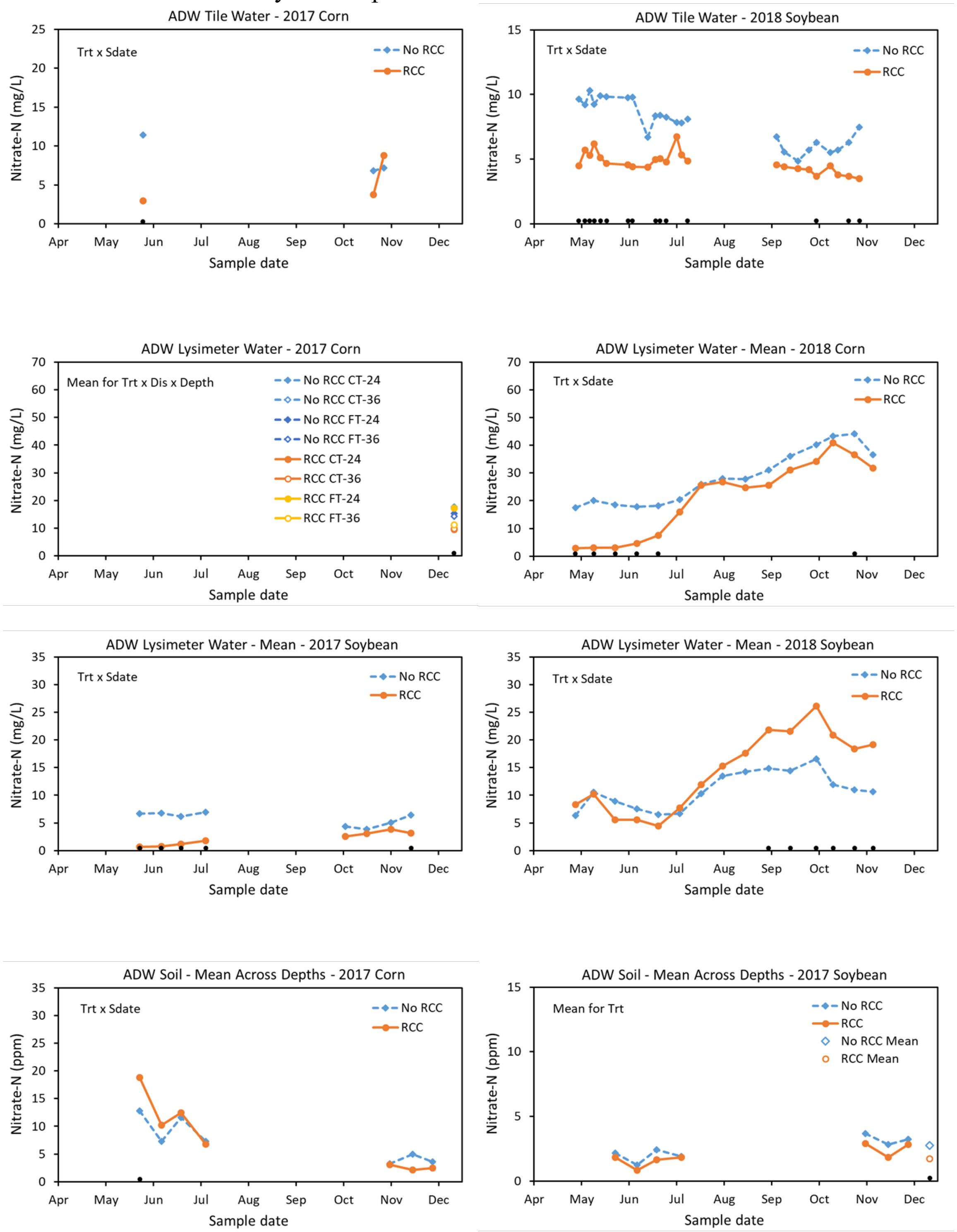

Figure 12. Time series graphs for nitrate-N concentration at the Northwest Research Farm (NWRF) site, with significant management practice and/or sample date interaction. Black dots represent significant difference at a sample date or mean (P = 0.10). Fall applied N (F) and spring preplant N (S). See Table 3 footnote for lysimeter placement codes.

