Effect of a rye cover crop and crop residue removal on corn nitrogen fertilization

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Introduction

Nitrogen (N) fertilizer applications are necessary for high yield corn production. However, water quality impairment related to N loss from corn and soybean fields continues to be a concern in Iowa, including meeting the USEPA nitrate (NO_3^-–N) drinking water standard, meeting proposed surface water quality nutrient criteria, and reducing N export to the Gulf of Mexico. Therefore, in-field production practices are needed to aid in reduction of NO_3^- leaching and movement to water systems. One practice that has been promoted is cover crops. Due to cost, timely planting, success in establishment, and winter hardiness, winter rye (*Secale cereal* L.) has been a common cover crop choice. However, the impacts of winter rye on row crop productivity differ among geographic areas and ecosystem conditions, including the influence on N recycling, corn N fertilization requirement, and crop yield. With N returned 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 annual crop N uptake? These cover crop issues are not as important with cereal cover crops preceding soybean, but are for corn. Research is not clear on these questions, including the long-term impact for N fertilization and nutrient cycling.

Producers have several choices of diverse tillage practices for their cropping systems. However, no-tillage has become an important soil management practice to help reduce water and wind erosion, as well as nutrient runoff, while conserving soil moisture for crop use. No-tillage also benefits farmers by reducing labor and time requirements, as well as equipment and fuel costs. In some situations, no-tillage may result in lower corn yield compared to tillage, but not necessarily change fertilizer N response. Also, no-tillage corn systems have shown a greater profitability in moderately to well-drained soils, compared to soils with poor internal drainage and high clay content.

The increased use of corn biomass for livestock feed, bedding, or as a bioenergy resource is an ongoing issue in Iowa. The removal of corn residue from fields reduces the amount of plant material remaining for soil surface protection, reduces carbon return to soil and potential soil organic matter, and alters the cycling of plant nutrients. This could potentially affect nutrient availability for crop use. Therefore, it is necessary to evaluate the short and long-term impacts of corn residue harvest on soil properties and nutrient supply to crops, including optimum corn N fertilization requirement.

The determination of optimal N fertilization rates is difficult due to the complexity of N cycling, which can be altered with different soil tillage and cropping practices, such as cover crops or combination crop grain and biomass harvest. This report presents the results of two studies focused on evaluating corn N fertilization and crop productivity: 1) no-tillage corn-soybean production in a winter rye cover cropping system, and 2) continuous corn with contrasting tillage and rates of corn residue harvest.

Rye cover cropping system

Study sites were initiated at four Iowa State University Research and Demonstration Farms in the fall of 2008. The sites represent major crop production regions, soils, and climatic conditions in Iowa: Agricultural Engineering and Agronomy Research Farms, Ames (Clarion loam); Armstrong Research Farm, Lewis (Marshall silty clay loam); Southeast Research Farm, Crawfordsville (Mahaska silty clay loam); and the Northeast Research Farm, Nashua (Floyd loam). All sites are in a no-tillage corn-soybean rotation. Treatments are arranged in a split-plot design with four replications. The main plot is winter rye and no rye cover crop and the split plot N rate applied to corn (0 to 200 lb N/acre in 40 lb increments) as side-dress coulter-injected urea-ammonium nitrate (UAN) fertilizer shortly after planting. The winter rye variety is Wheeler, drilled after corn and soybean harvest at 1.0 bu/acre.

In 2008, post-harvest profile soil samples (0-3 ft depth in 1-ft increments) were collected to determine initial soil NO_3^-–N. Each year soil was sampled to determine profile NO_3^-–N in the early spring prior to planting and late spring in early June (0-1 and 1-2 ft) in corn plots that received no N fertilizer, and in the fall (0-3 ft depth in 1-ft increments) in the 0, 120, and 200 lb N/acre rates following crop harvest and before planting/growth of the rye cover crop.

The aboveground rye biomass was sampled in the spring before control with herbicide at five to ten random 1-ft^2 areas (number depending on rye growth), with calculated dry matter (DM) adjusted for rye row spacing. Soybean and corn were planted in 30-inch rows, with the planters equipped with residue cleaner attachments. The intended planting of soybean was any time after rye control, and the corn planting waiting at least 7 days after rye control in an attempt to reduce allelopathic or other effects of the cereal rye on corn establishment and growth. The intent was to not overly delay corn and soybean planting. If soil conditions allowed, the attempt was to kill the rye with glyphosate application in mid- to late April, but sometimes that was delayed due to wet soils.

