NITROGEN FERTILIZATION REQUIREMENT AND CORN-SOYBEAN PRODUCTIVITY IN A RYE COVER CROPPING SYSTEM

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Introduction

Nitrogen (N) fertilizer inputs for intensive corn-based cropping systems can increase nitrate (NO_3^-–N) concentrations in groundwater. Nitrogen transport in surface water to the Gulf of Mexico is also an on-going issue for the upper Mississippi river basin, especially areas with large corn and soybean acreage. Education and policy efforts have focused on improvement in N application rate, timing, management, and crop N use efficiency. However, additional means to reduce N loss are needed. Recent efforts have refocused on practices to keep soluble NO_3^-–N and soil-bound N in fields. One practice receiving attention and agency cost share is cover crops.

Corn N fertilization results in residual NO_3^-–N in the soil profile after crop maturity. The amount is dependent on factors such as N application rate, rainfall, soil texture, and crop yield. Residual NO_3^-–N is subject to off-season loss (fall to early spring) as there is no active crop (in a corn-soybean row crop system) to assimilate N. Cover crops have been shown to help retain NO_3^-–N and protect the surface soil from erosion. In some situations, cover crops have increased yield of the row crop. Many cover crops can be used, but due to seed availability, cost, and winter hardiness, winter rye (*Secale cereal* L.) has been a common choice.

Many questions arise as producers consider implementing a cover crop system, including the potential need to adjust corn N fertilization rate. Results of prior research with cereal cover crops has been inconsistent in regard to N supply and effect on corn fertilization rate requirement, with differences related to soil properties such as texture and organic matter (Kessavalou and Walters, 1997; Vyn et al., 2000; Andraski and Bundy, 2005). Of particular interest is what happens to the N taken up by the cover crop. It is known that temperature and precipitation affect the decomposition of the cover crop biomass (Ruffo and Bollero, 2003), but more research is needed to understand N cycling to the soil as cover crop biomass degrades. Is it immobilized by microbial processing of the cover crop biomass due to high carbon content, or does it add to plant-available N during corn N uptake? This is not as important of an issue with cereal cover crops preceding soybean, but is for corn. The objectives of this research were to determine long-term corn response to applied N, corn N fertilization requirement, nutrient cycling, and crop productivity in a corn-soybean rotation when grown in sequence with a winter rye cover crop. This report only covers the initial and partial second year of the cover crop system, with the research expected to continue for several years.

Materials and Methods

In the fall of 2008 four sites were initiated at Iowa State University Research and Demonstration Farms representing major soil, climatic, and crop production regions in Iowa: Agricultural Engineering and Agronomy Research Farms, Ames (central); Armstrong Memorial Research and

Demonstration Farm, Lewis (southwest); Southeast Research and Demonstration Farm, Crawfordsville (southeast); and the Northeast Research and Demonstration Farm, Nashua (northeast). All sites are in a corn-soybean rotation, with each crop present each year. Treatments are arranged in a split-plot design, four replications, with main plot winter rye cover crop (rye and no rye) and the split plot N rate applied to corn (0, 40, 80, 120, 160 and 200 lb N/acre) as side-dress coulter-injected urea-ammonium nitrate (UAN) fertilizer shortly after planting. The rye variety is Wheeler, drilled no-till after corn and soybean harvest at 60 lb seed/acre. The first cycle of the rye cover crop system was planted in the fall of 2008 and the second cycle in the fall 2009. Rye planting dates across sites were distributed from early to mid-October in 2008 and late September to late October in 2009, with date depending on crop maturity and fall harvest conditions, but generally earlier in the fall of 2009. In each year and at all sites the rye was successfully established, but fall growth was not large (observed but not measured) and somewhat variable due to site geographic location and seeding date.

In 2008 initial soil samples were collected to determine routine soil tests with phosphorus (P) and potassium (K) applied as needed for optimal corn and soybean production. Post-harvest profile soil samples (0-1, 1-2, and 2-3 ft) were collected to determine initial soil NO_3^-–N. In the spring of 2009 and 2010, before planting and in late May/early June, soil samples were collected at 0-1 and 1-2 ft in corn plots receiving no N fertilizer. In the fall following crop harvest and before planting/growth of the rye cover crop, soil was sampled to 3 ft depth (1-ft increments) to determine profile NO_3^-–N. Six cores per plot were collected in a set pattern across the middle two corn rows. The 0, 120, and 200 lb N/acre rates were sampled following corn and after the 2009 year also following soybean (by replicate in the fall 2009 with soybean).

