I. A Long-term Evaluation of Nitrogen Application Timing and Cover Crops Impacts on the Fate and Availability of Nitrogen Fertilizer and Crop Production on Tile Drained Fields

II. Cooperators and Locations

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Industry Advisory Board:

Robert Fish, Certified Crop Advisor;
Mclean County Soil and Water Conservation Society
Illinois Natural Resources Conservation Service

Location: Lexington, IL is the location of the Nitrogen Management Research Field Station (NMRFS). The initial funding to establish this site was provided by NREC in 2013 for tile installation and the equipment purchase was completed in 2014. The cooperating landowner and farmer are very pleased with the products and knowledge that the project generates and are looking forward to further investigation of the impacts cover crops and adaptive nitrogen fertilizer management on tile drainage fields. Portions of this grant also took place, near the NMRFS, at the Illinois State University Research and Education Farm, Lexington, Il.

III. Background

The contribution of nitrogen (N) from the Upper Mississippi River Basin to the hypoxic zone in the Gulf of Mexico continues to be an environmental issue and a threat to the sustainability of row crop agriculture. Due to the severity of this N loading issue, many Corn Belt states were required by the USEPA Gulf of Mexico Hypoxia Task Force to develop a Nutrient Loss Reduction Strategy (NLRS) to reduce N and P loading by 45% by 2025. The NLRS developed by most Corn Belt states such as IL, OH, MN, IA, and IN, concluded that cover cropping is the most effective and economically feasible in-field strategy that can be adopted on a large scale to achieve the proposed nonpoint nutrient loss reduction goals. However, results from recent surveys indicate that only 5% of row crop land nationally has adopted cover crops due to limiting factors such as the lack of knowledge on how cover crops affect N cycling and the fate of fertilizer N within different N management systems. The integration of cover crops into a farmer's existing crop and N management systems requires scientists to answer three distinct questions before voluntary adoption can be considered and behavior can be adjusted: (1) Do cover crops reduce the amount of fertilizer N loss through tile drainage? (2) What percentage of cover crop scavenged N will be available to the following crop? and (3) How does the timing of cover crop residue N release correlate with the N demand of corn and soybeans? The scientific community has developed a firm understanding of the first question, namely how cover crops scavenge soil inorganic N which helps prevent N loading through tile drainage. However, no studies have quantified the second and third questions. The lack of available information on cover crop N uptake and release dynamics has made it difficult for farmers to successfully integrate cover crops into their current crop and N management systems, and as a result, the possible short-term benefits of cover crops are largely not valued.

IV. Objectives

1. Quantify the impact of N application timing and cover crop inclusion on the distribution of soil NO_3-N, nitrate-N losses through tile drainage, and corn and soybean N uptake and yield.

2. Investigate the impact of cover crop inclusion on N_2O release.

3. Utilize ^{15}N methods to identify whether cover crops primarily take up soil or fertilizer N.

4. Determine the impact of cover crops on the fate and availability of fall and spring applied fertilizer N using ^{15}N methodology.

5. Utilize ^{15}N methods to determine the synchrony of the timing and quantity of cover crop residue N release and corn and soybean N demand.

V. Activities and Findings

Weather

Air temperature and precipitation data were recorded at the research site to examine the influence of weather on both environmental and agronomic fates N in conventional and sustainable agriculture systems. During the cover crop growing seasons (September-April), a variety of different weather conditions were experienced with a notably: cold-dry season in 2015, warm-wet season in 2016, a warm-dry season in 2017, and a cold-wet season in 2019.

Air Temperature (°F)						
	2014	2015	2016	2017	2018	2019
Jan	17.7	23.7	25.6	30.1	23.0	21.8
Feb	15.3	17.1	31.3	39.1	29.5	27.7
Mar	32.4	36.4	45.9	40.4	35.5	35.5
Apr	50.4	52.5	50.9	55.5	43.3	50.8
May	63.6	64.3	61.8	60.7	70.6	61.9
Jun	72.5	70.7	73.8	72.8	73.7	70.9
Jul	68.5	72.1	73.8	73.7	71.9	75.8
Aug	71.1	70.1	73.8	67.7	72.5	70.5
Sep	62.6	68.5	69.2	65.9	68.7	69.6
Oct	52.1	54.0	58.1	56.5	52.4	51.4
Nov	34.0	44.6	45.9	40.1	34.0	34.7
Dec	31.5	39.5	28.4	26.9	32.7	33.7

Rainfall Totals (inches)						
	2014	2015	2016	2017	2018	2019
Jan	0.88	1.57	0.62	1.48	0.3	0.94
Feb	0.77	0.54	0.75	0.51	3.35	1.71
Mar	1.66	0.88	2.94	3.35	2.29	3.05
Apr	2.34	2.37	2.64	3.76	1.56	3.98
May	2.55	5.18	4.05	2.91	1.38	5.33
Jun	11.22	7.05	4.03	3.74	6.43	4.8
Jul	6.82	5.48	6.18	1.29	2.39	1.28
Aug	2.54	4.1	6.04	4.32	3.15	1.77
Sep	3.89	2.72	2.99	1.48	1.44	5.03
Oct	4.1	1.8	1.79	2.44	4.75	3.65
Nov	1.65	3.94	2.6	1.54	1.49	1.09
Dec	0.79	5.97	0.78	0.04	2.68	0.64

Figure 1. Average monthly air temperature (°F) and rainfall totals (in) from the weather stations located at the research site. Colored cells indicate a greater than 10% difference from the 30 year average, with green depicting less than and blue depicting greater than 10% difference from the 30 year average.

Objective 1. The impact of N application timing and cover crop inclusion on the distribution of soil NO_3-N, NO_3-N losses through tile drainage, and cash crop N uptake and yield.

General Field Management

Important management dates are presented below (Table 1, 2). The cover crops were inter-seeded at a rate of 45-75 lbs ac^{-1} into the standing crops using a Hagie STS12 modified with an air seeding box in early September. Throughout the study, the daikon radish self-terminated through vegetative desiccation usually in mid-to-late December following several days of subfreezing weather conditions. The cereal rye, however, is a winter hardy species that was chemically terminated at least two weeks before the anticipated planting of the cash crop.

Field Activities	Corn Years 2014	2015	2017	2019
Tile Installation	Apr-18	-	-	-
Cover Crop Plant Sampling	-	Apr-14	Apr-12	Apr-22
Cover Crop Termination	-	Apr-16	Apr-12	Apr-24
Soil Sampling (0-80 cm)	-	Apr-16	Apr-25	-
Preplant Sidedress				May-16
Corn Planting	May-06	Apr-30	Apr-25	May-20
Spring Sidedress with AA		Jun-04	May-31	Jun-14
V6 Corn Plant Sampling	Jun-12	Jun-09	Jun-15	Jun-27
V12 Corn Plant Sampling	Jul-02	Jul-06	Jul-06	-
VT Corn Plant Sampling	-	Jul-14	Jul-13	Jul-19
Cover Crop Planting	Sep-04	Sep-05	Sep-15	Sep-25
Corn Grain Harvest	Oct-11	Sep-23	Oct-09	Oct-09
Soil Sampling (0-80 cm)	Oct-25	Oct-22	Nov-01	-
Cover Crop Biomass Sampling	Nov-13	Nov-25	Nov-14	
Fall Anhydrous Application	Dec-04	-	-	

Table 1. Field activities for corn years at NMRFS.

