# YIELD RESPONSE OF CONTINUOUS CORN TO RESIDUE REMOVAL, TILLAGE, AND NITROGEN RATE

BY

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THESIS

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ABSTRACT

Removing corn residue for use as biofuel may require adjustments in tillage systems and nitrogen rates. Research was conducted at DeKalb, Monmouth, Urbana, and Perry, Illinois to examine the response of three residue removal rates (full, partial, and none) and two tillage treatments (no-till and conventional (chisel) tillage) to four N rates (60,120, 180, and 240 lb N/acre) for five years, with years three through five examined here. Removing all of the residue raised yields in eight of the twelve site-years under no-till, but not when plots were tilled. At high N rates, there was not a significant difference in yields between conventional tillage and no-till in six of the twelve site-years tested when averaged across residue treatments. However, in the remaining six site-years, conventional tillage yielded significantly more than no-till in five of them, by an average of 12 bu/acre. When averaged from 2008 to 2010 across locations, conventional tillage yielded 12 bu/acre more than no-till under high N rates. Removing all or part of the residue increased yields by 10 bu/acre across years and tillage treatments. No-till with no residue removed yielded an average of 24 bu/acre less than all other residue-tillage treatment combinations at high N rates. No-till with partial residue removal yielded 17 bu/acre more than no-till with no residue removal, but was still significantly lower than the other 4 treatment combinations. Under conventional tillage, all three residue treatments showed a similar response to N rates across years, with yields increasing as more N was applied, and reaching a plateau between 150 and 200 lb N/acre at most locations. Under no-till, full and partial residue removal showed a very similar response to N rates as conventional tillage, but no residue removed required more than 200 lb N/acre to achieve maximum yields at every location except Urbana. This study suggests that the effects of residue removal depend on the

tillage system in place. Removing residue increased yields in no-till, but decreased them in conventional tillage.

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# INTRODUCTION

In 2008, 2009, and 2010, an average of 79.8 million acres of corn were harvested for grain in the United States, yielding an average of 157 bu/acre (USDA NASS, 2011). According to the "billion ton study," equal weights of grain and stover are produced by corn plants (Perlack et al., 2005). At a 1:1 ratio, about 300 million dry tons of corn stover were produced each year between 2008 and 2010. Of this stover, the billion ton study estimated that about 75 million tons could be collected with current tillage practices and collection practices.

Of the approximately 80 million acres of corn planted every year, the USDA's economic research service (ERS) projects that about 30% were under no-till management in 2009 (Horowitz et al., 2010). Crops planted under no-till systems can have delayed emergence because of cooler soils (Vyn and Raimbault, 1993). They found that all both fall and spring tillage increased yields over no-till. A 20-year study in Kentucky showed that the advantage of conventional tillage is highest right after plot establishment, with the difference between no-till and conventional tillage becoming smaller over time (Ismail et al., 1994). However, no-till systems can help reduce evaporation and help the crop use available water more efficiently (Dick et al., 1992).

When precipitation was below average, residue in the field can helped increase yields compared to plots with residue removed (Doran et al, 1984; Maskina et al., 1993; Coulter and Nafziger, 2008). When precipitation is average however, there was no significant difference whether or not residue was removed (Linden et al, 2000). Removing residue can also lower the crop's available water, by reducing infiltration rates during precipitation events. (Blanco-Canqui and Lal, 2007).

While tillage has no effect on fertilizer N uptake, soils that are plowed had 29% higher soil nitrogen uptake (Meisinger et al., 1985). The increased uptake of soil N allowed tilled plots to have better yields at low N rates than minimum tillage, but the yields were similar at high N rates (180 kg N/ha). Post-harvest soil nitrate levels were lower no-till than in minimum till and conventional tillage in an annual rotation of spring wheat, winter wheat, and sunflowers (Halvorson et al., 2001). Under irrigation, continuous corn had similar nitrogen fertilizer use efficiency between conventional tillage and no-till (Halvorson et al., 2006). Grain yields in no-till showed more of a linear response to N rate than conventional tillage, with conventional tillage having 16% higher maximum yields.

Coulter and Nafziger (2008) found that during years with lower than average rainfall, removing residue reduced not only the overall yields in no-till, but also the response to N rate (2008). They found that the EONR was 37% lower when all of the residue was removed, and the grain yields at the EONR were 17% lower compared to leaving all of the residue in place. Conversely, under conventional tillage, removing residue increased yields during years in which water was a limiting factor. In locations with adequate rainfall, residue removal had no effect on yields under conventional tillage. However, removing all or part of the residue in no-till plots increased yields by 8% compared to leaving all of the residue in place. There was not a significant difference in response to N rate between tillage treatments under normal rainfall conditions. The purpose of the current work was to study the continued effects of these treatments on grain yields and their response to N rate.

## LITERATURE REVIEW

### Conservation Tillage

"Conservation tillage is often defined as any crop production system that provides either a residue cover of at least 30% after planting to reduce soil erosion due to water or at least 1000 pounds per acre of flat, small grain residues (or the equivalent) on the soil surface during the critical erosion period to reduce soil erosion due to wind." (Simmons and Nafziger, 2009). In no-till operations, the soil is left completely undisturbed between harvest and planting. However, strip-till, ridge-till, and mulch-till allow for some soil disturbance, most often in the form of nitrogen application, deep tillage, or seedbed preparation.

Soil erosion has long been a factor when considering tillage operations, and the Food Security Act of 1985 allowed the government to mandate that farmers adhere to approved guidelines when farming on highly erodible land. According to the USDA Natural Resource Conservation Service (NRCS), a conservation plan on highly erodible land must "result in a substantial reduction in erosion" and "prohibit a substantial increase in erosion" (USDA/NRCS, 2006).