A Crop Circle ACS-210 active canopy sensor (Holland Scientific, Lincoln, NE) was used to estimate corn canopy biomass (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 plot. 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. Corn economic optimum N rate (EONR) and yield at EONR (YEONR) were determined from regression models fit to the N rate response and using a 0.10 $/lb N:$/bu price ratio.

Rye cover crop production

Each year the rye was successfully established, but fall growth was low and variable due to fall climatic differences among regions and years. Most of the rye growth occurred in the springtime and varied among sites and years depending on spring temperatures, soil moisture and timing of rye control. With the intent to not overly delay corn and soybean planting, the rye growth was often limited due to spring temperatures and timeliness for control.

Cold spring temperatures limited rye biomass dry matter (DM) in 2009 at all sites (< 400 lb DM/acre), except prior to soybean planting at Crawfordsville (1,110 lb DM/acre) as a result of a longer period for growth due to wet soil conditions during the intended rye control and soybean planting time that delayed field activities (Table 1). As expected, since the aboveground rye DM was low, the total N present in that biomass was also low (< 11 lb N/acre) for most sites (data not shown). This confirms that late fall rye planting combined with slow growth in the spring due to cold temperatures and early spring control resulted in low residual N uptake. The wet conditions in the years of study also resulted in low residual soil nitrate (discussed later), which resulted in rye that was N-supply limited.

In 2010, warmer early spring conditions resulted in greater aboveground rye DM production (> 500 lb DM/acre) at all sites compared to 2009. Since the aboveground rye DM production in 2010 was greater than in 2009, the total N present in that biomass was also greater (10 to 40 lb N/acre) but still relatively low at all sites (data not shown). With the increase in rye residue, and in combination with extended cold and wet conditions after planting (early May), corn establishment, development, and early growth was significantly impacted at Ames and Crawfordsville (discussed later). In 2011, aboveground rye DM production was greater than in 2009 but lower than in 2010.

The study intended to allow time for rye growth in the spring, but control the rye and plant corn and soybean crops in a timely manner. This resulted in a shortened period for spring rye growth and biomass production. When soils were wet and limited planned field activities, this resulted in a longer period for rye growth and increased biomass and N uptake (ex. at Crawfordsville). However, that also delayed corn and soybean planting.

Table 1. Aboveground winter rye dry biomass (DM) before controlling growth with herbicide.

Year	Crop	Ames	Crawfordsville	Lewis	Nashua
		- - - - - - - - - - - - - - - - - lb DM/acre - - - - - - - - - - - - - -			
2009	Before corn	150	85	310	35
	Before soybean	290	1,110	195	190
2010	Before corn	1,460	1,000	1,245	1,020
	Before soybean	765	2,345	590	665
2011	Before corn	550	1,200	380	245
	Before soybean	640	1,510	555	320

Soil nitrate

Initial fall 2008 soil profile NO_3^-–N concentrations were low (≤ 3.0 ppm) at all sites (data not shown) indicating little residual soil NO_3^-–N at any depth and no clear trend by depth. The samples were collected before any N rate treatments were applied; therefore, reflect background concentrations for the crop rotations at each site.

In general, profile soil NO_3^-–N concentrations were low (< 5.0 ppm) each year at all sites and sampling times (data not shown), with rye showing the potential to reduce soil NO_3^-–N only in early spring (2.0 ppm with rye and 3.6 ppm without rye). Soil NO_3^-–N concentrations were the same with and without rye cover crop in early June. No difference in NO_3^-–N concentrations due to the rye was observed in the fall after crop harvest; however, increasing N rate resulted in more residual soil profile NO_3^-–N, but concentrations were low. Mean across sites, years, and soil depth were 2.0, 2.5 and 3.1 ppm for the 0, 120 and 200 lb N/acre, respectively.

Soybean yield

Except for the Ames site in 2009, where the soybean yield with rye was greater than without rye, having winter rye in the system had no effect on soybean yield (Table 2). The greatest potential for a soybean yield response to rye was at the Crawfordsville site since the rye at that farm had a long spring period for growth and largest biomass production; however, no statistical difference was observed in any year. During the three years of study, no growth issues were observed at any site that might affect soybean production.