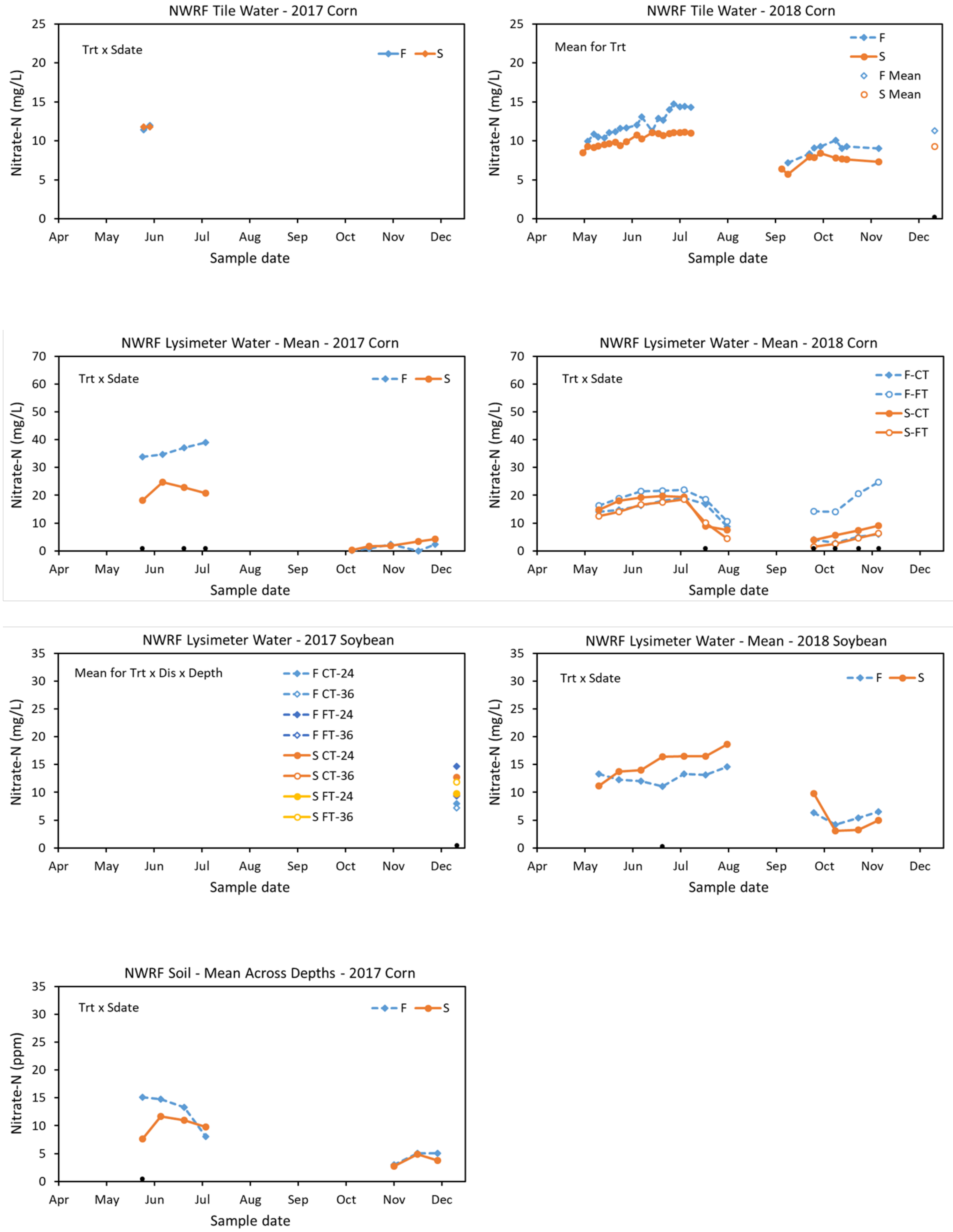

Figure 13. Linear and quadratic-plateau regression fit for the lysimeter water average nitrate-N concentration with the tile water nitrate-N concentration at the Northwest Research Farm (NRWF), restricted to the sample dates where there was soil sampling. See Table 3 for the significant correlation.