### Effects of Residue Removal on Soil Characteristics

Residue and SOC accumulating at the soil surface under no-till agriculture may be a concern when determining what type of N fertilizer to apply (Rice and Smith, 1983). They found that in two of three soil types, twice as much surface applied N fertilizer was immobilized in no-till than in plowed soils (14 vs 7%) after only seven days. On the third soil type, the no-till soils also immobilized twice as much fertilizer N as plowed soils, except that it wasn't significantly different until 35 days.  A study by Aulukh et al. (1984) found that adding wheat straw plus 100 kg N $ha^{-1}$ to fields doubled the amount of gaseous N lost over the course of a growing season compared to just 100 kg N $ha^{-1}$. Under no-till, 22.51 kg N $ha^{-1}$ was lost when fertilizer plus straw was added compared to 11.88 kg N $ha^{-1}$ with only fertilizer. When conventional tillage was performed, adding straw with the fertilizer increased the gaseous N loss from 4.28 to 7.25 kg N $ha^{-1}$.  When compared to no-till, conventional tillage plots had significantly higher N fertilizer immobilization. They concluded that the straw supplied energy to the microorganisms for immobilization.

A study in Connecticut showed that after 28 years, removing residue on no-till corn plots did not negatively affect soil organic carbon storage at the 0 to 15 cm depth (Hooker et al., 2005). However, in plots that were disked in the spring following fall moldboard plowing, removing corn residue resulted in significantly lower SOC levels. Clapp et al. (2000) found that when corn residue is returned to the plots, the SOC already in the soil takes longer to be broken down. When N was added to the plots separately from the residue, the SOC was broken down more quickly. However, when the N fertilizer was mixed with the residue in no-till and chisel plow plots the original SOC took much longer to break down.

Soil compression characteristics can be influenced by residue in or on the soil (Gupta et al., 1987). Laboratory tests determined that if the residue is uniformly distributed throughout the soil in amounts found in normal farming systems, it has little effect on compression characteristics of the soil. However, tractor traffic in a soil bin indicated that residue on the soil surface decreased the stress at 200 mm depth and tire sinkage when compared with bare soil. Soil bulk density increased when corn residue was removed from plots in Ohio, but there was no difference between 100% and 200% residue rates (Blanco-Canqui et al., 2006b). The soil bulk density was significantly reduced by residue left on the surface within one year. Volumetric water content decreased as more stover was removed, except during winter months.

The water infiltration rate was lower when residue was removed for two out of three soils in a study by Blanco-Canqui and Lal (2007). Stover removal also decreased the plant available water in the zero to six cm layer in all three soils. They found that corn plants in plots with at least 75% of stover removed were significantly taller during the first two weeks after emergence.

Klocke et al. (2009) found that evaporation from the soil covered with corn or wheat residue (89 to 100% surface coverage) had lower evaporation than bare soil in each of three years. They found that as the corn developed, evaporation in all plots declined in two of the three years; the increased evaporation in the third year was attributed to increased penetration of sunlight due to hail.  A study of data from three sites in Iowa, Colorado, and Washington analyzed data using the Simultaneous Heat and Water (SHAW) model to simulate freezing and thawing of soil (Flerchinger et al., 2003). Thirty-year simulations were run for four locations: Boise, ID, Spokane, WA, Des Moines, IA, and Minneapolis, MN. The results of the simulation showed that bare soil had the highest evaporation rates at all of the sites. In climates with more available water, residues that lay flat on the soil surface had the lowest evaporation. They found that soil warming for bare soil and flat residues were delayed by as much as five to nine days.

A three year study in Southern Wisconsin with corn planted for two growing seasons prior to data collection compared residue rates of 0, 1x, 2x, and artificial residue (fiberglass) at

1x level (Andraski and Bundy, 2008). They found that residue levels established after harvest did not have much effect on pre-plant soil nitrate levels. The artificial residue and normal residue rate had similar nitrate concentration changes from pre-plant to pre-sidedress. They concluded that soil temperature was the main factor affecting corn growth, rather than N immobilization or addition from the residue treatments. However, Yakle and Cruse (1983) found a significant residue age and residue placement effect on corn dry root and dry shoot weight. Residues placed below the seed decreased dry root and shoot weights of young corn plants. Fresh residue had a much larger impact on dry weights than partially decomposed residue, suggesting possible phytotoxic effects of fresh corn residue.

Both tillage and residue management can impact early growth and development of corn by affecting the temperature of the soil. Corn begins to germinate when the soil has warmed up to approximately 10˚ C (Hoeft et al., 2000). A tillage system study in central Iowa showed that as the amount of residue left over the seed zone increased, the average early growing season soil temperature decreased (Mock and Erbach, 1977).

Residue management within the seed row can provide the benefits of both residue removal and soil tillage (Kaspar et al., 1990). When residue cover was added back to the soil after tillage, moldboard plowing did not increase corn yields when compared to no-till. By removing the residue from the seed row in no-till systems, the soil can warm faster, resulting in more vigorous corn seedling growth. Removing an 8 cm band in the row resulted in a 2.5 day reduction in emergence time and a yield increase of 0.31 Mg $ha^{-1}$. As the residue free bands widened, the magnitude of response decreased. They concluded that the best compromise may be a 16 cm residue free band, which results in only a 3% yield reduction under central Iowa conditions.

Surface cover within the row was shown to have a positive linear relationship with the additional number of growing degree days required for emergence (Swan et al., 1987). Because of this, during years in which there were too few growing degree days to reach the maturity threshold, plots with high residue cover had decreased yields due to the corn plant failing to reach full maturity. Similarly, Johnson and Lowery (1985) found that conservation tillage reduced the soil temperature in the upper five cm. No-till, chisel till, and till-plant treatments had 3.4, 1.4 and 1.0˚ C lower soil temperatures at a five cm depth than moldboard plowing three days before planting in 1982. Corn seedling growth rates were reduced the most in no-till, followed by chisel plowing and till plant.