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

Year	Cover Crop	Ames	Crawfordsville	Lewis	Nashua
		- - - - - - - - - - - - - - - - - bu/acre - - - - - - - - - - - - - - - - - -			
2009	Rye	58.4a†	69.0a	65.2a	56.5a
	No rye	54.2b	69.8a	66.0a	57.8a
2010	Rye	53.6a	63.1a	61.0a	64.9a
	No rye	53.1a	61.7a	62.9a	65.9a
2011	Rye	56.5a	49.4a	66.9a	61.5a
	No rye	55.7a	53.8a	66.0a	62.0a

† Yields with the same letter within a site and year are not significantly different, $p \leq 0.05$.

Corn response

Corn had large growth response to applied N each year (Figure 1). The canopy NDVI values increased as N rate increased from zero N to maximum response (approximately 80 lb N/acre rate at the V10 growth stage). This indicates deficit N at low rates and no further increase in canopy response at rates greater than plant need. The winter rye cover crop did not influence corn canopy NDVI values in 2009; however, NDVI values were lower with rye in 2010 and

2011, especially in 2010. Greater rye DM production, combined with negative growth influences from cold and wet spring conditions, resulted in a greater negative rye cover crop effect on early season corn growth and development that year. Also, planter row residue removal was not adequate in 2010 at the Ames site, which also increased the negative influence of the rye on corn plant establishment and early growth. In addition, there was armyworm infestation that resulted in some plant damage and required an insecticide control at the Ames and Lewis sites in 2010. This also impacted early corn plant growth and corn canopy biomass.

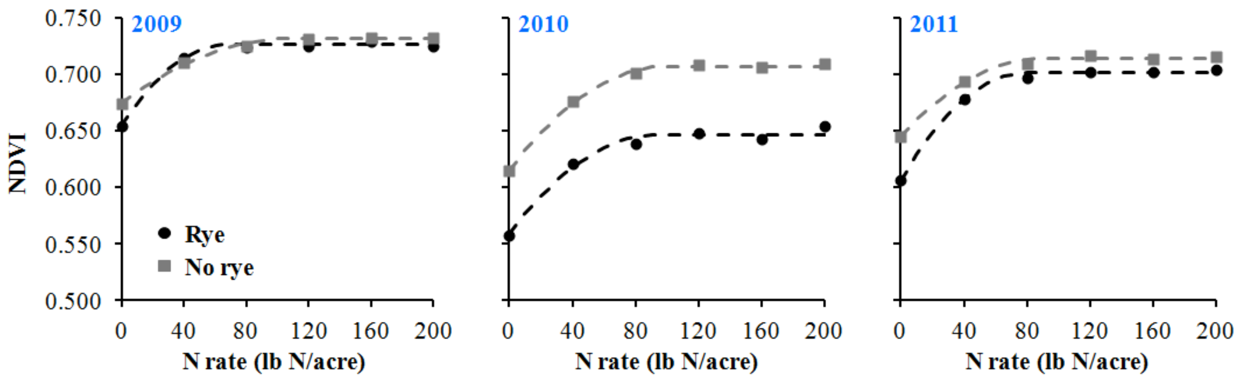


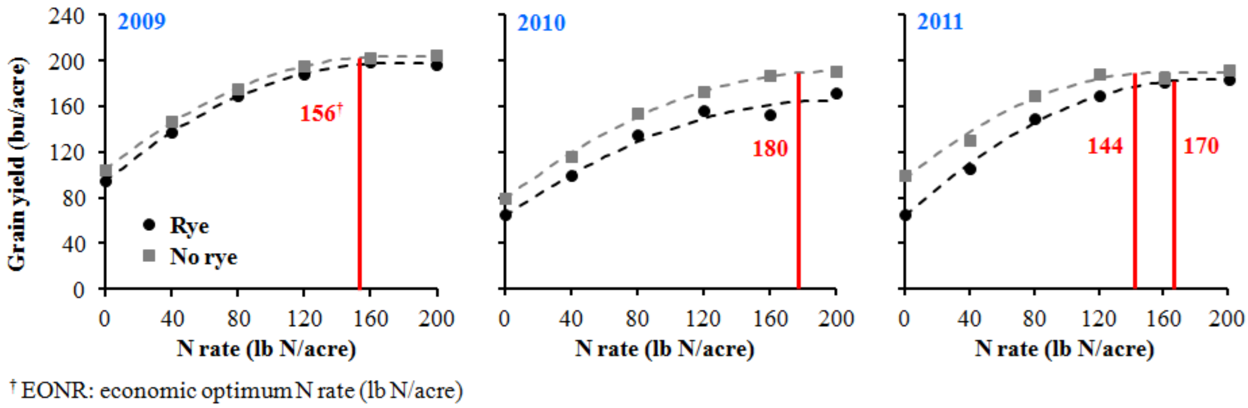
Figure 1. Corn plant canopy NDVI response to N rate across sites with and without winter rye.