In 2009 and 2010, before herbicide application to control the rye, the aboveground rye biomass was randomly sampled at five to ten 1 ft^2 areas (number depending on rye growth), with calculated dry matter (DM) adjusted for rye row spacing. In 2009 sampling was by replicate and in 2010 by plot. The samples were used to determine rye biomass DM and N uptake. The intent of the study was to allow time for spring rye growth, but still have timely corn and soybean planting. This decision will not maximize rye growth, and is an attempt to not have significant planting delays limit corn-soybean productivity. The corn and soybean were no-till planted with residue row cleaner attachments, waiting at least seven days from rye control to planting corn and planting soybean immediately after rye control.

The Crop Circle ACS-210 active canopy sensor (Holland Scientific, Lincoln, NE) was used to estimate canopy biomass (corn response to N rate and rye cover crop) at the mid-vegetative (V10) growth stage. The sensor was mounted on a mast, positioned mid-row, and carried by hand through the middle of each N rate plot at a constant speed and 2-3 ft distance above the corn canopy. The reflectance measurements were captured on-the-go with a handheld computer and averaged across each plot. Reflected light values were used to calculate the normalized difference vegetative index (NDVI). Corn and soybean grain yields were determined by harvest with a plot combine and reported at 15.5% moisture for corn and 13% for soybean.

Results and Discussion

2008 Initial Soil Nitrate

Across sites, soil profile NO_3^-–N concentrations were low (≤ 3 ppm) at all sites (data not shown). The samples were collected before any N rate treatments had been applied; therefore, reflect background concentrations for the crop rotations at each site. The concentrations indicate little residual soil NO_3^-–N at any depth and no clear trend by depth. The N applied across the study areas in the spring before corn planting was at a uniform agronomic rate range of 120-140 lb N/acre, and this is reflected in the low post-harvest NO_3^-–N concentrations.

Rye Cover Crop Production

The rye aboveground biomass produced at all sites was low (< 400 lb DM/acre) in 2009, except prior to soybean planting at Crawfordsville where the rye biomass was 1,110 lb DM/acre (Table 1). The low rye DM was not generally due to poor stand, rather to limited fall growth, slow growth in the spring due to cold temperatures, and a late fall rye planting combined with an early spring control. This is consistent with research conducted in British Columbia where late planted cover crops produced from 15 to 75% lower DM compared to early planted cover crops (Odhiambo and Bomke, 2001). As expected, since the aboveground rye DM was small, the total N present in that biomass was low (data not shown); less than 11 lb N/acre for all sites except for the Crawfordsville site before soybean planting where the rye contained 20 lb N/acre. This is consistent with research conducted in Wisconsin by Bundy and Andraski (2005) where winter rye did not utilize significant amounts of residual N due to the short period of time for cover crop growth. There was also some winter kill of the rye in the soybean stubble at Ames and Nashua, and that also contributed to low DM and total N uptake. The greater biomass production at Crawfordsville before soybean planting was due to a longer springtime period for growth due to wet conditions during the expected rye control and soybean planting time that delayed field activities. This is a similar result for the difference in rye DM at Ames and Nashua for the samples collected before corn planting compared to before soybean.

In 2010, the rye DM production before corn planting was greater than in 2009, mainly due to a much warmer early spring in 2010. The smaller rye DM at Crawfordsville was due to wet conditions and saturated soils/ponding in the early springtime. At the Nashua site, corn planting was at the same time as the other sites, however, since this site is located in the northern part of Iowa, cooler temperatures would be expected to result in slower rye growth compared to central and southern sites. With the greater rye growth, and in combination with extended cold and wet conditions (in May) that occurred after planting, corn establishment and early growth was significantly impacted at the Ames and Crawfordsville sites. This affected corn stand, development, and growth; with expectation of yield suppression (yield data not available for 2010). These effects in corn were much greater than at any site in 2009.

The rye aboveground biomass production before soybean planting was also greater in 2010 than 2009. Much of that difference was due to warm temperatures in April. The rye DM was greatest at Crawfordsville due to a longer springtime period for growth as that site again experienced wet conditions during the expected rye control period and soybean planting was delayed. The rye aboveground biomass production before planting soybean was less than before planting corn at three sites. The main reason for this was later rye seeding and less growth in the corn residue.