Field Activities	Soybean 2016	Soybean 2018
Cover Crop Plant Sampling	Apr-14	Apr-20
Cover Crop Termination	Apr-16	Apr-25
Soil Sampling (0-80 cm)	Apr-19	May-02
Soybean Planting	May-14	May-07
V4 Soybean Plant Sampling	Jun-24	Jun-25
R2 Soybean Plant Sampling	Jul-28	Jul-30
R4 Soybean Plant Sampling	Aug-08	
R6 Soybean Plant Sampling		Sep-10
R8 Soybean Plant Sampling	Sep-20	Sep-20
Cover Crop Planting	Sep-15	Sep-06
Soybean Harvest	Oct-21	Sep-28
Soil Sampling (0-80 cm)	Nov-01	
Cover Crop Biomass Sampling	Nov-20	Oct-30
Fall Anhydrous Application	Nov-21	-

Table 2. Field activities for soybean years at NMRFS.

Cover Crop Biomass and N Uptake

Over the course of this study, we determined that N application timing did not significantly affect cover crop biomass or N uptake. For this reason, results and discussion regarding cover crop growth will use averages across N application timing, unless otherwise stated. Above-ground biomass cover crop samples were collected in the fall before the daikon radish was winter terminated and in the spring before the chemical termination of the cereal rye. The graphs below represent the spring above ground biomass of the cereal rye. As shown in the Figure 2 below, cover crop biomass ranged from about 445 lbs ac^{-1} to 1,780 lbs ac^{-1} over the course of this study. This was largely due to weather conditions experienced during the cover crop growing season. In the fall of 2016 and spring of 2017, we experienced warmer than average air temperatures and this resulted in our largest cover crop biomass recorded over the course of the study. In contrast, in the spring of 2018, we experienced below average air temperatures, which resulted in the lowest spring biomass relative to the other years of the study. The variation of cover crop biomass and N uptake allowed us to evaluate the tile water quality and agronomic impact of a cereal rye dominant cover crop mixture under a range of performance levels.

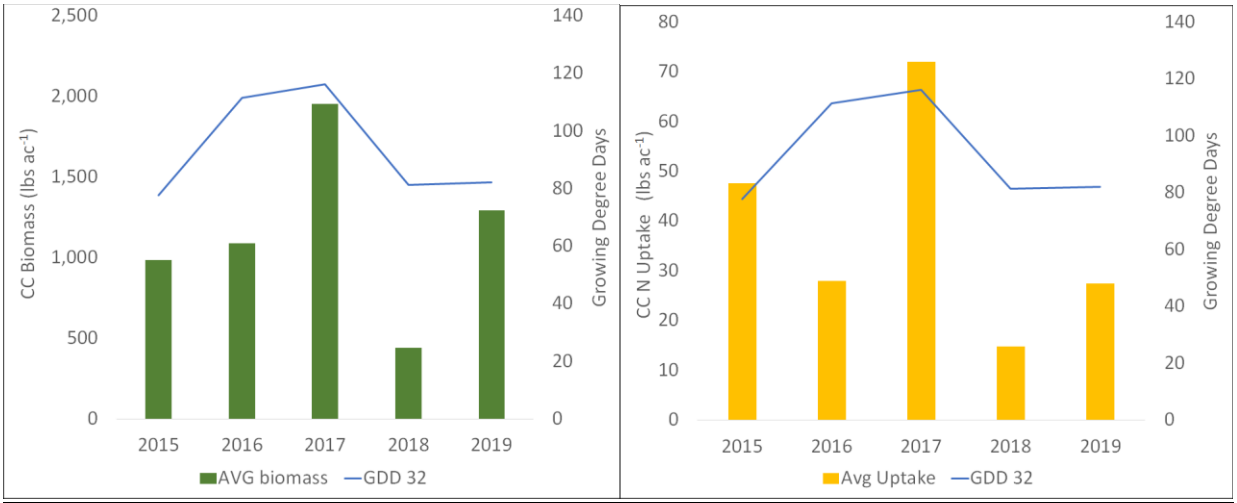

Figure 2. Average above-ground spring cover crop (CC) biomass (left) and N uptake (right) for each year. The odd number years precede a soybean cash crop and the even numbered years precede a corn cash crop. The blue line represents the number of growing degree days (GDD) during the cover crop growing season with a base temp of 32°F.

Soil Nitrate Distribution

This study indicates that cover crops have the potential to significantly reduce the amount of soil NO_3-N within the soil profile through growth from mid-Sept. to chemical termination of cereal rye in the spring. Furthermore, cereal rye reduced soil NO_3-N levels to less than those in a zero control, where no fertilizer N was applied. This reduction in soil NO_3-N can be attributed to the ability of the cover crops to absorb residual, mineralized, and fall applied N, reducing its vulnerability to leaching and denitrification.

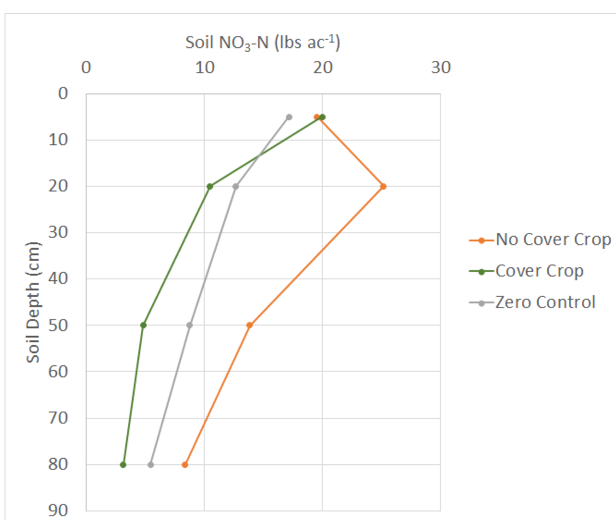

Figure 3. The shows the 5-year average distribution of soil NO_3-N in the spring over the course of the study

Water Quality - Soil NO_3-N Losses via Tile Drainage

In the Upper Mississippi River Basin, a consistent emphasis has been placed on transitioning fall-applied N to the spring as pre-plant or side-dress applications closer to the timing of peak N demand of corn to reduce the susceptibility of N loss from agricultural fields (4R N management). In our study, transitioning from fall applied N to the spring applied N did not result in a reduction in the flow-weighted NO_3-N and a 10% increase in NO_3-N load over a four period. Specifically in our study, when considering NO_3-N load, we observed 66% greater NO_3-N load for the spring applied N management system compared to the fall applied N management system during the soybean year. It is possible that transitioning N timing from fall to spring may reduce NO_3-N losses during the corn growing season; however, in the subsequent fallow period and soybean growing season there is potential for increased losses of residual NO_3-N. Additionally, this could be attributed to high mineralization of NO^3-N from 3.5% organic matter soil.