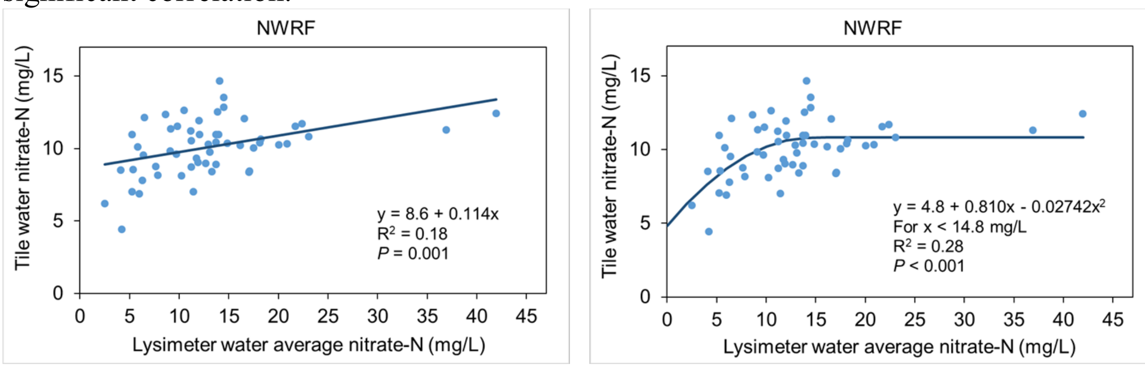

Figure 14. Linear and quadratic-plateau regression fit for the lysimeter water average nitrate-N concentration with the tile water nitrate-N concentration at the Northwest Research Farm (NRWF), for all sample dates in 2018 where there was lysimeter water sampling in the corn and soybean phases. See Table 6 for the significant correlation.

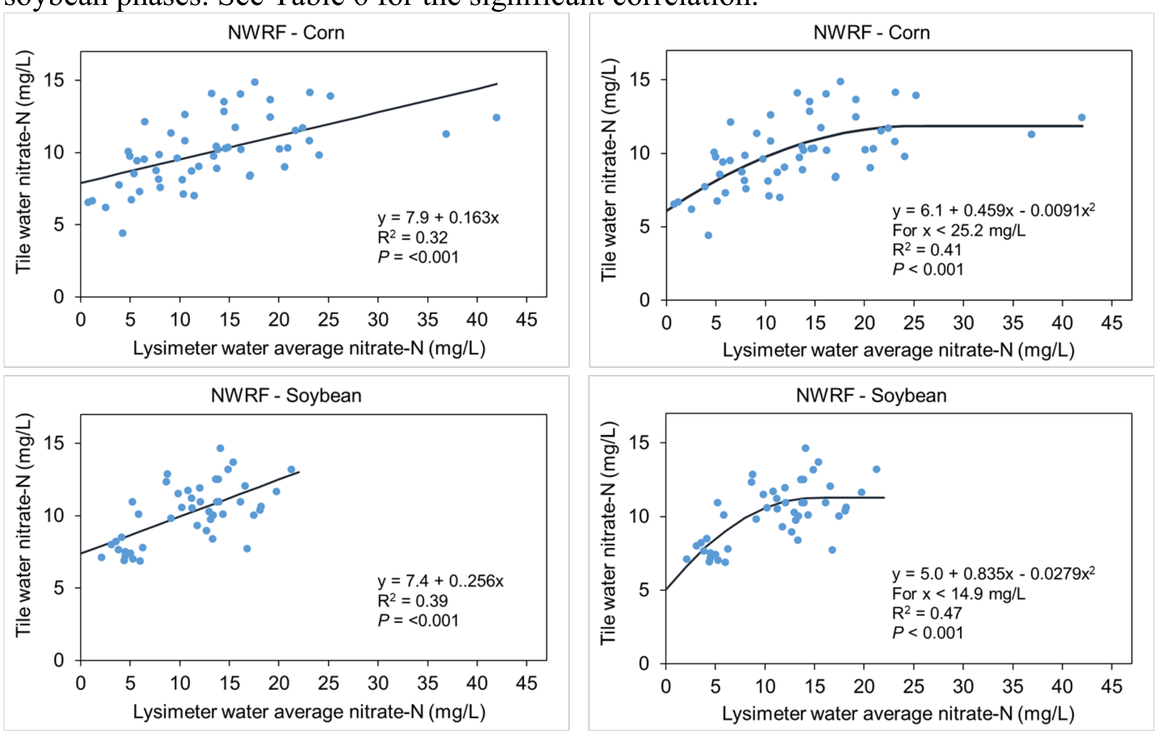

Table 1. Precipitation (inch) at the Agricultural Drainage Water Quality (ADW) and Northwest Research Farm (NWRF) sites.

