A Final Report Prepared for the Leopold Center for Sustainable Agriculture

June 30, 2021

# Integrating Rye Seed Production and Red Clover into Corn Systems and Nitrogen Management

Principal Investigator:
John Sawyer
Emeritus Professor
3208 Agronomy Hall
Iowa State University
Ames, IA 50011
Phone: 515-294-7078
jsawyer@iastate.edu

Co-Principal Investigator:
Antonio Mallarino
Professor
3216 Agronomy Hall
Iowa State University
Ames, IA 50011
Phone: 515-294-6200
apmallar@iastate.edu

Report prepared by John Lundvall (Research Associate), Camila Martins (Graduate Student), and John Sawyer (Emeritus Professor), Iowa State University, Department of Agronomy

## Nontechnical Summary

The focus of this project was to evaluate extended crop rotation and cover cropping system practices that have potential to reduce nitrate losses compared to a typical soybean-corn two-year rotation. The crop rotation was extended by drilling winter cereal rye for grain production after soybean harvest, frost-seeding (inter-seeding) a red clover cover crop prior to rye spring green-up, and planting corn after the clover cover crop. We split-applied six nitrogen (N) rates (at-planting and side-dressed) for cereal rye grain production and for corn to identify optimal agronomic rates. The N contributed by the clover legume cover crop, N amount supplied to corn, and the N fertilization rate reduction was measured in the subsequent corn crop.

Our findings support the proposal to integrate rye grain production with a clover cover crop into a soybean-corn rotation. Fall planted rye and frost-seeded red clover provided a green soil cover with living roots year-round. Clover, being a legume, increased plant-available N for corn, thus reducing the N fertilization requirement. Using the harvested rye seed as a cover crop after corn can provide additional green cover and continuous plant growth both above and below ground. The integrated small grain crop/clover cover crop, within the soybean/corn production system, was shown to positively affect corn N supply, have low residual soil nitrate, and afford a third cash crop alternative for Iowa farmers.

## Introduction

The corn-soybean rotation dominates land use in Iowa and the Upper Midwest. Unfortunately, the corn-soybean rotation reduces overall crop diversity and increases pest pressure. Intense, widespread use of two annual crops requires extensive N fertilizer use and results in increased risk for environmental impacts such as elevated nitrate-N loads in surface and ground water systems.

Nitrate from soil and applied fertilizer escapes farm fields by leaching through the soil profile to tile drainage or subsurface recharge to surface waters. Water leaving farm fields can reach groundwater sources used for drinking water and surface water bodies that feed the Mississippi River. High amounts of nitrate travel downstream in the Mississippi River and are deposited in the Gulf of Mexico, where they feed algal blooms with potential to create oxygen-deficient hypoxic zones.

To improve the quality of water leaving Iowa farm fields, the Iowa Nutrient Reduction Strategy (INRS) has a goal to reduce the annual nitrate-N load from farmland and other non-point sources by 41 percent. A key component of attaining that goal is improved nutrient management of thousands of individual farm fields comprising millions of crop acres across Iowa. Multiple cropping practices can be implemented to attain the goal of reducing nitrate-N losses. The Science Assessment for the Iowa Nutrient Reduction Strategy identified several practices that could reduce nitrate loss (SP 0435A). Three in-field practices with potential to have a major impact are use of cover crops, optimizing N application rates, and use of extended crop rotations. Of the three, extended rotation has the largest effect (42%), with rye cover crops next most beneficial (31%), and N rate to corn the least (10%, with the effect dependent on comparison to baseline N rate because as N rate increases nitrate-N concentration accelerates). These practices have potential to improve sustainability of agricultural production, increase soil health and productivity, increase crop grain yield while reducing negative effects on the environment, and providing economic profitability to farmers.

Farmers need viable crop production systems for economic profitability. The easiest transition regarding in-field practices to improve water quality, and most economically profitable, will be the most widely adopted without cost-share incentives. Cereal rye, for example, besides the current use as a successful cover crop in Iowa, can be used as a grain crop for feed and human food. The USDA/NASS 2020 crop values summary (USDA-NASS, 2021) has rye at $59 million in value. That amount should increase with greater rye seed demand.