This study has shown that cover crops have the potential to significantly decrease the nutrient load of subsurface drainage systems from agricultural fields in both spring and fall N management systems. A 31-63% reduction in flow-weighted NO_3-N concentration was observed despite N application timing. A major contributing factor of the NO_3-N reduction can be attributed to the ability of the cover crops to sequester residual, mineralized, and fall applied N, reducing its vulnerability to leaching and denitrification.

The “Legacy N” concept must be considered in future conversations on N loss reduction. Results from this study have shown that even when no N fertilizer was applied, we lost an equal or greater mass of NO_3-N via tile drainage, relative to the N fertilized plots. Furthermore, when considering the flow-weighted NO_3-N concentration of tile drainage water, the non-fertilized zero control was similar to the fertilized treatment. This sustained level of N loss from the non-fertilized treatment could be contributed to legacy N, which is influenced by long-term soil management and the inherent soil organic matter content and factors that affect soil N mineralization. The continuous loss of Legacy N renders 4R nitrogen management less effective in N loss reduction, relative to a cereal rye cover crop that scavenges fertilizer and soil derived N and slowly releases it to the soil solution.

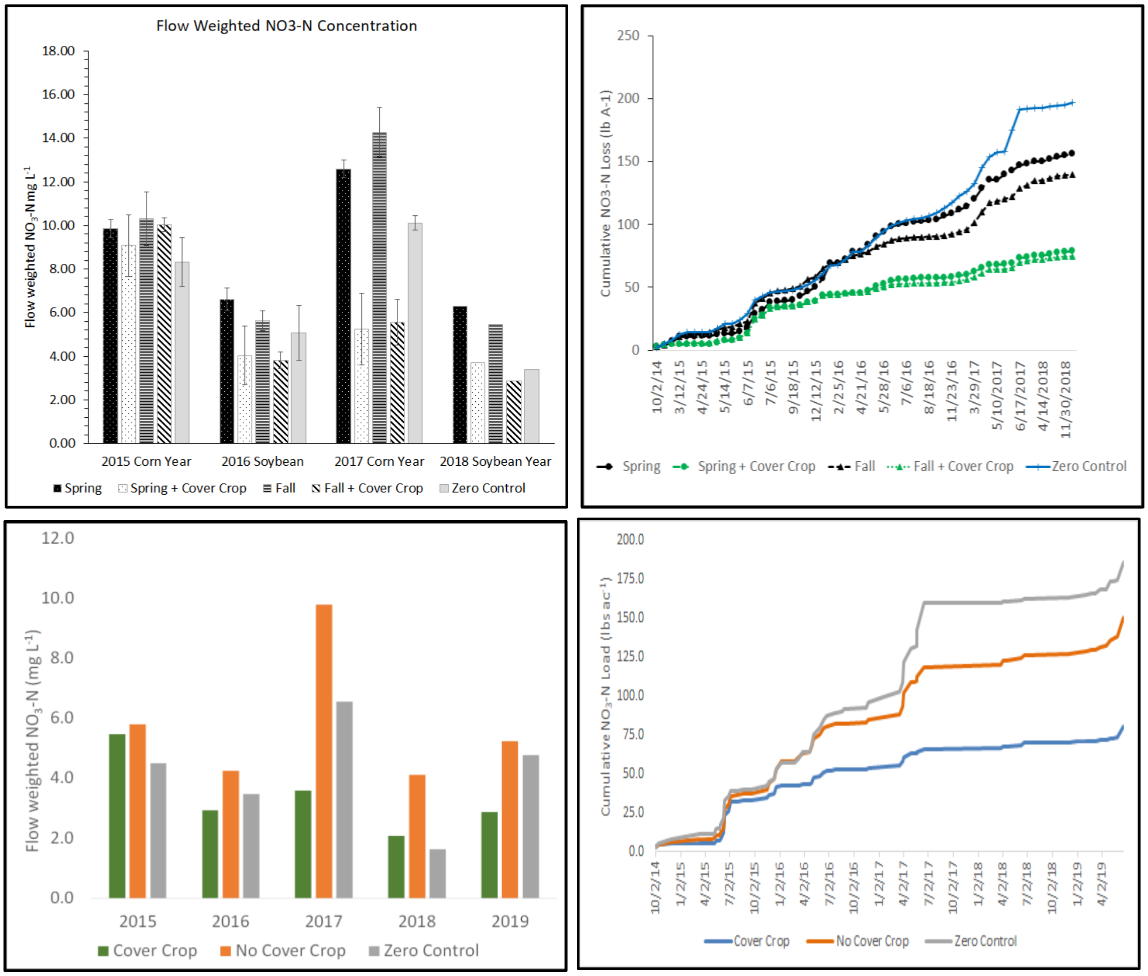

Figure 4. (top left) flow weighted NO_3-N concentration by treatment (top-right) cumulative NO_3-N load over the first 4 years of the study by treatment (bottom-left) average flow weighted nitrate-N concentration for each year (bottom-right) cumulative NO_3-N load over the course of the study.

Cash Crop Impact - N uptake and yield

This study has shown a risk to corn production with a cereal rye cover crop preceding corn crop resulting in a 18-25% decrease in corn yields in two of the three corn seasons (Figure 5). We see evidence that cereal rye reduces soil inorganic N concentrations before cover crop planting. Thus. reducing the availability of soil N to the following corn crop, resulting in a decrease in the corn crop above ground biomass and N uptake (Figure 6). The reduction in biomass and N uptake occurs around the V12-VT corn growth stages, with the deficit increasing as the corn plant matures. It is possible that growers could use cover crop indicators such as: growing degree days, biomass accumulation, and N uptake to predict the need for adaptive fertilizer N management practices to compensate for the soil N scavenged by the cereal rye cover crop.

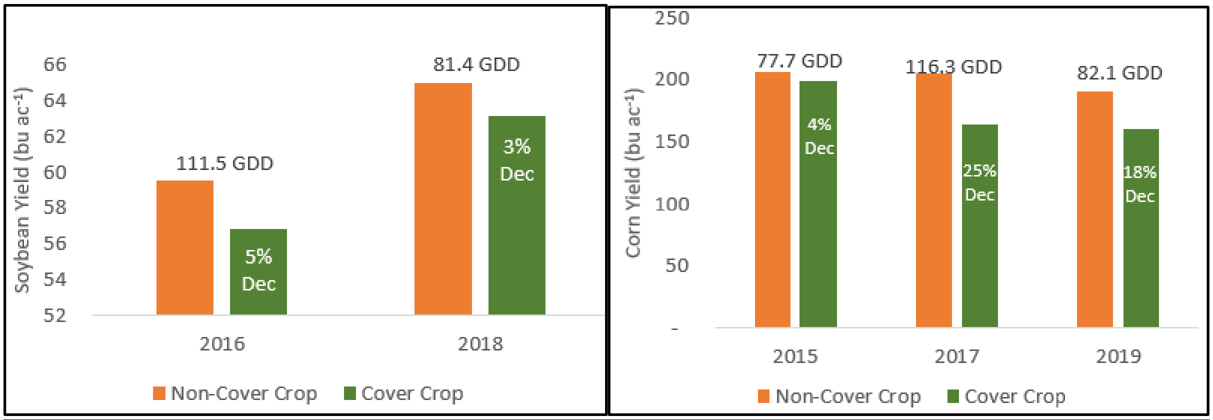

Figure 5. Average corn and soybean yield over the course of the study. The growing degree days presented represent cover crop season preceding the cash crop with a base temperature of 32°F