	ADW			NWRF		
Month	2017	2018	30-yr avg	2017	2018	30-yr avg†
Jan	1.7	0.9	0.9	1.0	0.7	0.6
Feb	1.6	0.4	0.8	0.8	0.8	0.6
Mar	1.1	2.0	2.1	1.4	2.0	1.9
Apr	4.8	1.3	3.3	3.2	1.5	3.1
May	6.0	4.3	4.1	3.0	4.4	3.9
Jun	3.0	8.8	4.9	1.9	6.3	5.0
Jul	0.6	2.3	4.7	1.3	3.1	3.9
Aug	4.3	6.6	4.7	4.3	4.2	3.7
Sept	0.0	7.1	2.9	2.3	8.2	3.5
Oct	0.0	3.4	2.1	3.3	2.1	2.1
Nov	0.0	1.0	1.8	0.2	1.2	1.5
Dec	0.0	2.3	1.3	0.2	1.5	0.9
Total	23.1	40.4	33.5	22.9	36.0	30.7

† The NWRF 30-year average is from the weather station at Cherokee, IA.

Table 2. Number of sample dates within the lysimeter/soil sampling period for the 2017 and 2018 years for the Agricultural Drainage Water Quality (ADW) and Northwest Research Farm (NWRF) sites.

	Tile		Lysimeter		Soil	
	Total†	Useable‡	Total	Useable	Total	Useable
2017						
ADW	11	3	10	8	7	7
NWRF	7	2	10	9	7	7
2018						
ADW	34	24	15	15	8	8
NWRF	39	29	15	11	7	7

† Number of sample dates within each of the corn and soybean crop phases.
‡ Useable number indicates sample dates within a measurement method where a management practice had data for at least one replicate. That is, for a particular measurement method (tile, lysimeter, or soil) if there was a sample date with a management practice that had no data for all three replicates, then that sample date was removed for both corn and soybean phases for that method so a management practice by specific measurement method statistical analysis could be conducted across sample dates.

Table 3. Correlation of tile water nitrate-N concentration with lysimeter water and soil nitrate-N concentration for the Agricultural Drainage Water Quality (ADW) and Northwest Research Farm (NWRF) sites. By individual plot for data in 2017 and 2018 (across corn and soybean phases), restricted to the dates where there was soil sampling. Tile and lysimeter water mg/L and soil mg/kg nitrate-N. Correlation values in bold are statistically significant, $P \leq 0.10$.

	ADW			NWRF		
Measure†	r‡	*P*‡	n‡	r	*P*	n
Lys-CT24	0.16	0.160	76	**0.30**	0.060	40
Lys-CT36	0.07	0.550	79	**0.24**	0.095	49
Lys-FT24	0.04	0.784	63	**0.36**	0.014	46
Lys-FT36	0.08	0.459	80	**0.38**	0.008	49
Lys-Avg24	0.13	0.251	78	**0.38**	0.005	53
Lys-Avg36	0.08	0.468	81	**0.36**	0.006	55
Lys-AvgCT	0.13	0.252	81	**0.33**	0.014	53
Lys-AvgFT	0.07	0.536	80	**0.40**	0.003	53
Lys-Avg	0.11	0.338	81	**0.42**	0.001	55
Soil-12	0.13	0.261	81	0.10	0.465	55
Soil-24	0.08	0.452	81	**0.23**	0.086	55
Soil-Avg	0.12	0.272	81	0.16	0.245	55

† Measure codes: Lys, lysimeter; CT, next to tile; FT, between tile; Lys-Avg, average of 24 and 36 inch lysimeter depth, average of CT, average of FT, and average of the four lysimeter placements and depths; Soil-12, 12-24 inch depth; Soil-24, 12-24 inch depth; Soil-Avg, average of two soil depths.
‡ The r is Pearson correlation coefficient, *P* probability level, and n correlation sample pair number.