Effects of Tillage on Soil Characteristics

Tillage operations affect the addition (sequestration) or loss of soil organic carbon (SOC). Under no-till operations, SOC begins to accumulate near the surface (Dick, 1983). In 18- and 19-year studies on two different soil types in Ohio, SOC concentrations in the 0 to 1.25 cm profile were 2.2 to 2.5 fold higher in no-till than with moldboard plow tillage or moldboard tillage plus pre-plant tillage. SOC concentrations were higher for no-till down to 7.5 cm, but at deeper levels SOC concentrations differed among soil types. Plots with Hoytville soil had significantly higher SOC concentrations from 7.5 to 15 cm under no-till than under tillage plots, but below 15 cm, plots with tillage treatments had higher SOC concentrations. However, in the Wooster soil, SOC concentrations were not significantly different between tillage treatments below 7.5 cm.

A study by Wander et al. (1998) found that while soil carbon and particulate organic matter increased in the zero to five cm profile under no-till at two of three Illinois locations (Monmouth and Perry), overall carbon sequestration rates were higher at only one location (Monmouth). At DeKalb, whole soil and particulate organic matter carbon below the zero to five cm profile was significantly lower under no-till when compared to conventional tillage. A study in France also found distinct stratification under no-till corn production (Balesdent et al., 1990). They found that 75% of the organic carbon in the zero to thirty cm layer was in the zero to five cm range. However, they found that between 10 and 20% of the total carbon returned to the soil was much deeper, (30 to 80 cm range).

A tillage study using fields in Kansas that had been in tillage studies ranging from 15 to 40 years also showed that changes between no-till and tilled plots occurred mostly in the zero to five cm range (McVay et al., 2006). They found that at the zero to five cm depth no-till plots had significantly higher soil organic carbon (measured as Mg $ha^{-1}$) than reduced till or conventional tillage at four out of five locations. Mahboubi et al. found similar results in a 28-year continuous corn study in Ohio (1993). They found that in the top 0 to 15 cm, the average organic carbon levels across both sites for no-till was 85% higher than for chisel plow, and 163% higher than for moldboard plow.

A projection by Lee et al. (1993) that utilized data from 100 randomly selected sites throughout the U.S. using the Erosion Productivity Impact Calculator model showed that the current trend towards adoption of conservation tillage practices will increase the carbon content in the top 15 cm by 0.2 kg $m^{-2}$ over the next 100 years. No-till practices would increase carbon content of the same layer by 0.4 kg $m^{-2}$, and a no-till system with a winter cover crop would increase it by 0.8 kg $m^{-2}$. A global analysis of published data from experiments longer than five years in duration showed that a transition from conventional tillage to no-till sequesters 57 ± 14 grams of C $m^{-3}$ per year (West and Post, 2002). They found that carbon sequestration rates reach their maximum in five to ten years, and that by 15 to 20 years after the transition, they decline to near zero.

McCarty et al. (1998) studied the effects of tillage treatments on stratification of soil carbon to assess how quickly different layers developed. They found that during the transition from conventional tillage to no-till, stratification happens in a relatively short time period. During the first three years, SOC levels in the 0 to 2.5 cm range increased by about 38% (3 mg C per g soil). The change in the 2.5 to 5 cm range was slightly positive (between 0 and 1 mg C per g soil), and both the 5 to 12.5 and 12.5 to 20 cm ranges decreased slightly (between 0 and -1 mg C per g soil). After three years, the total soil N in the 0 to 2.5 cm layer increased by 30% (more than 0.15 mg N per gram of soil) and the 2.5 to 5 cm increased slightly (less than 0.05 mg N per gram soil). The deeper layers from 5 to 12.5 and 12.5 to 20 cm decreased only slightly (less than -.05 mg N per gram of soil) (McCarty et al., 1998). Biomass N in the top 0 to 2.5 cm layer increased by 87%. Similarly, Al- Kaisi and Yin (2005) found that both no-till and strip till significantly increased both the SOC and the mineral fraction carbon (MFC) in the 0 to 5 and 5 to 10 cm ranges after 3 years when compared to chisel plow tillage. They found that both no-till and strip-till had more than 30 and 35% higher SOC and MFC than chisel-till, respectively.

Blanco-Canqui et al. (2009) found that no-till soils were less susceptible to compaction than soils under conventional tillage and moldboard plowing. They found that plowed soils compacted more easily than no-till soils under the same water contents and compactive forces, and plowed soils became compacted at lower water contents. They found that maximum soil bulk density had a negative correlation with SOC concentrations. They concluded that the no-till-induced increase in SOC decreased the amount of compaction compared to plowed soils. Contrasting results were found in a tillage study in Kansas on fields that have been in tillage studies ranging from 15 to 40 years (McVay et al., 2006). Soil bulk density at the zero to five cm depth was higher under no-till in two out of five locations with no significant difference at the other three.

In a 28 year study in Ohio, Mahboubi et al. (1993) found that within the tire traffic zone, there was no difference in moisture release characteristics between no-till, chisel plowing, and moldboard plowing. In the non-compacted row zone, they found that no-till treatments lost less water than the moldboard and chisel plowed treatments when suction tests were performed on undisturbed soil cores. Blanco-Canqui et al. (2009) found that small aggregate particles in dry no-till soils (4.75-8 mm, -155 MPa) required twice the kinetic energy by raindrops to dislodge them than soils under chisel and moldboard plowing at three of four locations, and 1.5 times more kinetic energy at the fourth site. At field capacity (-0.03 MPa), the kinetic energy to disintegrate aggregates was between 1.5 and 4 times higher for no-till than chisel and moldboard plowing. They found that between 35 and 50% of the variability in aggregate resistance to raindrops was due to increases in soil organic carbon from no-till practices.

A study on five silt loams soils and one silty clay loam in Kentucky showed that in well-drained soil, plowed treatments had higher net N mineralization than no-till treatments (Rice et al., 1987). When the soils were poorly drained, the no-till plots had higher net N mineralization.

All of the plots had tall fescue (*Festuca arundinacea* Schreb.) growing in them prior to the tillage treatments being applied.