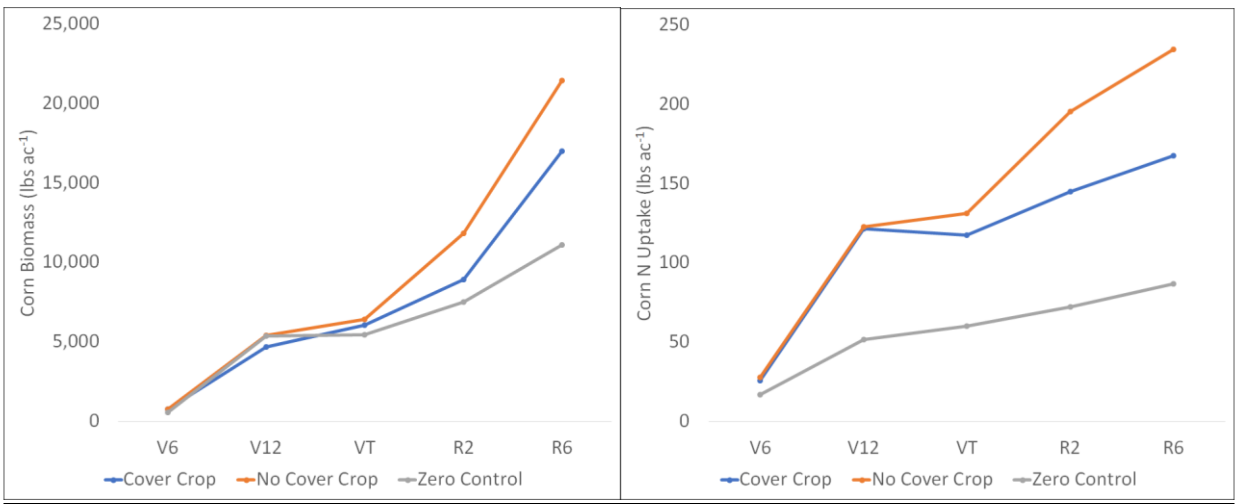

Figure 6. Average dry weight biomass (left) and N uptake (right) of corn cash crop at critical growth stages averaged across three growing seasons (2015, 2017, and 2019)

Objective 2. The impact of cover crops on N_2O emissions

Equipment for air sampling was installed as weather allowed in the spring before cash crops were planted, and air samples were collected weekly early in the season then biweekly later in the season as the rate of N_2O emissions decreased. Soil N_2O emissions were measured using nonsteady-state vented closed chambers and cumulative N_2O fluxes were calculated by linear interpolation between sampling events. Periods of elevated N_2O emissions coincided with high daily rainfall events, though large variability was observed. Total N_2O emissions in 2018 were 5x greater than emissions in 2017, on average. In cover crop treatments the majority of these emissions occurred in June - July 2018, which had 3.8 more inches of rainfall than June-July 2017. This also coincides closely with the timing of peak cover crop related microbial activity and decomposition. It is likely that increased emissions is related to increased mineralization and denitrification, which are sensitive to precipitation and residue moisture. N_2O emission data from 2019 will be added to future reports.

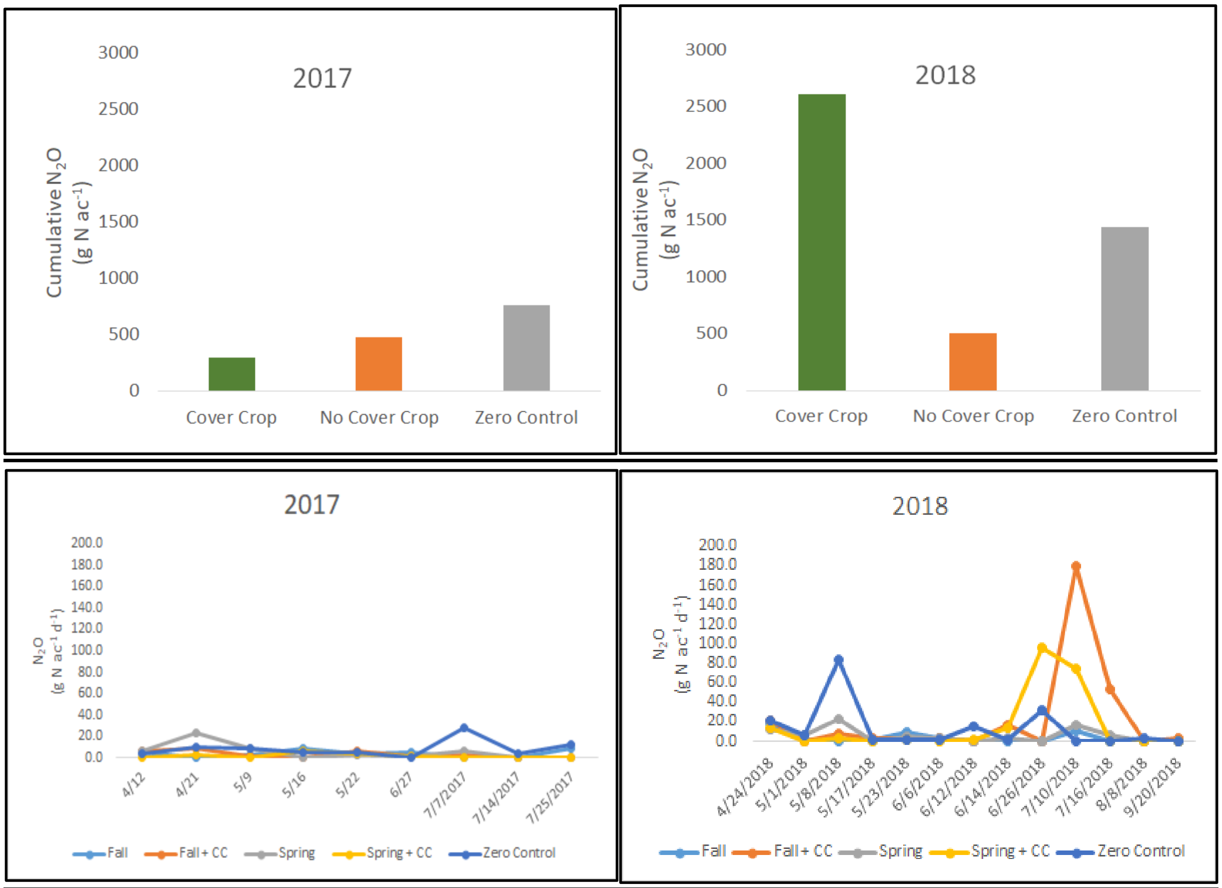

Figure 7. Cumulative N2O fluxes (g N ac^{-1}) calculated by linear interpolation between sampling events for 2017 (top-left) and 2018 (top-right). Daily soil N_2O fluxes (g N_2O/ac per day) for 2017 (bottom-left) and 2018 (bottom-right)

Objective 3 - Utilize ^{15}N methods to identify whether cover crops primarily take up soil or fertilizer N.
Objective 4 - Determine the impact of cover crops on the fate and availability of fall and spring applied fertilizer N using ^{15}N methodology.