Corn grain yield increased with N application at all sites each year (Figure 2). In 2009, and due to low rye DM production, the corn yield N response was the same with or without the rye cover crop, although the yield at the EONR was 6 bu/acre lower. In 2010, corn yields with the rye cover crop were much less across N rates than without the rye. At the EONR, corn yield with rye was considerably lower (26 bu/acre). In 2011, corn yields were reduced with the rye at lower N rates, but only 6 bu/acre less at the EONR. These yield responses would be a reflection of the rye effect on corn establishment and early growth. Despite the effect on corn yield, the EONR was the same with and without rye in 2009 and 2010 (Figure 2), and slightly higher (26 lb N/acre) in 2011 due to differences at two sites that year (Crawfordsville and Lewis, individual data not shown). Each year the EONR was high for a soybean-corn rotation, a reflection of the wet conditions each year.

Having rye preceding corn resulted in reduced corn grain yield, with an across sites and years mean of 13 bu/acre or 7% lower yield. The EONR across sites and years was similar with or without rye, only 5 lb N/acre higher for corn in the rye system. Overall, having corn planted after rye resulted in decreased yield, but limited effect on corn N fertilization rate requirement. This does indicate potential for lower corn N use efficiency with the rye cover crop system. Other plant measurements in this study may provide more information about that.

Summary

Including a rye cover crop in the corn-soybean no-tillage cropping system resulted in reduced soil NO_3^-–N early in the spring although all soil NO_3^-–N concentrations were low, had no effect on soybean grain yield, resulted in reduced corn grain yield, and no average effect on corn EONR. The three years of study had wet growing season conditions, which resulted in higher than normal response to applied N and EONR. Data from a long-term period will help confirm the crop responses in the rye cover cropping system and potential need for adjusting the N fertilization requirement in corn.



	Yield at the EONR (bu/acre)		
Cover crop	**2009**	**2010**	**2011**
Rye	197	167	183
No rye	203	190	189

Figure 2. Corn grain yield response to N rate across sites with and without winter rye.

Corn residue harvesting

Field sites were established in the fall of 2008 at two Iowa State University research farms representing contrasting soils and climatic conditions in Iowa; Agricultural Engineering and Agronomy Research Farms, Ames (Canisteo silty clay loam) and Armstrong Research Farm, Lewis (Marshall silty clay loam). The experimental design was a randomized complete block with three replications. The main plot was tillage system (no-tillage and fall chisel plow with spring field cultivation), split plot corn residue removal rates (0, 50, and 100%), and split-split plot N fertilization rates (0 to 250 lb N/acre in 50 lb increments) as coulter-injected urea-ammonium nitrate (UAN) solution shortly after planting. Corn residue was removed in the fall by raking and bailing before tillage (Figure 3).