Effects of Residue and Tillage on Yields

A three year study in Nebraska to determine the effects of residue on no-till soils determined that complete residue removal resulted in a 21% grain yield reduction for corn when averaged over all three years (Doran et al., 1984). However, heat and drought negatively affected yields during one of the years, and removing all of the residue that year resulted in a 75% yield reduction. During the other two years of the study, complete residue removal reduced yields by 19 and 13% when compared to zero residue removal (although the 19% yield reduction was not statistically significant). Over 13 years, when precipitation was average or slightly lower than average in Minnesota, there was no significant difference in corn yields between plots with residue removed or returned (Linden et al., 2000). In years that were drier than average, plots with residue returned had 22% higher yields than those with residue removed. Similarly, a study in Eastern Nebraska found that while tillage was not significant, plots with 150% of the amount of stover from the previous years' crop had 16% higher yields than plots with no residue (Maskina et al., 1993). Addition of 150% stover levels increased soil organic matter and total N by 10 and 12%, respectively, compared to plots with residue removed.

A study on soils in a long term tillage experiment found that removing corn stover after harvest reduced both grain and stover yields in sloping, erosion-prone, unglaciated soils (Blanco-Canqui et al., 2006a). They found that this happened in a relatively short period (17 months) on sloping soils. Dick et al. (1991) found that when converting a field to no-till, initially no-till yields are lower than those under conventional tillage. However, over time no-till practices increased yields when compared to conventional tillage for well drained soils. On poorly drained soils, they found that conventional tillage always had higher yields, though these yield differences decreased over time.

A long-term tillage experiment in Ontario showed that no-till treatments had a two-day delay in emergence time when compared to fall moldboard and chisel plowing followed by secondary tillage in the spring (Vyn and Raimbault, 1993). Over the 15 years of the study, the average grain yields for no-till were significantly lower than those under any of the tillage treatments. Fall moldboard plowing, fall chisel plowing and spring moldboard plowing had approximately 16%, 10% and 7% higher yields, respectively, than no-till. They found that after a conversion to no-till corn, the yields tended to increase in comparison to fall plowing during the first eight years. In Kentucky, researchers found that over a 20-year period, during which continuous corn was grown, no-till had higher yields in seven years, conventional tillage had higher yields in six years, and yields were not significantly different in seven years (Ismail et al., 1994). The plots were established on soil that was previously a long term bluegrass horse pasture. All six years in which conventional tillage had higher yields than no-till occurred in the first twelve years of the experiment. During that period, no-till had higher yields than conventional tillage only three times. During the final seven years (no grain yield was recorded in one year due to extreme drought) no-till had higher yields than conventional tillage in four years.

Labeled ammonium sulfate or ammonium nitrate was used to study corn nitrogen utilization differences between minimum tillage practices and moldboard plow tillage

(Meisinger et al., 1985). They found that tillage practices did not have a significant effect on fertilizer N uptake. However, plow tillage had more soil nitrogen uptake late in the season than minimum tillage practices. Plow tillage had higher grain yields at low rates of nitrogen fertilizer, but the yields were similar at high N rates. They did not find a significant tillage effect on fertilizer N uptake by the corn plants. Similarly, Halvorson et al. (2006) found that continuous corn under no-till and conventional tillage had a similar response to nitrogen fertilization. There was a significant N rate response within each tillage group, with conventional tillage having 16% higher yields than no-till. Both tillage systems had a 43% nitrogen fertilizer use efficiency across N rates and years.

Coulter and Nafziger (2008) performed the first two years of research on the combined effects of residue removal and tillage treatments on yields at four Illinois locations. In their experiment, both dry and normal conditions were present, with residue removal providing different effects between the two. They found that under dry conditions (Perry, IL), full residue removal reduced yields by 10.3% on no-till fields compared to no residue removal. Removing residue also decreased the EONR by 37% and the yields at the EONR by 17% on no-till. In the chisel-till plots, full residue removal had 12% higher yields than no residue removal. However, the dry conditions only occurred at one location, and that location did not ever experience normal growing conditions during the experiment.

Under better-watered conditions (Monmouth, DeKalb, and Urbana, IL) the effect of residue removal on no-till fields was reversed, with no residue removal having 8.4% lower yields than full residue removal. In the chisel-tilled fields, no differences were observed under normal conditions between residue treatments. Full and partial residue removal had a similar yield response to N fertilization, with identical EONRs and yield at EONR. When none of the residue was removed, the EONR increased by 13%, but the yield at EONR decreased by 4%. Overall, they found that when moisture was limited, only no-till had a significant grain yield response to N rate. They theorized that leaving the residue in place in no-till systems conserved additional soil moisture, allowing the crop to respond to N fertilization. When there was adequate moisture present, removing residue from the plots resulted in chisel-till and no-till plots having similar grain yields. However, when residue was left in place, chisel-till had higher yields than the no-till plots. Residue removal appears to be beneficial because less fertilizer N was required across tillage systems, likely due to reduced immobilization of N by microbes decomposing the residue.

# MATERIALS AND METHODS

## Design

This experiment was described in detail by Coulter and Nafziger (2008). The experiment was laid out as a split-split plot design in a randomized complete block design with four replications. The main plot was residue removal (full residue removal, partial residue removal, and no residue removal). Full residue removal was achieved by chopping the corn stover, raking it into windrows, baling, and removing it. To achieve full removal, hand raking additional stover was required. For partial residue removal, the plots were raked and baled, followed by chopping the remaining stover to achieve uniformity. Based on visual observation, we estimated that the partial removal treatment removed about 50% of the corn stover. Plots with no residue removed were chopped following harvest.

The spit plots were tillage treatments (no-till and conventional tillage). Conventional tillage consisted of chisel plowing in the fall to a depth of 25 cm, and using a field cultivator in the spring to prepare the seedbed to a depth of nine cm. The split-split plots were nitrogen rates (60, 120, 180 and 240 lb/acre). Each treatment remained in the same plot every year. Residue and tillage treatments were established as soon after harvest as possible.