Table 4. Correlation of lysimeter water collected between tile lines with soil nitrate-N concentration for the Agricultural Drainage Water Quality (ADW) and Northwest Research Farm (NWRF) sites. By individual plot for all data in 2017 and 2018, restricted to the dates where there was soil sampling. Lysimeter water mg/L and soil mg/kg nitrate-N. Correlation values in bold are statistically significant, $P \leq 0.10$.

	ADW			NWRF		
Measure†	r‡	*P*‡	n‡	r	*P*	n
FT24 vs.						
Soil-12	**0.27**	0.005	110	**0.40**	<0.001	81
Soil-24	**0.62**	<0.001	110	**0.63**	<0.001	81
FT-36 vs.						
Soil-12	**0.31**	<0.001	138	**0.40**	<0.001	86
Soil-24	**0.52**	<0.001	138	**0.32**	0.003	86

† Measure codes: FT-24, lysimeter at 24 inch depth between tile; FT-36, lysimeter at 36 inch depth between tile; Soil-12, soil sample for 0-12 inch depth, Soil-24, soil sample for 12-24 inch depth.
‡ The r is Pearson correlation coefficient, *P* probability level, and n correlation sample pair number.

Table 5. Correlation of tile water nitrate-N concentration with lysimeter water nitrate-N concentration for the Agricultural Drainage Water Quality (ADW) and Northwest Research Farm (NWRF) sites in the corn phase for the 2018 spring period only (beginning year sample to early July). By individual plot, for all dates where there was lysimeter water sampling. Tile and lysimeter water mg/L nitrate-N. Correlation values in bold are statistically significant, $P \leq 0.10$.

	ADW			NWRF		
Measure†	r‡	*P*‡	n‡	r	*P*	n
Lys-CT24	0.04	0.828	28	0.37	0.102	21
Lys-CT36	0.21	0.295	28	0.19	0.331	28
Lys-FT24	0.12	0.589	24	**0.59**	0.002	24
Lys-FT36	**0.48**	0.009	29	0.27	0.158	23
Lys-Avg24	0.15	0.438	29	**0.48**	0.008	29
Lys-Avg36	**0.46**	0.013	29	0.22	0.230	31
Lys-AvgCT	0.21	0.263	29	**0.37**	0.047	30
Lys-AvgFT	**0.33**	0.085	29	**0.38**	0.039	30
Lys-Avg	**0.35**	0.061	29	**0.39**	0.032	31

† Measure codes: Lys, lysimeter; CT, next to tile; FT, between tile; Lys-Avg, average of 24 and 36 inch lysimeter depth, average of CT, average of FT, and average of the four lysimeter placements and depths.

‡ The r is Pearson correlation coefficient, *P* probability level, and n correlation sample pair number.

Table 6. Correlation of tile water nitrate-N concentration with lysimeter water nitrate-N concentration for the Northwest Research Farm (NWRF) site. By individual plot in 2018, for all dates where there was lysimeter water sampling. Tile and lysimeter water mg/L nitrate-N. Correlation values in bold are statistically significant, $P \leq 0.10$.

	Corn			Soybean		
Measure†	r‡	*P*‡	n‡	r	*P*	n
Lys-CT24	**0.61**	<0.001	30	0.25	0.221	25
Lys-CT36	**0.41**	0.007	43	**0.44**	0.006	38
Lys-FT24	**0.61**	<0.001	33	**0.70**	<0.001	31
Lys-FT36	**0.52**	<0.001	42	**0.69**	<0.001	37
Lys-Avg24	**0.60**	<0.001	43	**0.50**	0.002	36
Lys-Avg36	**0.47**	<0.001	49	**0.62**	<0.001	40
Lys-AvgCT	**0.53**	<0.001	46	**0.47**	0.003	39
Lys-AvgFT	**0.58**	<0.001	56	**0.78**	<0.001	38
Lys-Avg	**0.61**	<0.001	49	**0.67**	<0.001	40

† Measure codes: Lys, lysimeter; CT, next to tile; FT, between tile; Lys-Avg, average of 24 and 36 inch lysimeter depth, average of CT, average of FT, and average of the four lysimeter placements and depths.
‡ The r is Pearson correlation coefficient, *P* probability level, and n correlation sample pair number.