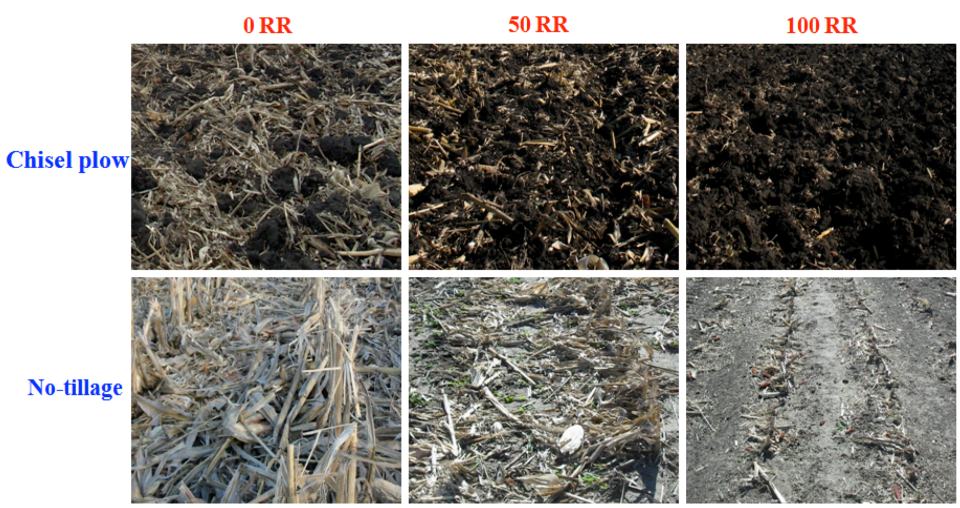


Figure 3. Pictures of the soil surface after tillage and residue removal (RR).

In the fall of 2008, post-harvest profile soil samples (0-3 ft depth in 1-ft increments) were collected to determine initial soil NO_3^-–N. After establishment of the study sites, soil was sampled early in the spring prior to planting and early June (0-1 and 0-2 ft) in corn plots not receiving N fertilizer, and post-harvest in the 0, 150, and 250 lb N/acre rates (0-1, 1-2, and 2-3 ft) to determine soil profile NO_3^-–N. A Crop Circle ACS-210 active canopy sensor was used to estimate NDVI at the mid-vegetative (V10) corn growth stage. Corn grain yields were determined by harvest with a plot combine and reported at 15.5% moisture. Corn EONR and YEONR were determined from regression models fit to the N rate response using a 0.10 $/lb N:$/bu price ratio.

Soil nitrate

Initial soil profile NO_3^-–N concentrations across sites and depths were low (< 5 ppm) (no soil NO_3^-–N data shown). This indicates little residual NO_3^-–N and low background levels from the previous corn production. Across sites and years, tillage and residue removal did not affect soil profile NO_3^-–N in the spring (plots with no N applied). A NO_3^-–N concentration difference was measured between spring preplant and early June, however, the difference was small and could be an indication of low net mineralization or corn N uptake. All spring NO_3^-–N concentrations were quite low (≤ 3 ppm). Post-harvest soil samples did not show an effect of tillage system or residue removal rate on soil profile NO_3^-–N concentrations. Soil NO_3^-–N concentrations were low across sites and years, and only increased when 250 lb N/acre were applied in 2009 (3.0 ppm) compared to the 0 and 150 lb N/acre (2.0 ppm). These low profile NO_3^-–N concentrations would be the result of the wet conditions each year, and the continuous corn yield response to high N rates.

Corn response to nitrogen application

Canopy NDVI values indicated N stress with no applied N and low N rates, and also indicated the plant biomass increase and reduction in N stress with increasing N rate (Figure 4). Across years, corn had higher NDVI values at the V10 growth stage when the soil was tilled. This indicates increased corn plant biomass when using chisel plow as a soil management practice compared to no-tillage. Corn also had higher NDVI values when residue was removed, including when no N was applied. This indicates greater soil N supply to corn with crop residue removal. The N rate where the NDVI values plateaued was lower with residue removal (data not presented, but shown in Figure 4). These results indicate increased corn plant biomass and lower N rate stress with tillage and full or partial residue removal, and is likely a reflection of changes in soil conditions with tillage and residue removal that influence early season crop growth; such as differences in N availability, soil temperature, and soil N mineralization/immobilization associated with degradation of high C:N ratio corn stover.