Residue and tillage treatments were established in the fall following harvest each year unless noted. Plots were planted using a no-till planter positioned approximately halfway between the rows from the previous year's crop. Crop yields were determined by harvesting the center two rows along the length of the plot. The split-split plots were 6.1 m wide (eight 76 cm rows) by 8.1 to 13.1 m long, depending on location.

Soil P, K, and pH were maintained according to recommendations from the Illinois Agronomy Handbook (Fernandez and Hoeft, 2009). Weeds were controlled using both pre-emergence and post-emergence herbicides (depending on need) which varied by year and location.

DeKalb

The DeKalb trial was located at 41°55'N, 88°45'W, and was established on Flanagan silt loam soil (fine, smectitic, mesic, Aquic Argiudolls). Nitrogen in the form of 28% UAN was injected after planting. The plots were planted with Pioneer hybrid 33N12 at 39,000 seeds acre$^{-1}$ on 5 May 2008, and N was applied on 23 June 2008. Due to weather conditions, residue was not removed from the plots until spring for the 2009 growing season. Tillage and planting both occurred on 23 May 2009. Pioneer hybrid 34F97 was planted at a population of 38,000 seeds acre$^{-1}$, and N was applied on 24 June 2009. Due to wet conditions, grain harvest was delayed until 2-4 December 2009, and so residue was not removed until spring 2010 for the 2010 growing season. Tillage occurred on 15 April 2010, and plots were planted with Pioneer hybrid 33W84 on 28 April at 36,000 seeds acre$^{-1}$. N was applied the day after planting, and harvest occurred on 12 October 2010.

Monmouth

The Monmouth trial was located at 40°54'N, 90°38'W, on a Muscatune silt loam (fine-silty, mixed, superactive, mesic, Aquic Argiudolls). N was applied as injected 28% UAN solution before planting. The plots were planted with corn hybrid DeKalb 61-69 at 36,500 seeds acre$^{-1}$ on 5 May 2008, and harvest was on 10 October 2008. Pioneer hybrid 35K04 was planted at

36,500 seeds acre$^{-1}$ on 6 May 2009, and harvest was on 12 October 2009. The plots were planted with DeKalb hybrid 59-35 at 37,600 seeds acre$^{-1}$ on 20 April 2010. Grain harvest was on 13 September 2010.

Urbana

The Urbana trial was located at 40°6'N, 88°12'W, on a Flanagan silt loam (fine, smectitic, mesic, Aquic Argiudolls). N was injected as 28% UAN sidedressed approximately by stage V5-V6. Plots were planted with Pioneer hybrid P32T85 at 36,000 seeds acre$^{-1}$ on 1 May, 23 May and 22 April, 2008, 2009, and 2010, respectively. Following late harvest in fall 2009, residue removal and tillage were delayed until spring 2010.

Perry

The Perry trial was located at 39°46'N, 90°44'W, on Clarksdale silt loam soil (fine, smectitic, mesic, Udollic Endoaqualfs). Each year, following harvest at the Perry location, DAP (18-46-0) was applied to the whole field at a rate of 130 lb/acre, which means that 23 lb N/acre was applied to all of the plots, in addition to regular nitrogen applications. Normal N applications were applied as injected 28% UAN within approximately 2 weeks before planting each year.

The plots were planted with Pioneer hybrid 32T85 at 32,000 seeds acre$^{-1}$ on 5 May 2008, and were harvested on 26 October 2008. Pioneer hybrid 32T85 was planted at a population of 35,000 seeds acre$^{-1}$ on 24 April 2009, and harvested on 17 October 2009. The plots were planted with Pioneer hybrid P1395XR at 35,000 seeds ha$^{-1}$ on 15 April 2010, and harvest was on 8 September 2010.

Data Analysis

Statistical analyses were performed using the SAS 9.2 statistical analysis software package (SAS Institute, 2008). Data were analyzed using the mixed procedure of SAS. Residue removal rate, tillage, and N rate were fixed factors in all analyses done. During single site-year analysis, replications were considered random. Replications and years were considered random in multi-year analysis. Replications, years, and locations were considered random when the data was analyzed across years and locations. Fixed effects were tested for significance at alpha=0.10. In order to separate residue and tillage effects in light of the large three-way interaction, data over the highest two N rates (180 and 240 lb N/acre) or only the highest N rate (240 lb N/acre) – whichever was necessary to eliminate the interaction – were analyzed separately. Most producers use N rates of 180 to 220 lb N/acre for continuous corn; hence we used data only from the higher N rates to analyze and discuss residue and tillage effects, unless otherwise noted. The two higher N rates were used when possible to increase the sample size.

When the quadratic function for N rate was significant in single years and across years, PROC NLIN was used to fit a quadratic plus plateau (Q+P) function if the coefficient of determination was higher than just the quadratic function. If the quadratic function for N rate was not significant, a linear function was used. Coefficients from the quadratic portion of the Q+P were used to calculate the N rate for maximum yields and (EONR). In cases in which the N rate for predicted maximum yields was higher than 240 lb N/acre, a value of 240 lb N/acre was used. EONR values for each residue removal and tillage treatment combination were calculated as the point at which the slope of the quadratic response was equal to the ratio of input cost (N fertilizer price $/lb N) to output price (corn price $/bu). Using a ratio of 0.1, N rate for predicted maximum yields and EONR values were calculated for each site-year, and for the data at each site, and across years and locations.

# RESULTS

## Weather

2008 was a good growing season at all locations, with favorable weather and good yields. With the exception of a dry August, rainfall was adequate at all locations (Table 1). After a cooler than normal May, temperatures were at or somewhat lower than normal for the rest of the season

In 2009, rainfall was close to normal throughout the growing season, but from July on, temperatures were cooler to much cooler than normal (Table 1). This delayed maturity and greatly delayed harvest, and residue removal and tillage could not be done at DeKalb and Urbana until the spring of 2010.