This project focused on a cropping system that can incorporate the three important N reduction practices: longer rotation/small grains, cover crop, and N rate. The rotation for this project was soybean–cereal rye for grain with inter-seeded clover–corn. That cropping system addresses several important issues: a cash grain crop (cereal rye) that is easily incorporated into current farmer crop production systems, an additional cover crop option (red clover), change in the N rate input across the rotation with expected lower N fertilization rate for cereal rye compared to corn, a cereal crop with different plant N uptake pattern compared to corn, a fall-seeded small grain crop (rye) that will act as a cover crop following soybean and thus providing soil profile nitrate reduction and erosion control, clover that can fix N, and clover that disrupts the sequence of a cereal crop (corn) following a cereal rye cover crop and reduces the N rate needed when corn follows a clover green manure crop (and that also acts as a cover crop from summer to the next spring). Red clover is a traditional legume forage crop that is frost-seeded in the spring into small grains, and therefore has time to grow in the summer, fall, and following spring; thus providing time to absorb soil inorganic N and symbiotically fix N before termination as a cover crop with net N release to corn. Extending the crop rotation by inserting a small grain and a clover cover crop between corn and soybean crops has potential to break disease cycles and serve as a non-host for pests like soybean cyst nematode. Rye grain harvested in mid-summer can be marketed to the livestock or food industry or be used as cover crop seed. The clover could also be harvested for forage.

There is old research and recommendations within Iowa about N fertilization rate for some small grain cereals such as oats and wheat. However, there has been no research to investigate the N fertilization rate requirement for cereal rye grain production in Iowa, or within a cereal rye/clover system. Further, we identified a need for additional/current research on the impact of red clover as a cover crop on the corn N fertilization requirement, especially within rye crop production. While components of a small grain/clover system are generally known, there is limited specific information about cereal rye grain production in Iowa conditions. The goal of this research was to study the soybean–cereal rye grain production/clover cover crop–corn grain cropping sequence. Specific objectives were to determine the N fertilization rate requirement for cereal rye grain production, effect of inter-seeded red clover on rye production, impact of the clover cover crop on corn optimal N fertilization requirement and yield, and influence of the cropping system on soil nitrate-N.

## Project Design, Methods, and Materials

Field research began in the fall 2017 with cereal rye planting following soybean harvest at two Iowa State University Research and Demonstration Farms. Project work each year was conducted at the Agricultural Engineering /Agronomy Farm (AEA) near Ames and the Northern Research and Demonstration Farm near Kanawha. At both Ames and Kanawha field sites were secured to establish rye plots following soybean in fall 2018. All four sites were soil sampled after soybean harvest and phosphorus, potassium, sulfur, or lime applied as needed before rye planting. The overall project consisted of a no-till, three-year cropping system of soybean–cereal rye grain crop/inter-seeded red clover cover crop–corn. The field experiments were conducted consecutively for the cereal rye and corn phases of the rotation. The cereal rye phase took place during the 2018 and 2019 growing seasons, with a new rye experimental area each year; the corn phase took place during the 2019 and 2020 growing seasons.