Key Points

Cereal Rye interaction with Fall and Spring applied N

- Fall applied N fertilizer increases cereal rye growth in the spring compared to cereal rye that did not receive fall N. This increased growth results in the assimilation of 16-34% of fall applied N into cereal rye by spring.
- When N is applied in the fall, up to 46% of cover crop N is from fertilizer and the remainder is soil derived. In contrast, when N is applied in the spring 23% of cover crop N is from fertilizer and the remainder is soil derived.

Nitrogen Application Timing and Cover Crop Effect on Corn N Recovery

- Combined fertilizer N recovery at harvest within the corn plant and topsoil (1-foot) ranged from 39.9 - 49.4% and 47.2 - 71.3% for the fall and spring applied N, respectively.
- Combined fertilizer N recovery (corn plant + 1-foot of soil) in the cereal rye treatments was lower than those observed in the controls.
- On average 53% of fertilizer N was not recovered in the corn plant or topsoil (1-foot). Unrecovered fertilizer N may have remained in the undecomposed cereal rye biomass pool, corn roots, or have been lost via leaching or denitrification. Future research should focus on future understanding these possible fates of fertilizer N.

Nitrogen Application Timing and Cover Crops Effect on Corn Yield

- Spring versus Fall applied N, into a living cover crop stand, resulted in greater corn N uptake and corn yield.

General Research Design and Management

In 2018 and 2019, 12 micro plots (8.2x 8.2 feet) were established at the Illinois State University farm in Lexington, IL. Micro plots were organized in a complete randomized block design that included two N timing treatments (fall N and spring N) and two cover crop treatments (cereal rye and no cereal rye). Important management dates are presented below (Table 3). Cereal rye was drilled each fall after harvest at a rate of 50 lbs. ac^{-1}. Each year anhydrous ammonia was applied at a rate of 180 lbs N ac^{-1} in the fall and spring. Anhydrous ammonia was applied at a target enrichment of 4% by atom ^{15}N. Check plots were managed the same as enriched micro plots, but did not receive ^{15}N fertilizer, for use in ^{15}N recovery calculations. In the spring, cereal rye was terminated with an application of glyphosate shortly after spring N application occurred. As weather conditions allowed, corn was planted on 30 inch rows at a rate of 32,000 seeds ac^{-1}.

Date	Activity
11/27/2017	Applied fall anhydrous ammonia
4/13/2018	Applied the spring anhydrous ammonia
4/29/2018	Sprayed CC w/ Glyphosate
5/19/2018	Planted the corn
6/26/2018	Plant Sampled (V5)
7/30/2018	Plant Sampled (Vt)
9/18/2019	Plant and Soil sampled (Harvest)
10/24/2018	Planted CR in next years plots
11/21/2018	Applied fall anhydrous ammonia
4/24/2019	Applied the spring anhydrous ammonia
5/17/2019	Sprayed CC w/ Glyphosate
6/3/2019	Planted Corn
7/12/2019	Plant Sampled (V5)
8/9/2019	Plant Sampled (Vt)
10/24/2019	Plant and Soil sampled (Harvest)

Table 3. Field Management Dates for 2018 and 2019.

Objective 3 - Sources of Cover Crop N

Data in this study demonstrated that cereal rye interaction with fertilizer N varies with fertilizer N application timing (Fall or Spring) (Table 4). We observed that fall N application increased cereal rye biomass by an average of 1,277 more lbs ac^{-1} and N uptake by 60 lbs ac^{-1} when compared to spring N treatments. Furthermore, cereal rye following fall N application recovered 21% (38 lbs N ac^{-1}) more fertilizer N then cereal rye in plots where N was applied in the spring. It is important to remember that cereal rye had an average of 165 days to interact with fall applied fertilizer relative to only 20 days to interact with spring applied N. These findings first suggest that CR protects both fall and spring N when applied in a living stand and the degree of interaction increases with greater time between N application into the cover crop and the spring termination date.

N Timing	Biomass (lbs ac-1)	N Uptake (lbs N ac-1	C:N	Fertilzer N Uptake (lbs N ac-1)	Fertilzer N Recovered (%)
2018					
Fall N	1634 (346)	62 (10.8)	11.3 (0.7)	30.2 (13.1)	16.9 (12.7)
Spring N	1173 (222)	40.4 (6.5)	12.5 (0.7)	6.7 (2.7)	3.7 (2.6)
2019					
Fall N	3767 (481)	134 (17.0)	12.5 (0.8)	61.0 (6.8)	34.2 (6.6)
Spring N	1675 (226)	27.4 (3.6)	26.4 (1.8)	8.1 (2.9)	4.5 (2.8)

Table 4. Cereal rye composition in 2018 and 2019. Values in parentheses indicate standard error.

Objective 4-Recovery of Fertilizer N in the Soil and Corn

In this study, despite considerable cereal rye growth, we only observed minimal evidence that cereal rye reduced total corn N uptake or uptake of fertilizer N (Figure 8). In 2019, cereal rye plots slightly reduced total N uptake and fertilizer uptake. In 2019, the effect of cereal rye was only evident when N was applied in the fall. In which case, cereal rye reduced total N uptake by 27% and fertilizer use efficiency by 6.4%, relative to the fall N control without cereal rye. Where cereal rye reduced fertilizer use efficiency, we also observed an 8-17% reduction in corn yields (Figure 10). Therefore, there is a need to further investigate management strategies that may maximize N availability to corn following cover crop termination. Such as, early cover crop termination, starter fertilizer, and N applications at or near corn planting or during grain fill.

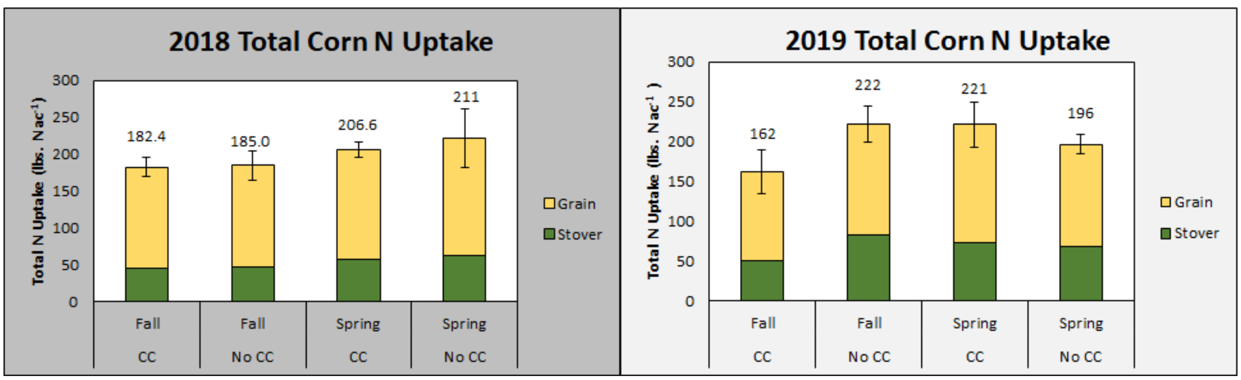

Figure 8. Total Corn N Uptake in 2018 (left) and 2019 (right) at corn harvest. Bars indicate standard error. Values on top of each column are total N uptake for that treatment.

