Effects of Cover Crop combinations and Fertilizer Application Timing on Nitrogen Leaching

Final Report for GNC12-160

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Project Information

Summary:

This project is designed to evaluate the economic and environmental benefits to farmers of using cover crops in Central Illinois and the North Central Region. Cover crops have the potential to reduce nitrate leaching from row-crop, tile drained fields common in the region. Cover crop use may allow farmers to reduce nitrate fertilizer applications adding to the profitability of Central Illinois farms. Tile-drained fields in the region have been linked to nitrate pollution in surface waters. Cover crop use may also prevent this pollution improving drinking water quality and making farming more sustainable. The outcomes of this project will be: 1) increased knowledge of cover crop use to Central Illinois farmers, 2) increased adoption of cover crop use by farmers 3) possible reduction of nitrate concentration in surface waters. This project may increase the profitability of farms and reduce the environmental footprint of farming across the North Central Region.

Introduction:

Introduction

Nitrogen (N) pollution from fertilizer continues to be an environmental issue that threatens row crop agriculture in the Upper Mississippi River Basin. Studies have shown that agriculture fields dominated by tile drained row crop management can cause increased nitrate loss via tile water (Baker, 1975) (Gast, 1978)(Jaynes, 2001)(Dinnes, 2002)(Smiciklas, 2008). Nitrate loading has impaired drinking water supplies locally in Illinois, making it more expensive to treat and provide safe drinking water to the public. On a national scale, N loading in the Mississippi River has led to the development of a hypoxic zone (dead zone) in the Gulf of Mexico.

Little progress has been made to reduce N loading into the Mississippi River and to the Gulf of Mexico. One study found that over a ten year period (1998-2008) attempts to reduce N flux into the Mississippi river have not significantly reduced N concentrations (Sprague, 2011). In Illinois, best management practices (BMPs) such as grassed water-ways, stream buffers, and strip-till farming have been introduced to reduce nutrient loading in surface runoff. However, these BMPs were found to be ineffective at reducing nitrate concentrations in surface water (Lemke, 2011). The authors of this study concluded that tile drainage provided a pathway nitrate to bypass surface BMPs and flow directly to waterways. Nitrate leaching to tile water is a non-point source problem. Fall applied N (common in Central Illinois) has been shown to leach below the root zone of corn (Hubbard, 1991), where it becomes susceptible to leaching into tile water. Planting of cover crops offers a non-point source solution, to this non-point source problem. Cover crop roots can intercept fall applied N that otherwise would percolate below the root zone of corn (Dean, 2009). In the Northeast, forage radish has been shown to reduce nitrate leaching deep in the soil profile. In theory, cover crop mixtures including forage radish should reduce the amount of nitrate in tile water and escape into the environment.

The original intent of this project was to evaluate the impact of cover crops and N fertilizer timing on the efficiency of N management in Central Illinois fields. The original treatments involved multiple cover crop treatments that received nitrogen in the fall and spring. The treatments included Figure 1):

· Fall Applied Anhydrous – No Cover Crop · Fall Applied Anhydrous – Tillage Radish/ Cereal Rye · Fall Applied Anhydrous – Cereal Rye · Fall Applied Anhydrous – Tillage Radish/ Oats · Fall Applied Anhydrous – Tillage Radish · Fall Applied Anhydrous – Cereal Rye/Tillage Radish/ Crimson Clover · No Cover Crop/ No Nitrogen	· Spring Applied Anhydrous – No Cover Crop · Spring Applied Anhydrous – Tillage Radish/ Cereal Rye · Spring Applied Anhydrous – Cereal Rye · Spring Applied Anhydrous – Tillage Radish/ Oats · Spring Applied Anhydrous – Tillage Radish · Spring Applied Anhydrous – Cereal Rye/Tillage Radish/ Crimson Clover · No Cover Crop/ No Nitrogen

NOTE: In 2013, the project reported failed cover crop establishment in the projects first year. Cover crops failed to establish again in the projects second year, despite attempts to modify our cover crop planting methods as described in the 2013 Annual report. As a result cover crop impact was not evaluated as part of this study. Therefore, the objectives of the project were adjusted and augmented to focus on the nitrogen timing aspect of the project.

<u>Adjusted Objectives</u>

Objective 1: Compare the impact of fall and Spring N applications across multiple rates on the distribution of soil Inorganic N within the soil profile.