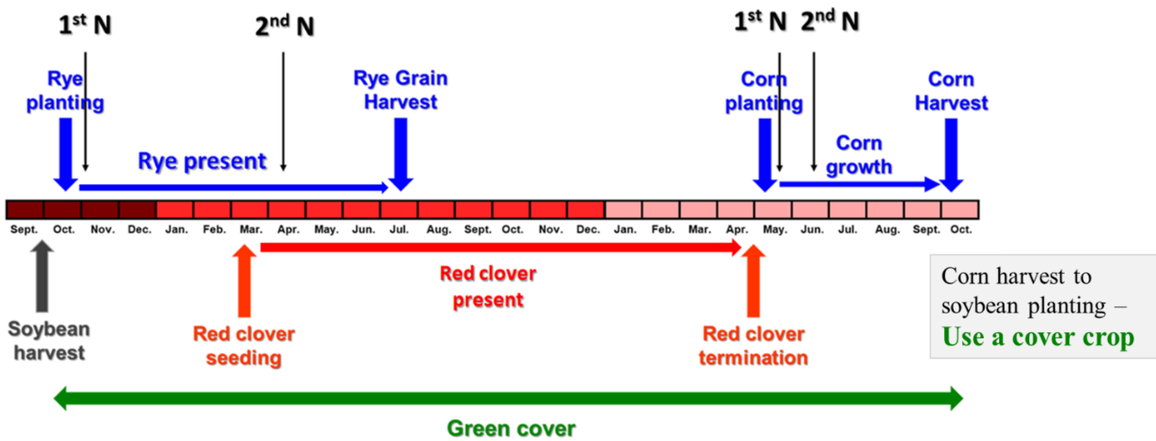



Figure 1. Schematic design of our 2017-2020 research that keeps “green cover” (living plants and active roots) on the landscape to reduce nitrate loss. Though not included in this project, we encourage establishment of a cereal rye cover crop ahead of the subsequent soybean crop.

Rye phase treatments were arranged in a split-split-plot randomized complete block design, with red clover as the whole plot (with and without clover), rye as the split-plot (two varieties), and six N rates as the split-split-plot (0, 25, 50, 75, 100, and 125 lb N/acre) with broadcast surface-applied urea treated with urease inhibitor. The rye N rates were split-applied, with 25 lb N/acre at rye planting and the remainder in spring at rye green-up. Six N rates were applied to the cereal rye to determine economic optimal N rate.

Two cereal rye varieties were used for the study. The rye varieties were chosen as contrasting varieties. ‘ND Dylan’ is a newer, higher grain yield potential “Northern variety” (2016 release) from North Dakota and ‘Elbon’ is an older more forage-type “Southern variety” (1956 release) from Oklahoma with a lower winter hardiness than ND Dylan. Elbon is commonly used as a rye cover crop. Estimates of per-pound seed count and germination were provided for each variety and rechecked for the fall rye planting. All rye plots were no-till drilled at a rate of approximately 1.1 million pure live seeds/acre. Our target rye planting date was mid-September; however, delayed soybean maturity and a wet period of frequent rainfall delayed rye planting each year (2017: Oct. 19 at both sites; 2018: Sept. 24 at Ames, Oct. 23 at Kanawha). Plant height, number of seed heads, and grain yield were determined in the rye crop. Post-rye harvest soil profile nitrate-N to the two-foot depth was measured at 0, 75, and 125 lb N/acre rates. Canopy sensing (NDVI, Normalized Difference Vegetative Index) was used to assess the rye N status. Yield response was used to determine the agronomic optimum N rate (AONR) from the rye grain production.

Each spring medium red clover ('Ruby' brand, inoculated) was broadcast in mid-late March ("frost seeded") at 15 lb pure live seed per acre. Frost seeding dates in 2018 were Mar. 12 (Ames) and Mar. 13 (Kanawha) and in 2019 were Mar. 27 (Ames) and Mar. 28 (Kanawha). Clover establishment was good, especially in the Elbon rye variety where the rye plant stand was lower. After rye grain harvest in July of each year rye straw was baled and clover allowed to grow throughout the summer and fall as a cover crop. Clover growth was excellent due to timely summer rainfall. Weeds were controlled by mowing the non-clover treatments. The clover was not mowed.

In the two corn years (2019 and 2020) following the rye production crops, corn with and without clover was the main plot, and N rate the split-plot (0, 50, 100, 150, 200, and 250 lb N/acre). Six N rates were applied to corn to determine impact of the clover cover crop on corn yield and corn response to N fertilization rate. The clover spring regrowth was herbicide-terminated in spring of each corn year (2019: Apr. 24 at both sites; 2020: Apr. 21 at Ames, Apr. 24 at Kanawha). Corn was no-till planted approximately one to two weeks after clover cover crop termination, with persistent rain delaying 2019 corn planting (2019: May 16 at both sites; 2020: Apr. 29 at Ames, May 1 at Kanawha). SuperU urea (urease and nitrification inhibitor treated) was the N source, broadcast split-applied with 50 lb N/acre at planting and the rest side-dress applied at approximately the V4 corn growth stage (2019: Jun. 10 at Ames, Jun. 11 at Kanawha; 2020: Jun. 4 at Ames, Jun. 8 at Kanawha). The six N rates applied to corn plots corresponded to N rates applied to previous year's rye plots (i.e. zero-N corn plots following the zero-N rye plots, with 50, 100, 150, 200, and 250 lb N/acre corn rates following 25, 50, 75, 100, and 125 lb N/acre rye rates).