In both years, N application timing influenced the recovery of fertilizer N at harvest (Figure 9). On average, spring N application resulted in 25 lbs ac^{-1} greater fertilizer N uptake when compared to treatments that received N in the fall. This is a 13.8% increase in fertilizer use efficiency. We observed the greatest differences in fertilizer use efficiency (Figure 9) in 2019 when spring N treatment increased fertilizer use efficiency by 20%, compared to fall N application. In 2019, the time period of March - June had precipitation well above the 30-year average (5.5 more inches of rainfall then the same period in 2018). It is likely that precipitation resulted in greater losses of fall applied N, relative to the spring applied N before corn planting, thus reducing recovery in the corn.

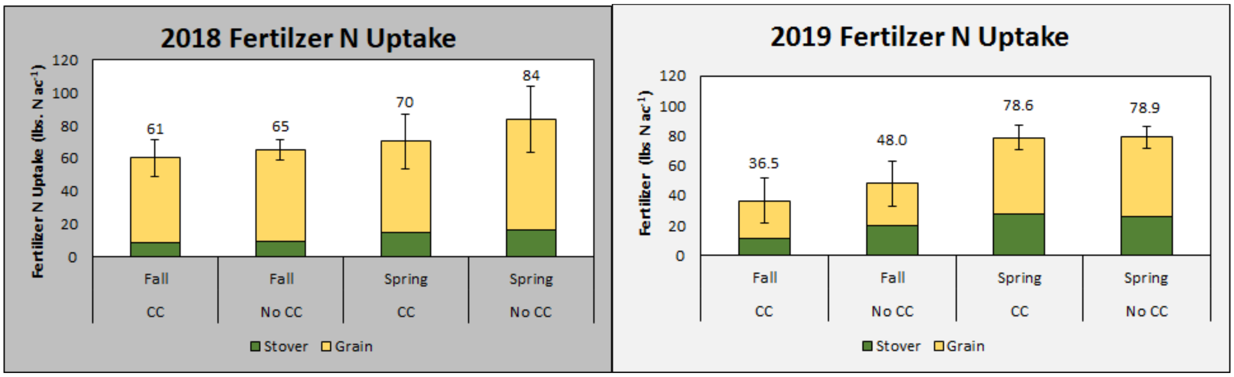

Figure 9. Fertilizer N uptake in 2018 (left) and 2019 (right) at corn harvest. Bars indicate standard error. Values on top of each column are total fertilizer N Uptake for that treatment.

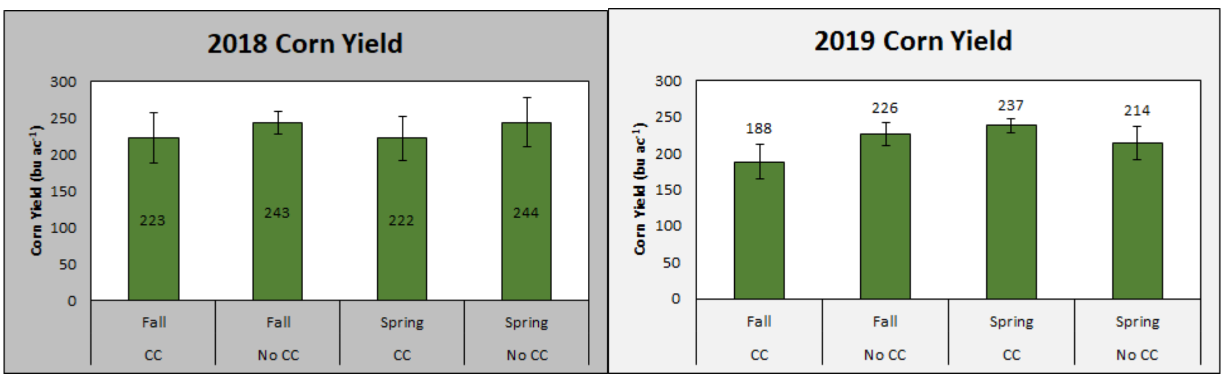

Figure 10. Fertilizer N uptake in 2018 (left) and 2019 (right) at corn harvest. Bars indicate standard error. Values on top of each column are total fertilizer N Uptake for that treatment. Corn yield measurements are based on hand harvest from micro plots.

Fertilizer N Recovery in the Soil

Anhydrous ammonia N was banded into the soil at a depth of 7-8 inches during each fertilizer N application. As the season progresses, it is assumed that the band disperses in the soil towards the location where corn was planted. Data from this study demonstrated that the anhydrous ammonia band is still clearly evident in both 2018 and 2019 in some treatments (Figure 11). When N was fall applied, cereal rye reduced the dispersion of fertilizer N relative to the control treatment. As a result, a strong anhydrous ammonia band (Figure 11, 0 Inches) was evident in both years of the study.

Fertilizer N recovery in the soil was greatest in 2019, with an average of 16.7% and 24.7% of fall N and spring N, respectively, recovered within the top 1-foot of soil. In contrast only 13.5% and 12.6% of fall N and spring N, respectively, were recovered in 2018. In both years, the greatest total fertilizer N recovery was in the spring N treatment without cereal rye (Figure 12). In contrast, fall N treatment with cereal rye had the lowest total N recovery in both years. We know from other research presented in this report that cereal rye reduces N leaching and loss via tile drainage in both fall and spring N systems by assimilating N into its biomass. It is possible that a considerable portion of fall applied N fertilizer remains in the cereal rye residue, and was not recovered in this study.

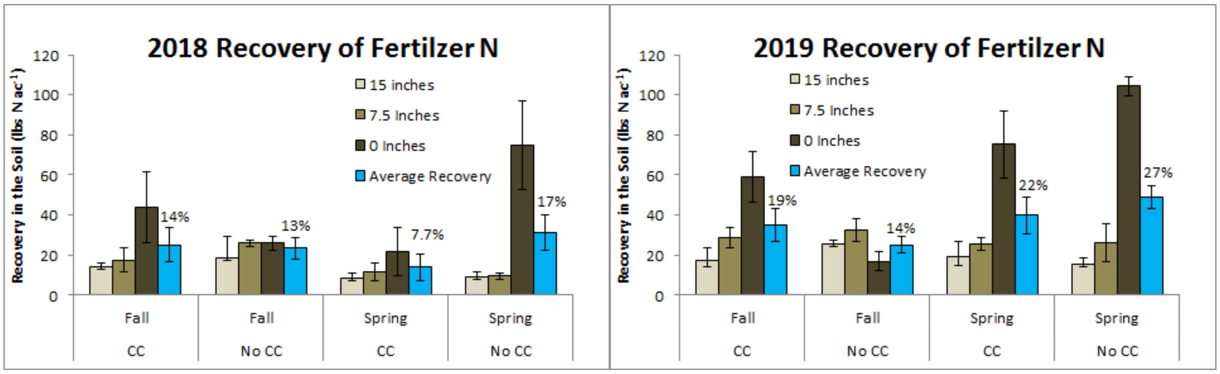

Figure 11. Recovery of fertilizer N in the soil with distance from the anhydrous ammonia band at harvest in 2018 (left) and 2019 (right). Bars indicate standard error. Blue columns represent average recovery in lbs. Ac^{-1}. The values in parenthesis is the average percent fertilizer N that was recovered in the soil for each treatment.