Objective 2: Investigate the impact of N timing and rate on Corn N uptake and grain production in Central Illinois.

Objective 3: Evaluate nitrogen rates and timing for corn production in Central Illinois across multiple on-farm trials.

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Project Objectives:

Objectives and Performance Targets

- Objective 1: Compare the impact of fall and Spring N applications across multiple rates on the distribution of soil Inorganic N within the soil profile.
  - Nitrogen application resulted in greater soil inorganic N compared to plots that did not receive N fertilizer. Fall applied N resulted in greater inorganic N in the spring immediately before corn planting, compared to spring N. In contrast, Spring N application resulted in greater inorganic N in the Fall after harvest. With both N timings, there is risk of N loss to the environment. Therefore, there is a need for Midwest farmers to consider N conservation practices when applying N in either the fall or spring.

- Objective 2: Investigate the impact of N timing and rate on Corn N uptake and grain production in Central Illinois.
  - N timing did not have an impact on Corn production. However, at the

highest N rate fall applied N resulted in a greater corn N concentration at harvest then spring applied N. Rate of N application did have an impact on Yield. However, the benefit of increasing N rate was not significant after 168 kg N ha-1.

- Objective 3: Evaluate nitrogen rates and timing for corn production in Central Illinois across multiple on-farm trials.
  - On farm trials indicated that nitrogen rate had a greater influence on grain yield then nitrogen timing. However, the optimum N rate varied greatly between experiment sites. This indicates that need for farmers to establish field specific N rates based on local soil conditions.

Cooperators

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Research

Materials and methods:

Materials and Methods

The experimental site of objectives 1 and 2 was located at the Illinois State University Farm Lexington, Illinois. The dominant soil within the experimental field is the Drummer silty clay loam soil series. The Drummer series is poorly drained and requires tile drainage, and is typical of soil in Central Illinois and the North Central Region. In fall 2012, cover crop seeds were broadcast into standing soybean using a PTO mounted broadcast spreader following defoliation of soybean plants. We observed that the presence of soybean leaves on the ground may have prevented good seed to soil contact and negatively impacted cover crop establishment. In fall 2013, cover crop seeds were planted into standing corn using a modified sprayer and drop air seeder (image 1). In 2012 we noted that the crop canopy shaded out the cover crops and may have hampered establishment. However, aerial application of cover crop seed is a common method to plant cover crops in the Midwest with successful cover crop establishment across the region. It is, perhaps more likely that dry fall conditions prevented cover crop growth. It has been established that for aerial/broadcast application to be successful, seeding must be followed by a significant rainfall event to promote growth. This did not occur near cover crop seeding in either 2012 or 2013.

Research plots received anhydrous ammonia with nitrapyrin at rates of 0, 56, 112, 168, and 224 kg ha-1 in either the fall (November 2012) or spring (June 2013). Fall anhydrous was after harvest and spring anhydrous was side-dressed into corn at the V4 growth stage. Soil samples were taken from each plot to a depth of 80 inches in the spring before corn planting and in the fall after harvest. Plant samples were collected at V6 (after spring N application), VT and R6 and were analyzed for percent N. This was used to establish the impact of timing and rate on corn N uptake. Soil inorganic N analysis was determined by selective membrane diffusion (TL-2800 Ammonia Analyzer, Timberline Instruments) and the plant tissue analysis was accomplished by dry combustion (Rapid N analyzer, Elementar Americas, Mt. Laurel, NJ).

To achieve Objective 3, several research sites were established, where we examined the optimum N rates and timing across Central and East Central Illinois. On farm experiments were established in Perdueville, Dewey, Pesotum, Bismarck, Clarence, Potomac, and Tolono Illinois. Treatments included fall and spring side dress applications of anhydrous ammonia with nitrapyrin at rates of 0, 56, 112, 168, and 224 kg ha^{-1}. These treatments were arranged in a complete factorial design with three replications. Data collected from each site consisted of only corn gran yield for each treatment.