Canopy sensing (NDRE, Normalized Difference Red Edge index) (V9 corn growth stage) and ear leaf SPAD meter readings (R1 corn growth stage) were used to assess the corn N response as related to fertilizer N rate and N supplied from the clover. In the spring at time of clover control, soil profile nitrate-N to the two-foot depth was measured and aboveground biomass sampled from the clover and non-clover (some volunteer rye and weeds). All alive and dead plant biomass was sampled (rye stubble, weeds, winter-killed clover growth, new clover growth, volunteer rye). Weed growth was minimal in the clover cover crop, with no volunteer rye. Soil profile nitrate (two-foot depth) was determined at the time of clover control, at LSNT (late spring soil nitrate test) sampling time, and post-corn harvest in the 0, 150, and 250 lb N/acre rates. Corn grain yield with and without clover was used to estimate N supplied from the clover.

## Summary Results and Discussion

### *Rye Phase*

Table 1 contains the results for rye grain yield, plant height (to tip of grain seed head), number of heads per acre, and rye canopy sensing NDVI across all four site-years (two locations and two years). Across N rates, rye grain yield of the ND Dylan variety was consistently higher than the Elbon variety. Rye grain yields were relatively low for both varieties. The low yields achieved may have resulted from late fall planting dates and less-than-ideal spring/summer weather conditions (wet and relative high heat for small grains) which caused rye plant stress and compromised yield potential.

Rye canopy sensing NDVI values reflected rye response to increasing N rate and were greater for ND Dylan than Elbon, reflecting greater plant canopy and stand for ND Dylan. The smaller plant canopy index and seed head count for Elbon was also visually observed in the spring – an indication of lower over-wintering stand and less tillering. The NDVI reached a maximum value at approximately the same N rate as grain yield for each variety. The ND Dylan variety was slightly taller and had a greater seed head count than the Elbon variety, a reflection of better stand establishment and greater tillering with ND Dylan. Both varieties increased in plant height and number of heads in response to N application.

Cereal rye grain yield responded to N application rate. The across-site AONR was similar for both varieties, 85 lb N/acre for ND Dylan and 89 lb N/acre for Elbon. At the AONR, grain yield was higher for ND Dylan, 49.8 bu/acre, versus 33.8 bu/acre for Elbon. These results indicate a need to apply N for optimal cereal rye grain production, approximately 87 lb N/acre. As the rye grain yield response was linear to a plateau yield (Figure 2), the AONR is also the economic optimal N rate (EONR) as long as the N:grain price ratio is greater than the linear equation slope.

Post-rye harvest soil nitrate-N in the top two feet of soil was overall low (17, 18, and 21 lb nitrate-N/acre for the zero, 75, and 125 lb N/acre rates, respectively), increased only slightly with N application, and was not impacted by inter-seeded clover. At approximately the AONR, there was only a 1 lb N/acre increase in profile nitrate-N compared to no N applied.

Table 1. Rye grain production and plant measurements, 2018-2019 across with and without inter-seeded red clover for each variety. Rye plant height and seed head count after full plant height achieved, and rye crop canopy sensing at Feekes' growth stage 9/10 (full flag leaf emergence).