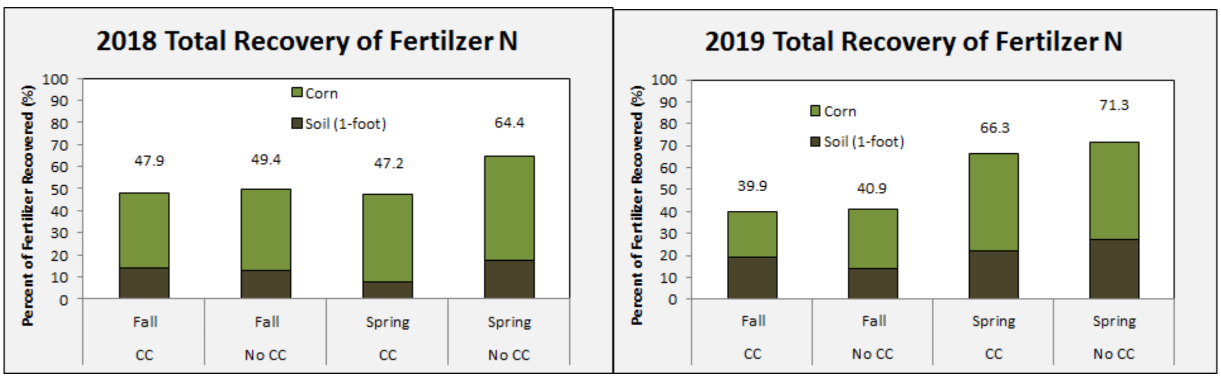

Figure 12. Total recovery of fertilizer N in the soil and corn at harvest in 2018 (left) and 2019 (right). Bars indicate standard error. Blue columns represent average recovery in lbs. ac^{-1}.

Objective 5 - Data Utilize ^{15}N methods to determine the synchrony of the timing and quantity of cover crop residue N release and corn and soybean N demand.

Key Points

- Cereal rye N has the potential to contribute approximately10% of cereal rye residue N to the following cash crop. However, depending on the weather conditions, crop utilization can range from 1.5-10.1% by crop maturity. The recovery of cereal rye N also varies with soil type (drainage class) and precipitation that drives residue moisture and decomposition. Ultimately, our study suggests that cereal rye N is not a meaningful source of N for the immediately following crop so then should be planted prior to soybean to reduce negative experiences.
- Depending on timing and weather conditions 1.8 - 55% of cereal rye N can be found in the1-foot soil depth.

General Research Design and Management

In 2018 and 2019, 12 micro plots (8.2x 8.2 feet) were established at the Illinois State University farm in Lexington, Il. Micro plots were organized in a complete randomized block design that included two cash crop treatments (corn and soybean) following spring terminated cereal rye. Important management dates are presented below in Table 5. Cereal rye was drilled each fall after harvest at a rate of 50 lbs. ac^{-1}. To create labeled cereal rye biomass, nursery plots near to the micro-plots were created that received 3 applications of enriched ammonium chloride in the spring. In the spring cereal rye was terminated with an application of glyphosate, and cereal rye shoot residue was removed from microplot and replaced with labeled cereal rye residue from nursery plots. Cereal rye was allowed to decompose in micro plots and tracked during the following growing season.

Important Management Dates			
2018		2019	
Date	**Activity**	**Date**	**Activity**
3/27/2018	1st Round of NH4Cl nursery plots	4/2/2019	1st Round of NH4Cl nursery plots
4/10/2018	2nd Round of NH4Cl nursery plots	4/9/2019	2nd Round of NH4Cl nursery plots
4/19/2018	3rd Round of NH4Cl nursery plots	4/16/2019	3rd Round of NH4Cl nursery plots
4/29/2018	Sprayed CC w/ Glyphosate	4/24/2019	Sprayed CC in Corn Residue w/ Glyphosate
4/30/2018	Harvested the nursery and the micro plots	5/3/2019	Applied unlabeled and labeled cc biomass from the nursery to the corn residue micro plots.
5/2/2018	Applied unlabeled and labeled cc biomass from the nursery to the micro plots.	5/17/2019	Sprayed CC in Soybean Residue w/ Glyphosate
5/19/2018	Planted the corn and soybean plots.	5/23/2019	Applied unlabeled and labeled cc biomass from the nursery to the soybean residue micro plots.
5/21/2019	Placed Metal Strips	6/3/2019	Planted Corn
6/26/2018	Plant and Soil Sampled	6/4/2019	planted soybeans
7/30/2018	Plant and soil sampled	6/7/2019	Soil Sampled
9/21/2018	Plant and soil sampled	7/12/2019	Plant and soil sampled
9/21/2018	Harvested Corn Plots	8/9/2019	Plant and soil sampled
9/23/2018	Planted CR in the Corn residue plots	10/24/2019	Plant and soil sampled
10/22/2018	Harvested Soybean Plots		
10/24/2018	Planted CR in the Soybean Residue		

Table 5. Field Management dates for 2018 and 2019.

Results

Recovery of Cereal Rye N in Corn and Soybean.

Across both years, an average of 6.4% of cereal rye N recovered in the cash crop by harvest and the range of recovery was 1.5 - 10.1% (Figure 13). In 2018, cereal rye biomass in the micro plots was on average 1,265 lbs ac^{-1} had with an average N uptake of 36 lbs N ac^{-1}, and C: ratio of 14. In 2018, we saw the greatest rate of cereal rye N uptake during the period of vegetative growth (V6 - Vt) in both corn and soybean. At maturity corn had taken up 10.1% of cereal rye residue N that was applied (3.6 lbs N ac^{-1}) and soybean had assimilated 7.3% (2.6 lbs N ac^{-1} (Figure 14) . In contrast, the average cereal rye biomass in 2019 was 2,770 lbs ac^{-1}, had an average N uptake of 45 lbs N ac^{-1}, and a C:N ratio of 22. In 2019, at maturity corn had only taken up 6.6% (3 lbs N ac^{-1}) of cereal rye N applied to the micro plots and soybean only 1.5% (0.7 lbs N ac^{-1}). It is likely that a higher cereal rye residue C:N ratio reduced the rate of cereal rye decomposition and resulted in less recovery in the following cash crop. It is also likely that wet spring conditions, discussed above, also slowed decomposition and potentially increased the loss of cereal rye N via denitrification and leaching.