For Objectives 1 and 2 statistical analyses was conducted on soil inorganic N data, tissue N concentration data, N uptake, and yield using ANOVA as calculated by SAS (SAS I006EStitute, Cary NC). Tukey Multiple Means comparisons were used to compare treatments and a P value of

Research results and discussion:

<u>Results and Discussion</u>

Objective 1: Spring and Fall Soil Inorganic N

At the time spring soil samples were collected only the fall N application had occurred; therefore, spring N soil concentrations will only consist of observations made within fall N treatments. In general, soil nitrate concentrations increased as N application rate increased. Specifically, the greatest N rate treatments resulted in significantly more soil nitrate and soil ammonium at the 20-50cm depths (Figures 2a, b). Increased inorganic N at lower depths from increased rates of fall applied anhydrous is likely the result of nitrate movement to lower depths. This leaching occurred despite the presence of nitrification inhibitors. In fact the data indicates that, in all but the 224 kg N ha^{-1} treatment, nearly all of the fall applied ammonia had already been nitrified several weeks before corn N uptake (Figure 3). Fall N application resulted in greater soil inorganic N compared to zero control treatments. Increased soil inorganic N at the upper depths (0-5 and 5-20cm) in fall application plots compared to other treatments was likely caused by anhydrous ammonia application. These depths correspond directly with the injection region of knifed anhydrous ammonia. Increased soil nitrate at lower depths (20-50 and 50-80cm) in fall application plots relative to spring application and zero control treatments was likely caused by leaching of nitrified anhydrous ammonia applied in the fall.

In the fall of 2013, after corn harvest, spring applied N resulted in a greater concentration of soil nitrate in the soil profile relative to fall applied N (Figure 4). Specifically, spring applied N resulted in significantly more nitrate at the 0-5, 20-50, and 50-80cm depths. Overall, spring applied N significantly increased total inorganic N (TIN) by 48.35 kg ha^{-1} compared to fall applied N. Increased inorganic N from spring applied anhydrous ammonia is likely the result of less time for nitrification and leaching to occur before corn N uptake, relative to fall application. These findings correspond with other research that suggests that spring applied N results in more efficient fertilizer use by corn then fall applied N. However, residual N after harvest is an environmental concern due to risk of loss before N can be used by the following cash crop. Especially when fall are warm and wet for extended periods of time; weather conditions that encourage nitrification and leaching from the soil profile via tile drainage. This indicates that there is a need for Central Illinois farmers and farmers across the Upper Mississippi River Basin to adopt practices that will work to mitigate the loss of spring applied N as well as fall applied N.

Objective 2: Corn N Concentration, N Uptake and Yield

Tissue sampling at multiple growth stages allowed for an evaluation of corn health through the growing season as impacted by N timing and rate. At the V6 growth stage there were no significant differences between N rates in regard to % N. However, fall application N resulted in a significantly greater %N in corn tissue then spring application (Figure 5). Additionally, visual symptoms of N deficiency were present at the V6 growth stage for control and spring applied N treatments. Tissue test results showed that these treatments were below the sufficiency standard of 3.5%, compared to fall applied N treatments that exceeded this critical level. It should be noted that differing information exists about the importance of N stress at this growth stage. Some studies have indicated that stress and N deficiency at V5-V12 can negatively impact yield. However, other studies have demonstrated that under the right conditions the maximum potential corn yield could be obtained when N application was delayed until V11. By V12, there were no significant differences between spring and fall applied N treatments (Figure 6). This indicates that at this point spring N was being used by the corn by this growth stage. However, the 224 kg ha^{-1} rate did result in significantly greater N concentration then the 112 kg ha^{-1} and control treatments. Interestingly, only the control treatments did not meet the N critical levels at V12. This would imply that all N rates from 56 kg ha^{-1} to the 224 kg ha^{-1} resulted in sufficient N for corn growth. At the VT growth stages both timing and rate had a significant impact on N concentration (Figure 7). Spring applied N resulted in significantly greater %N then fall applied N and both timings resulted in greater %N then the control treatments. Additionally, the two greatest N rates resulted in significantly greater than all other rates. By the R6 growth stage only N rate had a significant impact on N concentration; there was no significant difference in N timing (Figure 8). Therefor any impact on N concentration from N timing had been overcome by the time corn was in the reproductive growth stage.