The 2010 season began normally, with early planting and normal to above-normal temperatures throughout the season (Table 1). Rainfall in May, June, and July was normal to very much above normal at most sites, and at some locations, especially Urbana, this likely resulted in root damage from which plants did not recover well. As a result, some periods of moderately dry weather in August and September caused water stress to develop, and yields were generally lower than normal, except at Monmouth.

Table 1 Monthly temperature and rainfall with departure from the 30-year average, at the four trial sites, 2008-2010.

| | Rainfall (In) | | | Average Temperature (°F) | | |
|---|---|---|---|---|---|---|
| | 2008 | 2009 | 2010 | 2008 | 2009 | 2010 |
| DeKalb | | | | | | |
| April | 3.9 (+0.6) | 4.3 (+1.0) | 2.6 (-0.6) | 48 (0) | 47 (-1) | 55 (+7) |
| May | 4.8 (+0.2) | 3.7 (-0.9) | 4.9 (+0.3) | 56 (-3) | 59 (0) | 62 (+3) |
| June | 3.6 (-0.5) | 4.1 (0.0) | 6.9 (+2.8) | 70 (0) | 68 (-2) | 70 (0) |
| July | 7.0 (+2.6) | 2.5 (-1.8) | 3.9 (-0.5) | 71 (-2) | 66 (-7) | 74 (+1) |
| August | 1.6 (-2.8) | 4.9 (+0.6) | 4.7 (+0.4) | 68 (-3) | 66 (-5) | 72 (+1) |
| September | 10.9 (+7.6) | 1.1 (-2.1) | 2.0 (-1.3) | 63 (0) | 61 (-2) | 63 (0) |
| Monmouth | | | | | | |
| April | 3.1 (-0.8) | 5.0 (+1.1) | 3.9 (0.0) | 49 (-4) | 50 (-3) | 58 (+5) |
| May | 2.7 (-2.1) | 5.1 (+0.3) | 11.0 (+6.2) | 59 (-4) | 62 (-1) | 62 (-1) |
| June | 6.8 (+2.4) | 7.5 (+3.1) | 11.3 (+6.9) | 71 (0) | 71 (0) | 73 (+2) |
| July | 2.7 (-1.6) | 3.2 (-1.1) | 3.2 (-1.0) | 72 (-3) | 68 (-7) | 76 (+1) |
| August | 2.5 (-1.6) | 6.3 (+2.2) | 1.8 (-2.2) | 70 (-3) | 68 (-5) | 74 (+1) |
| September | 9.3 (+5.7) | 1.4 (-2.2) | 5.4 (+1.9) | 64 (-2) | 63 (-3) | 65 (-1) |
| Urbana | | | | | | |
| April | 1.8 (-1.9) | 6.9 (+3.2) | 1.9 (-1.8) | 51 (-1) | 52 (0) | 59 (+7) |
| May | 5.9 (+1.0) | 5.1 (+0.2) | 3.1 (-1.8) | 50 (-4) | 63 (0) | 65 (+2) |
| June | 5.2 (+0.9) | 4.3 (-0.1) | 7.8 (+3.5) | 74 (+2) | 73 (+1) | 75 (+3) |
| July | 8.0 (+3.3) | 6.1 (+1.4) | 3.6 (-1.1) | 74 (-1) | 70 (-5) | 77 (+2) |
| August | 0.7 (-3.3) | 5.4 (+1.5) | 1.6 (-2.4) | 73 (0) | 71 (-2) | 77 (+4) |
| September | 8.0 (+4.8) | 0.6 (-2.5) | 3.0 (-0.1) | 67 (+1) | 67 (+1) | 68 (+2) |
| Perry | | | | | | |
| April | 2.9 (-0.9) | 5.2 (+1.4) | 4.9 (+1.1) | 51 (-2) | 52 (-1) | 60 (+7) |
| May | 3.0 (-1.3) | 4.7 (+0.5) | 4.9 (+0.7) | 59 (-4) | 62 (-1) | 64 (+1) |
| June | 6.2 (+1.9) | 5.1 (+0.8) | 10.7 (+6.4) | 72 (-1) | 72 (-1) | 75 (+2) |
| July | 4.2 (-0.2) | 2.8 (-1.6) | 11.5 (+7.1) | 74 (-2) | 70 (-6) | 77 (+1) |
| August | 1.9 (-2.0) | 5.3 (+1.4) | 3.8 (-0.1) | 71 (-3) | 70 (-4) | 76 (+2) |
| September | 11.9 (+8.3) | 1.5 (-2.2) | 4.8 (+1.2) | 64 (-2) | 65 (-1) | 67 (+1) |

DeKalb

At DeKalb, yields at the two highest N rates were similar in 2008 and 2010 (180 and 178 bu/acre, respectively), but were lower (145 bu/acre) in 2009 (Tables 1 and 3). Across the two highest N rates, the main effect of residue was significant in 2008, 2009, and across years (Table 2). Averaged across tillage treatments and the two highest N rates, full residue removal yielded significantly more than no removal each year and across years. When averaged across years, partial and full residue removal yielded nine and 11 percent (14.7 and 17.9 bu/acre) higher than no residue removal, respectively (Table 3).

At the two highest N rates, the main effect of tillage was significant in each year and across years, with chisel-till producing higher yields in all years (Tables 2 and 3). Averaged across all residue removal rates and the two highest N rates, chisel-till yielded seven percent (11 bu/acre) more than no-till. The residue x tillage interaction was significant in 2008 and 2010, and across years. Across years, increasing residue removal rates increased yields in both no-till and chisel-till. Chisel-till with full residue removal yielded four percent (7 bu/acre) more than chisel-till with no residue removal, but no-till with full residue removal yielded twenty percent (29 bu/acre) higher than no-till with no residue removal.