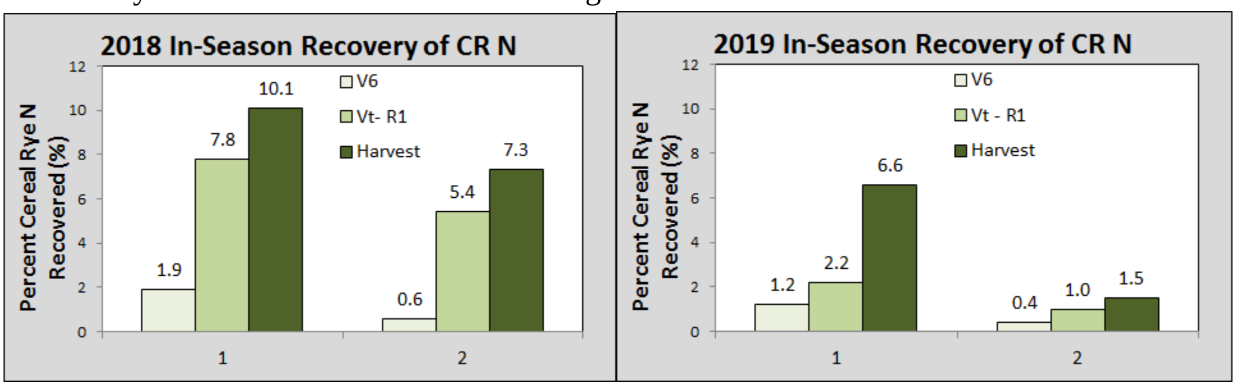

Figure 13. Recovery of cereal rye N as a percentage of cereal rye N applied in 2018 (left) and 2019 (right).

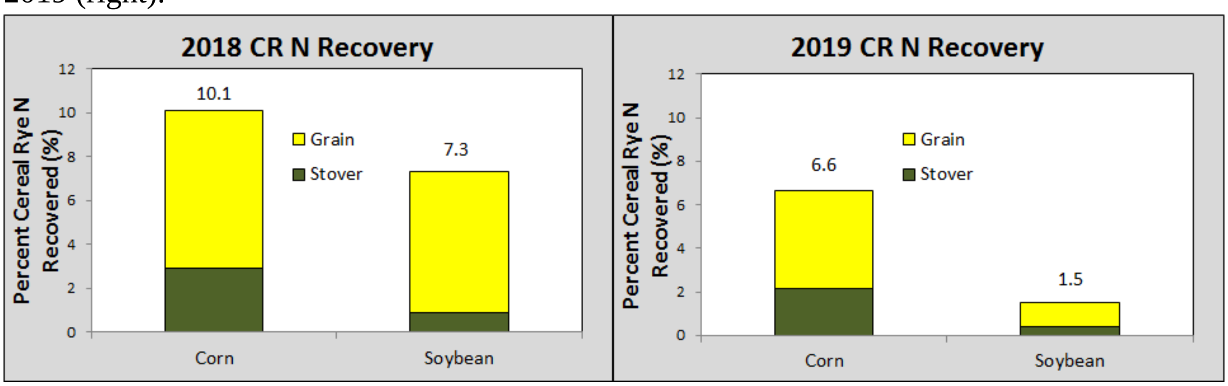

Figure 14. Recovery cereal rye N as a percentage of cereal rye N applied in 2018 (left) and 2019 (right) at harvest in grain and stover.

Recovery of Cereal Rye N in the Soil

In 2018, cereal rye N recovery in the top 1-foot of soil increased from 0 at termination 39.9% as the second soil sampling date, then dropped to 16.2% by the third sampling date (Figure 15). The drop off in cereal rye N recovery in the soil coincides with the point of peak N uptake in the corn and soybean plants (V6- R1). It is possible that the timing of this decrease in both the corn and soybean plots is partially a reflection of the competition for cereal rye N between the soil microbes in the cash crop. From the 3rd to 4th sampling date the amount of cereal rye N in the soil again rises to peak at 36.8% at harvest. During the entire 2018 season there is a greater recovery of cereal rye N in the soil of soybean plots relative to corn plots. This is likely due to less N uptake from the soil in soybean plants during the season. This is reflected in the soybean cereal rye N uptake (Figure 15). In contrast to 2018, we observed very low recoveries of cereal rye N in the soil in 2019. Cereal rye N in the soil was constant from planting until harvest, ranging from 1.8 - 17.8%. Lower recoveries were expected in 2019 due to heavy spring rains, which had the potential to drive losses of cereal rye N via denitrification and leaching.

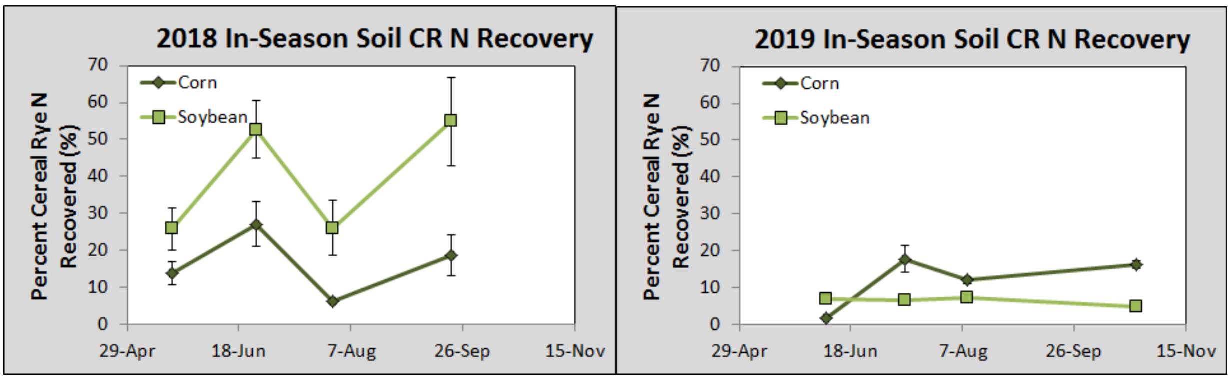

Figure 15. Recovery cereal rye N as a percentage of cereal rye N applied in 2018 (left) and 2019 (right) in the top 1-foot of the soil surface.

VI. Publications, Outreach, and Education Activities

Published and submitted manuscripts this NREC funded project:

Thompson, N.M., Armstrong, S.D., Roth, R.T., Ruffatti, M.D., and Reeling, C.J. Direct Short-Run Economic Returns to a Predominantly Cereal Rye Cover Crop Mix in a Traditional Midwest Corn-Soybean Rotation. Agronomy Journal. doi: 10.2134/agronj2019.07.0513

Roth. R., M.D. Ruffatti, P.D. O'Rourke, S.D. Armstrong. 2017. A cost analysis approach to evaluating cover crop environmental and nitrogen cycling benefits: A central Illinois on-farm case study. Agricultural Systems, DOI:10.1016/J.agsy.2017.10.007

Armstrong, S.D., R. Roth, and C. Lacey. 2017. Do Conventional Comparative Cost Efficiency Analyses Adequately Value Nitrogen Loss reduction best management practices? Agriculture Research & Technology, DOI: 10.19080/ARTOAJ.2017.12.555861

Ruffatti, M.D., Roth, R.T., Lacey, C.G. and Armstrong, S.D., 2019. Impacts of nitrogen application timing and cover crop inclusion on subsurface drainage water quality. Agricultural Water Management, 211, pp.81-88.

Outreach and Education Activities

- Livingston County Farm Bureau Agronomy Day Pontiac, IL
- Hamilton County Soil and Water Conservation District Pesticide Applicator and CCA Training Noblesville, IN
- Universities Council on Water Resources Annual Conference Snowbird, Utah