Corn N uptake was measured after plants had black layered and N uptake had ceased in the plant (Figure 9). N rate was the only factor that significantly impacted total N uptake. The two greatest application rates (168 and 224 kg ha^{-1}) resulted in increased N uptake by 120 kg ha^{-1} compared to the control. The 56 and 112 kg ha^{-1} rates also significantly increased N uptake relative to the control. No significance was found between spring and fall N timings in regards to total N uptake. This demonstrates that spring applied N treatments were able to overcome N deficiencies at early growth stages (V6). This observation is supported by that fact that across N timing all treatments (except the control) had sufficient levels of N by

VT. However, fall applied N (224 kg N ha^{-1}) resulted in significantly greater yield then spring applied N (224 kg N ha^{-1}) (Figure 10). It is possible that this difference in yield is explained by N deficiency in spring applied plots prior to V6. As expected, N rate did significantly impact yield. However, there were no significant differences between grain yields at the highest N rates. This observation suggests that there is only a limited benefit of increased N application (in the spring or fall) on corn yield.

Despite the fact that the fall application plots had greater soil inorganic N before corn planting, there were only significant differences in grain yield between spring and fall applied treatments at the highest N rate. Several weeks passed between the soil sampling date and the point at which corn began N uptake. During this time additional inorganic N in fall application plots was susceptible to loss via nitrate leaching and denitrification. It is interesting that, at the greatest N rate, fall application increased corn N concentration at harvest compared to spring applied N treatments. It is an indication that fall applied N, at this rate, was in slightly better condition at harvest then other treatments.

Objective 3: On farm Yield Trials

On farm trial data indicated that N rate had a greater impact on corn yield then N timing (Figure 11). The Perdueville and Dewey locations application rates of 56, 112, 168, and 224 kg ha^{-1} yielded significantly higher than the control. For both locations the dominant soil type for the experimental sight was a Drummer silty clay loam 0-2% slope. Nitrogen rates of 168 and 224 kg ha^{-1} resulted in the significantly greater yield than the control at Pestum and Lexington locations. The dominant soil type for these locations were Flanagan silt loam 0-2% and Drummer silty clay loam 0-2% slope respectively. At Bismarck the 112, 168, and 224 kg ha^{-1} application rates yielded significantly higher than the control. The dominant soil type for this location was Ashkum silty clay loam 0-2% slope. The Clarence experimental site had significantly greater yield at N application rates of112, 168, and 224 kg ha-1 then the control. The dominant soil type for this location was Clarence silty clay loam 0-2% slope. It was observed at the Potomac site that the 168 and 224 kg ha^{-1} rates yielded significantly higher than the control, 56, and 112 kg ha^{-1}, and the 56 and 112 kg ha^{-1} yielded significantly higher than the control rate. The dominant soil type was Ashkum silty clay loam 0-2% slope. At Tolono site had a dominant soil type of Drummer silty clay loam 0-2% and reported that application rates of 168 and 224 kg ha^{-1} yielded significantly higher than the control.

The 168 and 224 kg ha^{-1} treatments were not significantly different across all of the locations. This indicates that the extra 56 kg ha^{-1} of N added with the 224 kg ha-1treatments did not significantly increase yield. We know from other research, that increased N rate results in greater soil inorganic N in the spring and fall. Therefore, increased application rates without increased yield, is an economic and environmental concern to farmers in the Upper Mississippi River Basin. Due too lost profits spent on unused N fertilizer and the increased potential of N fertilizer to escape to the environment.

Soil type seemed to have a large impact on yield response to yield rate. For example, at the 3 sites with a drummer silt loam soil type there were no observed differences in yield between 56 and 224 kg N ha^{-1} treatments. Indicating that at these sites ¼ of the highest N rate was needed to maximize yield. Assuming a $0.50 per pound N source, this is a savings of $84 per ha^{-1}. Furthermore, the control yields for each location with a Drummer soil type was higher than all other locations. The drummer soil type had the greatest %OM and the second greatest CEC and water holding capacity, of all the soil types included in this study. The presence of a large OM pool to mineralize and release N as well as high CEC and water holding capacity contribute to this soil type's ability to produce high yield across multiple N rates. This is an illustration of how variation in soil type across the region (or within a single field/farm) can greatly impact the optimum N rate.

- Appendix A: Figures and Tables

Participation Summary

Educational & Outreach Activities

PARTICIPATION SUMMARY:

Education/outreach description:

Impacts and Contributions/Outcomes

Findings from this research and related project that are part of the Illinois State University Cover Crop Research program have been used a multiple growers meetings across central Illinois. Additionally, they have been published in two master thesis and multiple academic poster presentation and lecture opportunities. In the future data from this research program will be used by Illinois Extension, NRCS, and SWCS for outreach about cover crop cost-share programs. The data will also be presented to trade journals such as Prairie Farmer, Successful Farmer and Corn and Soybean Digest. Research findings will be published on websites of sustainable agriculture research groups such as Sustainable Agriculture Research and Education, and Midwest Cover Crops Council.