In general, and as in 2009, the relative amount of rye growth was not large unless rye control was significantly delayed. The intent of the study was to allow time for rye growth in the spring, but control the rye and plant corn and soybean crops in a timely manner. This results in a fairly narrow window for spring rye growth and biomass accumulation. As evidenced at the Crawfordsville site, allowing a longer spring growth period would provide for more rye DM production and N uptake. However, that also would delay corn and soybean planting, something not desired by most producers.

Table 1. Aboveground rye biomass dry matter (DM) before control with herbicide.

Year	Crop	Ames	Crawfordsville	Lewis	Nashua
		- - - - - - - - - - - - - - - - - -	lb/acre	- - - - - - - - - - - - - - - - - -	
2009	Before corn	150 b†	85 b	310 a	35 b
	Before soybean	290 a	1,110 a	195 a	190 a
2010	Before corn	1,460 a	1,000 b	1,245 a	1,020 a
	Before soybean	765 b	2,345 a	590 b	665 b

† Means followed by the same letter within a year are not significantly different, $p \leq 0.05$.

Across sites in 2010, the rye biomass DM was the same at low fertilizer N rates applied to the prior-year corn, but increased as N rate increased with the highest rates (Figure 1). This response indicates increased residual NO_3^-–N in the soil and enhanced uptake by the rye; but also indicates the rye was N-supply limited. That is, there was not adequate residual inorganic N in the soil to support full rye growth, even at the highest prior-year N rate applied to corn. Rye N uptake data for 2010 was not available for this report.

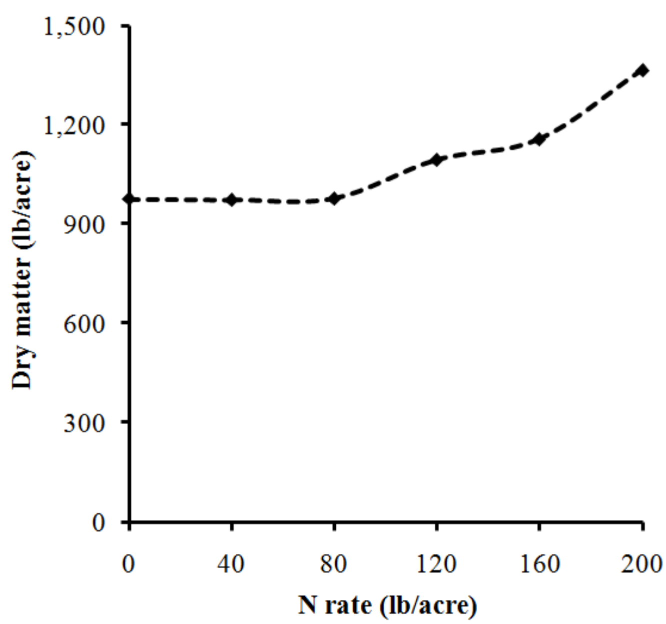

Figure 1. Effect of N rate applied to the prior year corn on aboveground rye biomass dry matter (DM), spring 2010.

Soil Nitrate

In 2009, the rye cover crop did not reduce soil NO_3^-–N concentrations in the spring preplant samples (compared to the no rye) at either depth at any site. Concentrations were low (< 6 ppm) because no rates had been applied and soil conditions were wet. The NO_3^-–N concentrations increased slightly from the spring preplant to the late spring sampling, but those concentrations were also low and not different between the rye and no rye cover crop. With no N rates having been applied, it appeared that the rye cover, either from an effect on soil mineralization or cycling N through the rye biomass (which was low in 2009), did not influence NO_3^-–N in the upper soil profile.

For the post-harvest profile soil samples collected in the fall of 2009, after the first year of the rye cover crop system, the rye did not influence soil NO_3^-–N concentrations at any site. Therefore, the soil NO_3^-–N is presented as an average across rye cover crop (Figure 2). Post corn harvest NO_3^-–N concentrations were increased with the spring applied 200 lb N/acre rate. Soil NO_3^-–N concentrations decreased as sampling depth increased, except at Nashua where there was no difference with depth. All concentrations were low, likely a result of a wet growing season and plant N uptake with high corn yield. Concentrations remained similar to the concentrations measured in late spring in plots where no N was applied.