| | ND Dylan | | | | | Elbon | | | |
|---|---|---|---|---|---|---|---|---|---|
| Fertilizer N Rate | Grain Yield | Plant Height | Seed Heads | Canopy Sensing | | Grain Yield | Plant Height | Seed Heads | Canopy Sensing |
| lb N/acre† | bu/acre | inch | no./ac x 1000 | NDVI | | bu/acre | inch | no./ac x 1000 | NDVI |
| 0 | 34.7 | 52 | 1160 | 0.585 | | 23.9 | 50 | 950 | 0.487 |
| 25 | 38.6 | 54 | 1270 | 0.633 | | 26.6 | 52 | 1020 | 0.520 |
| 50 | 43.5 | 55 | 1290 | 0.700 | | 29.3 | 53 | 1150 | 0.574 |
| 75 | 48.1 | 56 | 1470 | 0.741 | | 32.3 | 54 | 1150 | 0.614 |
| 100 | 49.0 | 57 | 1500 | 0.758 | | 33.8 | 55 | 1260 | 0.634 |
| 125 | 50.5 | 56 | 1540 | 0.774 | | 33.8 | 54 | 1300 | 0.620 |
| Pr>F‡ | <0.001 | <0.001 | 0.010 | <0.001 | | <0.001 | 0.013 | 0.006 | <0.001 |
| AONR§ (lb N/ac) | 85 | 62 | 109 | 85 | | 89 | 74 | 115 | 83 |
| Measurement§ | 49.8 | 56 | 1540 | 0.766 | | 33.8 | 54 | 1300 | 0.627 |

† Total N applied, 25 lb N/acre applied at rye planting, remainder top-dressed at rye green-up in spring.
‡ Significance of mean N rate response.
§ AONR, agronomic optimum N rate for yield or maximum N response rate, with associated plant measurement at the AONR.

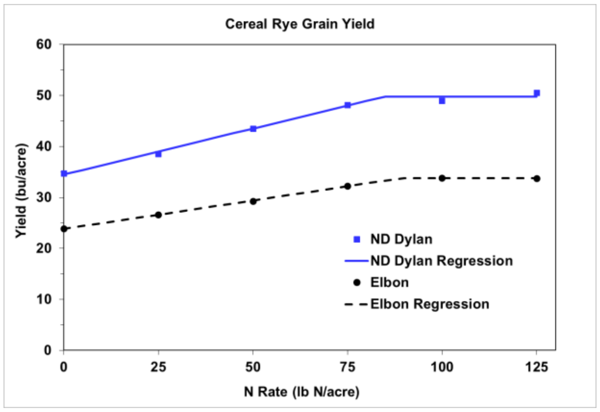


Figure 2. Cereal rye variety grain yield response to fertilizer N rate, 2018-2019. The regression linear-plateau join point represents the agronomic optimum N rate (AONR given in Table 1).

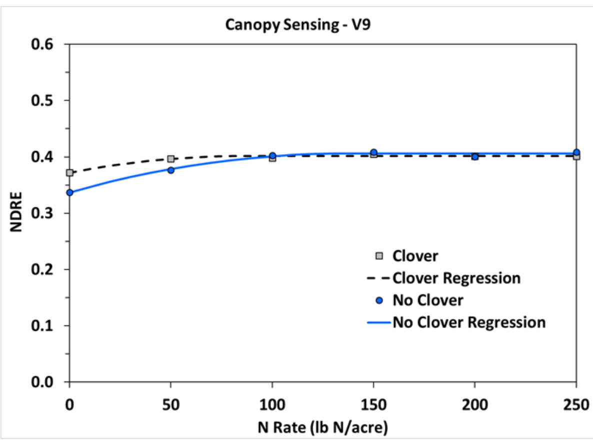
***Corn Phase***

The amount of aboveground biomass and total N at time of clover cover crop control in the spring was greater with the clover than without the clover (3150 vs. 1320 lb DM/acre and 59 vs. 29 lb N/acre), and there was no effect of the fertilizer N rate applied to the prior-year rye. The sampled biomass consisted of all alive and dead plant biomass material: in the clover cover crop rye stubble, winter-killed clover growth, and new clover growth; and in the non-clover rye stubble, volunteer rye, and any weeds.

Figure 3 shows the corn canopy sensing and ear leaf SPAD response to N rate with and without the clover, across sites and years. There was a clear N supply from the clover to the corn. With no N applied, and the lowest N rates, the corn canopy red-edge NDRE was greater following clover than the no clover (in the no clover, only prior-year rye crop stubble or volunteer rye). The difference between with and without clover became larger at the R1 corn stage (SPAD values, Figure 3), indicating increased N supply (mineralization) from the killed clover as the early season progressed. This could be expected, especially as the clover was controlled in the spring and the corn was no-till planted. As typically found, canopy sensing and SPAD readings plateaued when adequate or more than adequate N was available to the corn. The NDRE canopy sensing index, while an early season measure of plant canopy and N stress, had the same difference in AONR between with and without the clover cover crop (at 50 lb N/acre) as with the yield-based N response to the clover. Therefore, the newer NDRE (red-edge based) may have greater utility in N stress determination than the older NDVI (red-based).