Table 7. Across-year summary and statistical analysis for the rye cover crop (RCC) and no RCC, Agricultural Drainage Water Quality (ADW), 2017. Nitrate-N concentration means across yearly sample period by plot.

		Corn			Soybean		
Measure		RCC	No RCC	%†	RCC	No RCC	%
Tile	mg/L	2.9a‡	10.3a	72	5.8a	8.1a	28
Lysimeter	mg/L	11.1a	15.6a	29	2.4a	5.7a	58
Soil	ppm	8.0a	7.3a	-10	2.0b	2.5a	20
Crop Yield	bu/acre	186a	188a	--	29.5a	26.3a	--
Overall Site Project§							
Tile	mg/L	2.9b	10.4a	72	2.9b	7.0a	59

† The percent column indicates the nitrate-N change for comparison of the management practices [(No RCC minus RCC) divided by No RCC], with non-significant comparisons in the light font.
‡ Different letter within a row and crop indicates significant difference ($P = 0.10$).
§ Overall site project mean of four replicates, flow weighted.

Table 8. Across-year summary and statistical analysis for the rye cover crop (RCC) and no RCC, Agricultural Drainage Water Quality (ADW), 2018. Nitrate-N concentration means across yearly sample period by plot.

		Corn			Soybean		
Measure		RCC	No RCC	%†	RCC	No RCC	%
Tile	mg/L	8.2a‡	11.3a	27	4.7b	7.9a	41
Lysimeter	mg/L	20.0b	28.4a§	30	14.5a	10.0a	-45
Soil	ppm	6.0a	7.6a	21	2.0a	2.1a	5
Crop Yield	bu/acre	185a	185a	--	56.1a	53.6a	--
Overall Site Project¶							
Tile	mg/L	7.0a	10.1a	31	5.1a	7.1a	28

† The percent column indicates the nitrate-N change for comparison of the management practices [(No RCC minus RCC) divided by No RCC], with non-significant comparisons in the light font.
‡ Different letter within a row and crop indicates significant difference ($P = 0.10$).
§ Significant at $P = 0.104$.
¶ Overall site project mean of four replicates, flow weighted.

Table 9. Across-year summary and statistical analysis for the fall applied N (Fall N) and spring preplant N (Spring N), Northwest Research Farm (NWRF), 2017. Nitrate-N concentration means across yearly sample period by plot.

		Corn			Soybean		
Measure		Fall N	Spring N	%†	Fall N	Spring N	%
Tile	mg/L	12.5a‡	11.8a	6	10.8a	12.0a	-11
Lysimeter	mg/L	19.4a	13.0b	33	10.1a	11.4a	-13
Soil	ppm	9.2a	7.4b	20	4.0a	3.9a	3
Crop Yield	bu/acre	201a	201a	--	61.7a	66.9a	--
Overall Site Project§							
Tile	mg/L	13.2a	13.8a	-5	8.9a	12.2a	-37

† The percent column indicates the nitrate-N change for comparison of the management practices [(Fall N minus Spring N) divided by Fall N], with non-significant comparisons in the light font.
‡ Different letter within a row and crop indicates significant difference (*P* = 0.10).
§ Overall site project mean of four replicates, flow weighted.

Table 10. Across-year summary and statistical analysis for the fall applied N (Fall N) and spring preplant N (Spring N), Northwest Research Farm (NWRF), 2018. Nitrate-N concentration means across yearly sample period by plot.

		Corn			Soybean		
Measure		Fall N	Spring N	%†	Fall N	Spring N	%
Tile	mg/L	11.4a‡	9.2b	19	10.2a	10.1a	1
Lysimeter	mg/L	14.7a	9.6b	35	10.0a	11.6a	-16
Soil	ppm	7.3a	8.3a	-14	3.3b	4.1a§	-24
Crop Yield	bu/acre	197a	193a	--	68.8a	71.0a	--
Overall Site Project¶							
Tile	mg/L	11.5a	9.6a	17	11.6a	11.2a	3

† The percent column indicates the nitrate-N change for comparison of the management practices [(Fall N minus Spring N) divided by Fall N], with non-significant comparisons in the light font.
‡ Different letter within a row and crop indicates significant difference (*P* = 0.10).
§ Significant at *P* = 0.109.
¶ Overall site project mean of four replicates, flow weighted.