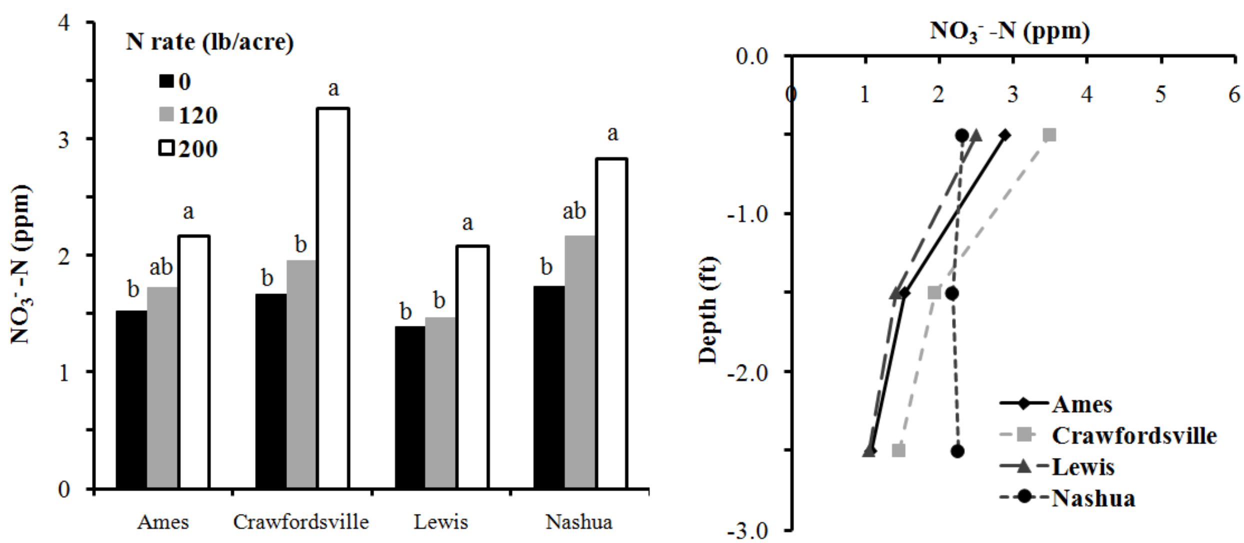

Figure 2. Soil profile NO_3^--N concentrations after corn harvest as affected by N rate (left) and sampling depth (right), fall 2009.

As with corn, the rye cover crop did not influence post-harvest profile soil NO_3^-–N concentrations following soybean at any site. Soil NO_3^-–N concentrations decreased as sampling depth increased except for Nashua, where there was no difference as was found at that site following corn (Figure 3).

In 2010, the rye cover crop reduced soil NO_3^-–N concentrations in the spring preplant samples (no N applied to prior year corn) at both depths and all sites (data not shown; concentrations were ≤ 1 ppm with rye and < 8 ppm without rye cover crop). This reduction could be associated with rye N uptake and/or cover crop carbon added to the soil influencing microbial immobilization in the upper soil profile. However, NO_3^-–N concentrations in late spring were similar for with and without the rye cover crop (< 4 ppm) at all depths and sites. Previous research conducted in Illinois suggested that rye has a slow decomposition during the growing season, and therefore may not contribute significant available N to corn and could immobilize soil N (Ruffo and Bollero, 2003). Strock et al. (2004), however, reported that the magnitude of a rye effect on soil profile NO_3^-–N concentrations varied with annual precipitation, which might also be the case here.

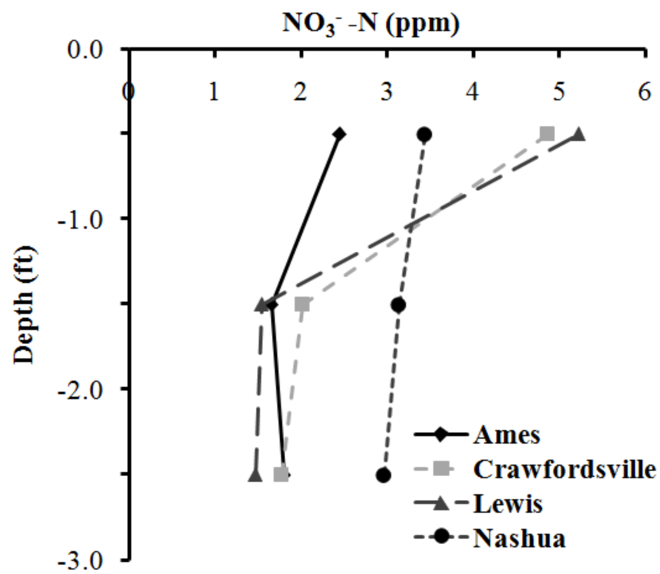

Figure 3. Soil profile NO_3^-–N concentrations after soybean harvest, fall 2009.