Corn yield response, as found for canopy sensing, indicated N supplied from the clover cover crop (Figure 4). With no fertilizer N applied, there was an approximate 46 bu/acre greater corn yield following the clover. With adequate fertilizer N application, corn yield was similar between the clover and no clover. The difference in AONR was used to determine N supplied by the clover, at approximately 50 lb N/acre, which reduced the corn optimal N fertilization requirement. There was no difference in corn population between with and without the clover cover crop (data not shown), therefore yield differences would be due to the clover cover crop presence or N supply from the clover.

The profile soil nitrate at time of clover control in the spring was low, not different between the N rates applied to the prior-year rye, and slightly higher with the clover than without (13 vs. 9 lb nitrate-N/acre). At the late spring soil profile sampling (early-mid June), there was no difference in concentration between with or without the clover (5 vs. 4 ppm in the top foot, respectively, with no at-planting N), with concentrations well below the LSNT critical level of 20-25 ppm. That result indicates the LSNT did not pick up the potential N supply from the clover. At the post-harvest soil sampling the profile nitrate-N amount increased with N rate as is normal, but most notably, the amount was increased considerably for the combination of clover and the highest N rate applied (14 vs. 74 lb nitrate-N/acre, respectively, for the zero and 250 lb N/acre rates). The profile nitrate amounts were consistently higher with the clover than without at each N rate. This indicates that when using the clover legume as a cover crop, the potential N supply from the clover must be taken into account when determining the N fertilization rate in order to avoid over-fertilization and enhanced profile nitrate carryover.



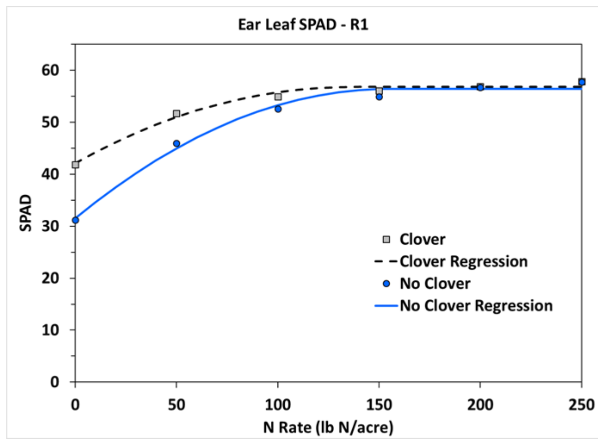




Figure 3. Corn canopy sensing (V9 stage) NDRE sensing index and ear leaf SPAD readings response to fertilizer N rate and the prior red clover cover crop, 2019-2020.

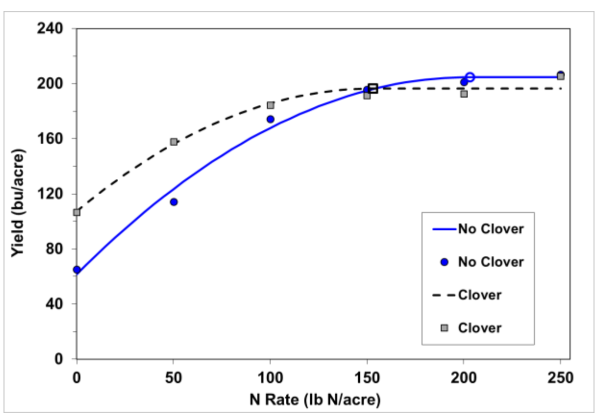



Figure 4. Corn grain yield response to fertilizer N rate and prior red clover cover crop, 2019-2020. The open symbols represent the AONR with and without clover based on the N rate response equations.