Response to N rate was highly significant in all years and across years at DeKalb, and accounted for 77% of total variation in yield across years. In 2008, chisel-till with no residue removal showed a linear response, resulting in the highest predicted maximum yields of 200.1 bu/acre, similar to predicted maximum yields of partial residue removal (199.4 bu/acre) (Table 4). The predicted maximum yields for chisel-till and no-till with full residue removal were about 10 bu/acre lower than chisel-till with no residue removal, but required much less N to achieve them (67 and 25 lb N/acre less, respectively).The EONR decreased as residue was removed, and chisel-till with full residue removal had a considerably lower EONR value (163 lb N/acre) than any other treatment combination.

In 2009, all of the treatment combinations had predicted maximum yields between 140 and 155 bu/acre, but the amount of N required to reach those yields differed depending on residue and tillage treatment (Table 4). Chisel-till with no residue removal, chisel-till with full residue removal, and no-till with full residue removal required between 170 and 185 lb N/acre to maximize yield; no-till with partial residue removal required 215 lb N/acre; and no-till with no residue removal and chisel-till with partial residue removal both showed linear responses, requiring 240 lb N/acre to reach maximum yields. No residue removal on chisel-till, full residue removal on chisel-till, and full residue removal on no-till all had EONR values less than 170 lb N/acre. No residue removal on no-till and partial residue removal on chisel-till both had EONR values of 240 lb N/acre.

Predicted maximum yields were similar among residue-tillage combinations in 2010, with yields of four treatment combinations within a range of 4 bu/acre (Table 4). All treatment combinations showed a linear response with the exception of no-till with full residue removal, to which a Q+P response was fit. When averaged across years, four of the residue x tillage combinations showed a quadratic response (Figure 4). None of the treatment combinations showed a linear response, and only chisel-till and no-till with full residue removal showed a Q+P response (Table 4). All of the predicted maximum yields were within seven bu/acre of one another, except no-till with no residue removal, which was 24 bu/acre lower than the next lowest yielding treatment combination. All of the treatment combinations required more than

200 lb N/acre to reach the maximum yields, and all had EONR values above 200 lb N/acre with the exception of no-till with full residue removal (EONR 193 lb N/acre). Economically optimal N rates were about 15 to 20 lb N/acre lower than the rate necessary to produce maximum yields.

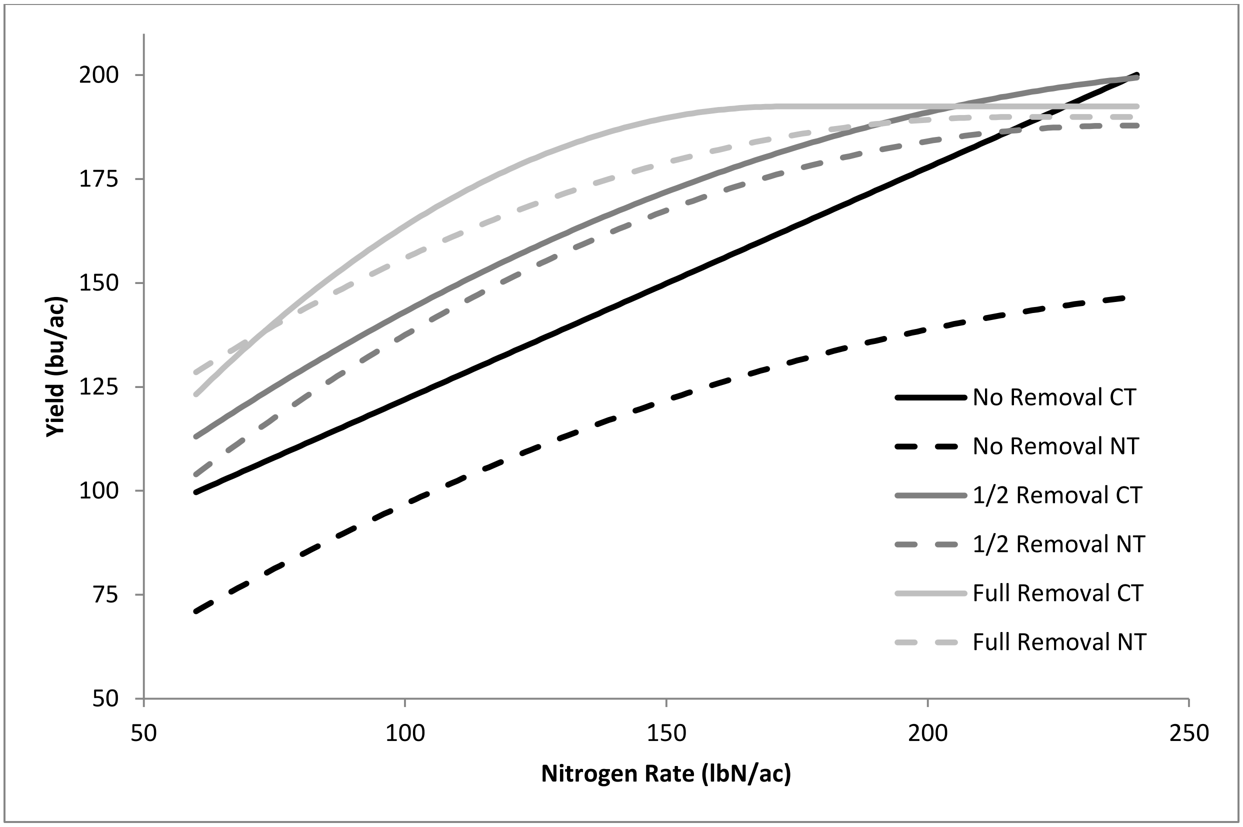


Figure 1 Yield response to N rate for combinations of residue removal and tillage, DeKalb, 2008.