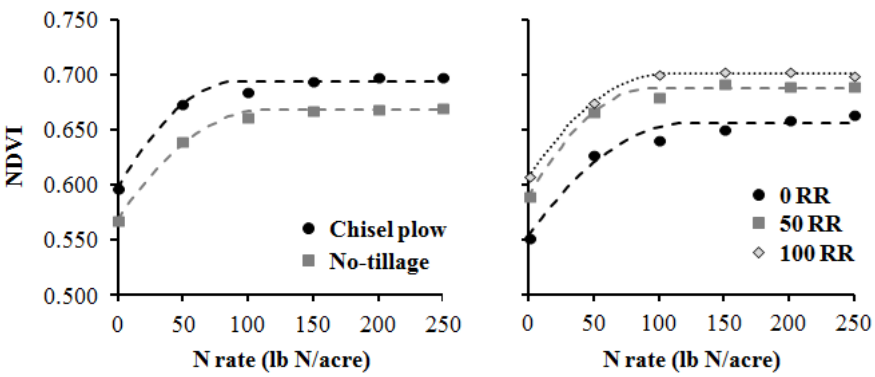
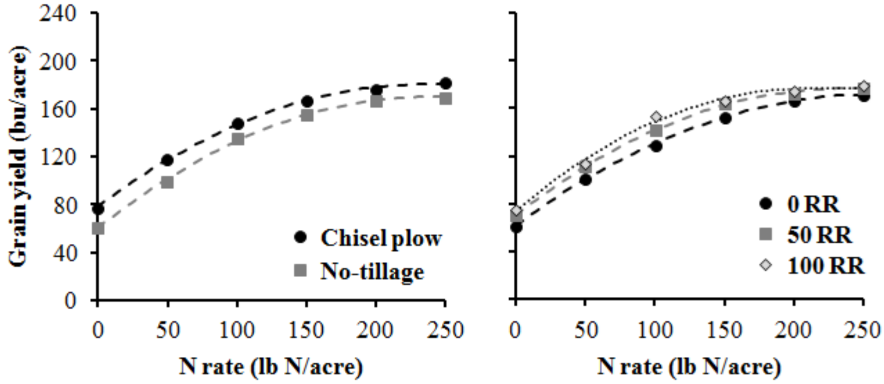


Figure 4. Corn canopy NDVI response to N rate across sites as affected by tillage system (left) and residue removal rate (right).

Corn grain yield increased with N application at each site each year. Yield across sites and years with the chisel plow system was 14 bu/acre higher compared to no-tillage, with that difference consistent across N rates (Figure 5). The removal of corn residue increased corn grain yield an average across N rates of 9 and 13 bu/acre for the 50 and 100% removal, respectively. As N rates approached the highest applied rate, however, the difference between residue removal and no removal decreased and at the YEONR was only 5 bu/acre lower when no residue was removed. These yield results reflect the canopy NDVI values measured at V10 and the lower corn plant stress when residue from the previous corn crop was harvested.

Tillage system had no differential effect on N response or EONR (Figure 5). Crop residue harvest, however, resulted in lower EONR than with no removal. The EONR with the 50 and 100% residue removal was 20 and 41 lb N/acre less, respectively, than with leaving all previous corn crop residue. The EONR values were quite high due to continuous corn and years with above normal rainfall.



Treatment		EONR† (lb N/acre)	YEONR† (bu/acre)
Tillage	Chisel plow	206	179
	No-tillage	210	168
Residue removal	None	228	170
	50%	208	175
	100%	187	175

† EONR, economic optimum N rate; YEONR, yield at the economic optimum N rate.

Figure 5. Corn grain yield response to N rate across sites as affected by tillage system (left) and residue removal rate (right).

Summary

The use of chisel plowing as a soil management practice increased corn plant response to applied N compared to no-tillage (V10 stage crop canopy NDVI values). Corn grain yield was 11 bu/acre (6%) lower with no-tillage at the YEONR, with no difference in EONR between tillage systems. In this continuous corn system, harvesting the previous corn crop residue increased mid-vegetative corn plant growth (canopy NDVI values); increased corn yield across all N rates by 9 and 13 bu/acre with the 50 and 100% residue removal, respectively, however, the difference at the EONR was only 5 bu/acre (3%); and decreased EONR by 20 lb N/acre (9%) and 41 lb N/acre (18%), with 50 and 100% residue removal, respectively. These results indicate a change in short-term conditions with corn residue harvesting that influences corn growth, yield, and N response. Likely factors include soil N availability, N immobilization/mineralization, high C:N ratio corn stover decomposition, and soil temperature. Long-term study will help confirm crop and soil responses across tillage systems and residue removal rate, and needed change in corn N fertilization requirement in a continuous corn system.

Acknowledgments

The rye cover crop project is part of a regional collaborative project supported by the USDA-NIFA, Award No. 2011-68002-30190, “Cropping Systems Coordinated Agricultural Project (CAP): Climate Change, Mitigation, and Adaptation in Corn-Based Cropping Systems.” Project Web site: sustainablecorn.org. This project is also supported in part by the Iowa Department of Agriculture and Land Stewardship, Division of Soil Conservation, through funds appropriated by the Iowa General Assembly. The corn residue harvesting project was supported in part by the Iowa State University Agronomy Department Endowment. Appreciation is extended to the personnel of the Iowa State University research and demonstration farms for their support of field activities.