Corn Nitrogen Response and Yield

In 2009 at all sites corn did respond to applied N (increased corn canopy NDVI measured at the V10 growth stage), but the rye cover crop did not influence NDVI values (individual data not shown). Across sites, the NDVI values were not different for with or without the rye cover crop across N rates (Figure 4). The NDVI increased as N rate increased from zero N to maximum response. This indicates deficit N at low rates, canopy response to an optimal rate, and then no change in canopy response at higher N rates (excess).

In 2010, all sites were N responsive as NDVI increased with N application (Figure 4), a similar trend as in 2009. However, the NDVI values were generally lower with or without N applied (no rye cover crop) than in 2009. This indicates some potential negative environment effects on corn growth. In 2010, corn in the rye cover crop system had significantly reduced canopy NDVI values at three sites (Ames, Nashua, and Armstrong), but not at Crawfordsville (individual site data not shown). With greater rye DM production, along with negative growth influences from cold and wet May conditions and poor stand establishment at the Ames site due to inadequate residue removal from the seed row at planting, there was a much greater rye cover crop effect on early season corn growth and development in 2010 than 2009. It is expected this will affect corn grain yield as well (yield data not available at the time of this report). In plots where corn was planted into the killed rye, corn germination was delayed compared to the no rye cover at the Ames site. This indicates some surface residue or allelopathic effects between the killed rye and corn, which reduced stand and early growth. An additional issue occurred at the Ames and Lewis sites where fall armyworm damage level in the corn planted into the rye cover crop required insecticide application.

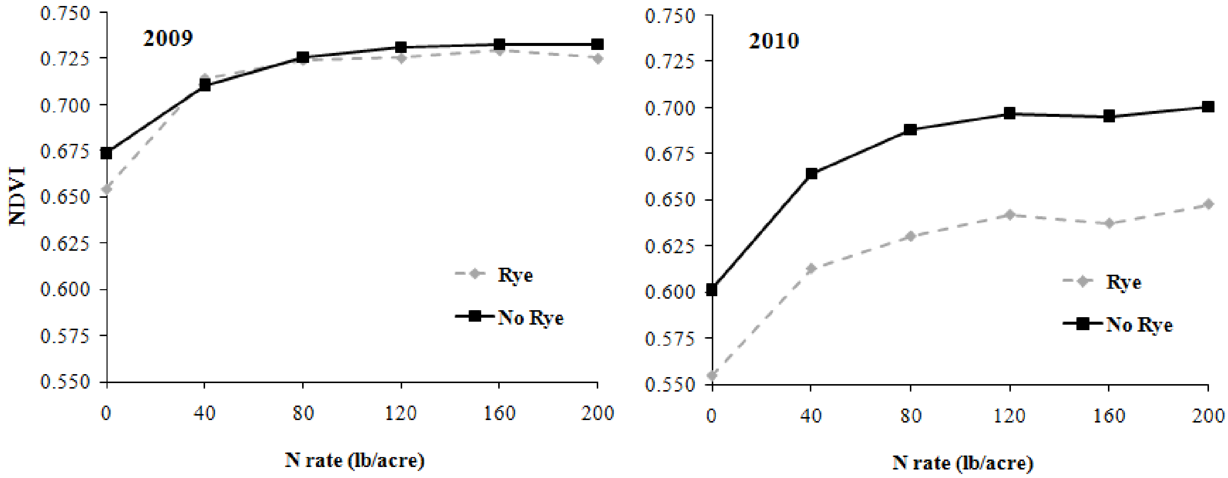

Figure 4. Corn plant canopy normalized difference vegetation index (NDVI), measured with a Crop Circle sensor, as affected by rye cover crop and N rate across sites, 2009 and 2010.

In 2009, corn grain yield increased with N application at all sites (N response across sites shown in Figure 5). The N response was the same with or without the rye cover crop; with this probably due to the low rye DM production in 2009. The economic optimum N rate (0.10 price ratio, $/lb N:$/bu corn grain) determined from the regression fit shown in Figure 5 was basically the same with rye and no rye cover (156 lb N/acre with rye and 158 lb N/acre with no rye). At individual sites, average corn grain yield was significantly lower in the rye cover crop at two sites (Ames and Lewis) and the same at the other two sites. Across sites and N rates, the mean rye cover crop effect was significant, with an average 7 bu/acre lower yield when corn was planted after the rye (164 bu/acre with rye and 171 bu/acre with no rye), indicating some negative impact of the rye cover crop on corn productivity.