Project Outcomes

Project outcomes:

Conclusions

Across all treatments, N application resulted in increased soil inorganic N below the 50cm depth in the soil profile compared to treatments that did not receive N fertilizer. The degree of leaching that occurred was impacted by both application timing and application rate. Fall N applications resulted in a greater concentration of soil inorganic N before corn planting compared to spring N applications. Spring N application increased the amount of soil N present at lower depths compared to fall N application. Across both timings, N rate dramatically influenced the amount soil inorganic N at lower depths after harvest. This residual N is susceptible to loss to the environment via tile drainage. In order to reduce N loss from farms to the environment best management practices, in addition to N application rate and timing should be considered. Cover crops, strip tillage, controlled drainage, bio reactors, and constructed wetlands are just some examples of other N management practices that might help intercept N fertilizer before it escapes to the environment.

Under weather conditions similar to 2013, substantial loss (>50%) of fall applied N can occur. Despite this loss, there was little evidence of a difference in corn yield or N uptake between spring and fall N application treatments. In fact, fall N treatments resulted in greater corn N uptake compared spring N during early growth stages. Access to greater N in fall applied treatments may have resulted increased resilience to stress at later corn growth stages. This is supported by our observation that fall application (at the highest N rate) increased yield compared to spring applied N. This benefit of fall applied N illustrates one consideration Central Illinois and Upper Mississippi River Basin (UMRB) farmers must weigh, against environmental risks, when making decisions about N application timing. Furthermore, establishing an optimum N application rate may have a greater agronomic and economic impact to UMRB farmers. Across the region it is common to apply 224 kg N ha^{-1} (200 lbs. ac^{-1}); our data suggests that this is not always the optimum N rate. In fact, we did not detect a significant difference in grain yield between 224 and 168 kg N ha^{-1} treatments. It should be noted that our results capture the impact of a drought during the previous year. This may have resulted in a greater amount of residual N then would normally occur. However, our finding agrees with the optimum Maximum Return to N (MRTN) for Central Illinois of 157 lbs. N/acre (assuming a $0.50 per pound N source and $4 per bushel corn. Therefore, the optimum N rate for a field may vary greatly across the UMRB and is often influenced by multiple variables including: CEC, Organic Matter, and water holding capacity. Thus it is important for farmers to look at field specific data when making N rate decisions for a particular field. In the future to achieve optimum yield and less nitrate loading more studies are needed to evaluate the efficiency of implementing variable N, seeding rates, and yield goals.

Accomplishments/Milestones

This project has succeeded in creating an advisory group that includes farmers, members from the agriculture industry, government and non-profit organizations to give advice and help promote cover crop research in Central Illinois. Farm members include Jeff Bender a Central Illinois farmer, Steve Groff a cover crop expert and Indiana farmer, Russell Derango Illinois State University Farm Manager. Industry contributors include ProHarvest Seed, United Soils, Inc. and members of the Illinois Council of Best Management Practices and the U.S.D.A Natural Resources Conservation Service. These individuals and groups have come together to give advice and help promote the newly created Illinois State University Cover Crop Research Program founded by Dr. Shalamar Armstrong.

Recommendations:

Areas needing additional study

This study has indicated the need for additional research that will help farmers establish optimum N rates on a sub-field level using field specific information. The ability to accurately predict Optimum N rate across a field and variable apply N (similar to what is commonly done for P and K fertilizer) would allow farmers to spend money only where N fertilizer is needed most. This would likely improve the economic performance of farms across the Upper Mississippi River Basin.

Establishing a better optimum N rate on the field level would also reduce the environmental impact, by placing N fertilizer only where it will be used by the intended cash crop.

Additionally, we observed that even at low N application rate considerable N leaching can occur. This demonstrates the need for research into innovative N conservation practices that will reduce N leaching. Such as: cover crops, strip tillage, controlled drainage, bio reactors, and constructed wetlands and other practices that might help intercept N fertilizer before it escapes to the environment.