***Summary***

The overall project documented that cereal rye responds positively to N fertilization when planted following soybean. Across the sites and years, the AONR (and EONR) was 85-89 lb N/acre, mean across varieties approximately 87 lb N/acre. The optimal N rate was similar for both rye varieties despite a considerable difference in yield level. The project also documented the N supplied to corn when red clover had been frost-seeded into the rye the prior year. In the two years of study, there was adequate moisture and excellent clover growth following rye harvest, which aided N fixation by the clover and subsequent N release to corn the following year. The project also highlighted the potential to successfully insert a rye grain crop into a corn-soybean system. The combination of the fall-seeded rye crop and frost-seeded clover “cover crop” provided a “green soil cover” of living plants from the time of soybean harvest, through a rye grain crop, and into a corn crop. Although not studied here, use of a cover crop after corn would provide an additional green cover and hence plant/crop growth on a continuous basis; especially in the spring of the year when the predominance of nitrate is lost from the corn-soybean rotation. In addition, rye N fertilization requirement is low (compared to corn) and rapid rye growth/N uptake during the spring would limit nitrate in the soil system. Such an overall crop production system should have a major effect on potential loss of nitrate from the soil system.

## Conclusions

Cereal rye grain production was successful each year and the rye consistently responded to N rate: plant canopy, leaf greenness, head count, height, and grain yield increased with fertilizer N application.

The inter-seeded red clover cover crop did not affect rye N response, rye grain yield, or post-harvest soil nitrate.

Cereal rye agronomic optimum N rate (AONR) was similar between the varieties, averaging 87 lb N/acre (85 and 89 lb N/acre, for ND-Dylan and Elbon, respectively); however, ND Dylan grain yield was higher than Elbon – a reflection of variety, winter hardiness/stand, and early growth.

Plant establishment and canopy “fullness” were greater with the “northern” ND-Dylan rye variety compared to the “southern” Elbon rye variety.

Post-rye harvest profile soil nitrate-N amount was low, slightly increased increasing N fertilization, and was not impacted by presence/absence of the inter-seeded clover. Where the 75 lb N/acre fertilizer rate had been applied (near the AONR), the post-rye harvest profile soil nitrate-N increased by only 1 lb nitrate-N/acre compared to where no fertilizer N had been applied.

The clover cover crop had a positive effect on reducing the corn N fertilization requirement, supplying an average 50 lb N/acre fertilizer equivalent with minimal to no impact on grain yield of the corn crop.

The clover cover crop had a larger impact on corn leaf greenness at R1 stage (SPAD meter readings) relative to earlier measures (canopy sensing at V9 stage or LSNT), confirming that mineralization of N from decaying clover increased during the growing season.

Higher soil profile nitrate-N concentration and profile totals during the corn year were associated with the clover cover crop and especially the high N fertilization rate – indicating the need to carefully consider the clover N supply in order to avoid over-fertilization and increase residual nitrate-N.

Cereal rye grain production with an inter-seeded clover cover crop offers potential for integration into a corn-soybean rotation cropping system. Extending a two-year crop rotation with cereal rye and a clover cover crop keeps a "green cover" with active roots on the landscape to help reduce nitrate loss. Further, cereal rye grain production has a low N-rate requirement and low residual nitrate-N impact while the clover offers additional soil health and wildlife benefits.

Further research is needed to increase cereal rye grain yields and improve standability of rye grown for grain harvest.

## Impact of the Results

The findings of this study support the initial idea to integrate rye grain production with a clover cover crop into soybean-corn rotations. Moreover, the project fits in the strategy of integrating different landscape management practices for improved crop production, soil resources, and water quality. Fall planted rye and frost-seeded red clover would provide a green soil cover with living roots year-round, helping with nitrate loss reduction between annual crops. Clover as a legume can also increase plant-available N for corn, reducing the needed N fertilization rate. Although not studied in this project, using the harvested rye grain as a cover crop after corn could potentially provide additional green cover and continuous plant growth both above and below ground. Therefore, this integrated grain crop-cover crop production system has potential to positively affect nitrate loss and provide soil improvement.

Further research is needed to assess management practices that promote better cereal rye agronomic performance. Even so, this integrated grain crop-cover crop production system has potential for an alternative rye grain crop within the traditional corn-soybean rotation, and to help reduce system-wide profile nitrate loss.