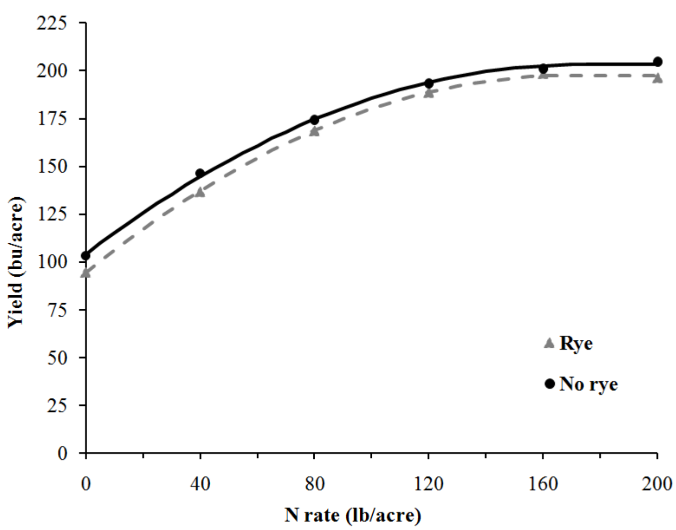

Figure 5. Corn grain yield response to fertilizer N rate with and without rye cover crop across sites, 2009.

Soybean Yield

Since N rates had not been previously applied, the soybean grain yields from 2009 are analyzed only for the effect of the rye cover crop (Table 2). Soybean yield was the same with rye and with no rye cover at three sites, but higher with rye cover at the Ames site. Across all sites, there was no yield difference due to the rye cover crop. Some differences in soybean yield might have been expected at Crawfordsville since this site had a long rye spring growth period and large biomass production at the time of planting soybean; however, no statistical difference was observed indicating the killed rye cover crop did not affect soybean growth. Soybean yield data for 2010 was not available for this report. However, no growth issues were observed that might affect soybean production.

Table 2. Soybean grain yield with and without rye cover crop, fall 2009.

Rye	Ames	Crawfordsville	Lewis	Nashua
	- - - - - - - - - - -	- - - - - - - - - - - bu/acre	- - - - - - - - - -	- - - - - - - -
With	58 a[†]	69 a	65 a	56 a
Without	54 b	70 a	66 a	58 a

[†] Means followed by the same letter are not significantly different, $p \leq 0.05$.

Summary

For both years, the winter rye cover crop was successfully established by drilling rye after corn and soybean harvest. The intent of the project was to allow time for spring rye growth but not significantly delay corn and soybean planting, which does not allow for maximum rye cover crop growth. Therefore, the amount of rye biomass production was influenced by springtime temperatures, the length of growth before herbicide control, previous crop, and prior year corn N rate. In the spring of 2010, the rye biomass production was greatest with the highest prior-year corn N rates, indicating a response to residual soil NO_3^-–N. As evidenced at the Crawfordsville site when wet spring conditions delayed rye control and planting, allowing a much longer rye spring growth period would provide for more DM production and N uptake, resulting in an increased recycling of NO_3^-–N. However, delaying rye control will also result in later corn and soybean planting, something producers prefer to avoid.

Despite the small amount of rye growth in 2009, there was a 6 to 7 bu/acre average across-site reduction in corn grain yield, with two of the four sites having a lower yield with the rye cover crop. This effect was not noted in the mid-vegetative corn canopy sensing and there was no difference in EONR between with or without the rye cover crop. That indicates no N supply difference or N fertilization rate requirement difference when rye does not affect corn growth. In 2010, however, the corn canopy sensing and visual observation indicated significant detrimental influence of the rye cover crop on corn establishment and growth. In addition, insect pressure from fall armyworm in corn planted into the rye required treatment at multiple locations in 2010. The expectation is that these effects will limit corn yield at some sites. Across sites, there was no effect of the rye cover crop on soybean yield (data only for 2009). Results presented are mainly from one year. Having results from more years will help confirm responses, and if the N response changes with multiple years of cover crop use before corn and soybean.

Acknowledgments

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