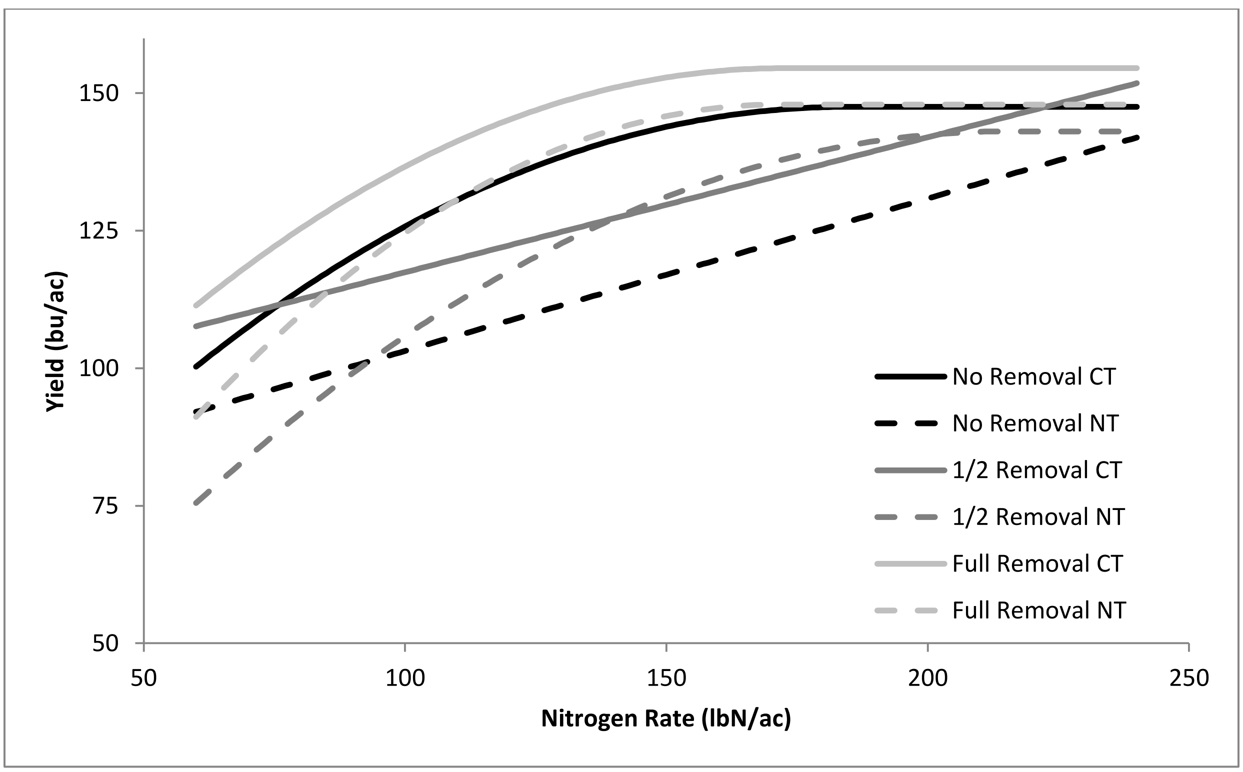


Figure 2 Yield response to N rate for combinations of residue removal and tillage, DeKalb, 2009.

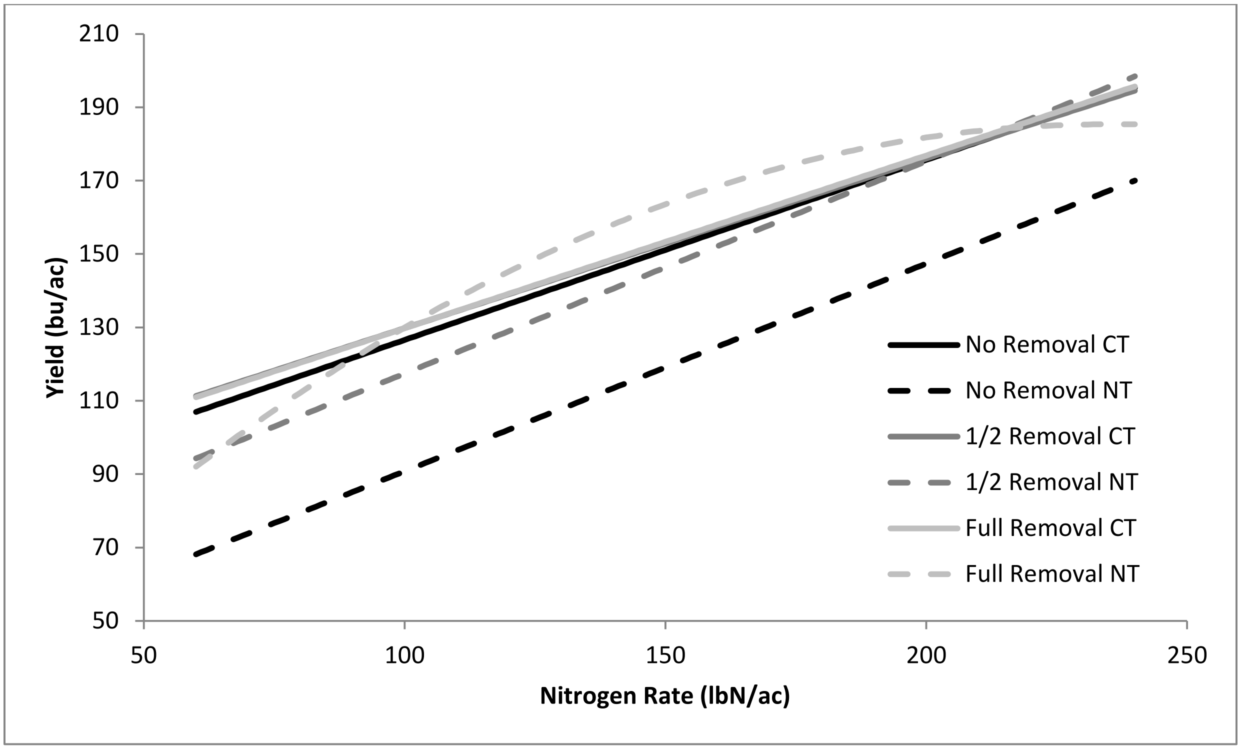


Figure 3 Yield response to N rate for combinations of residue removal and tillage, DeKalb, 2010.

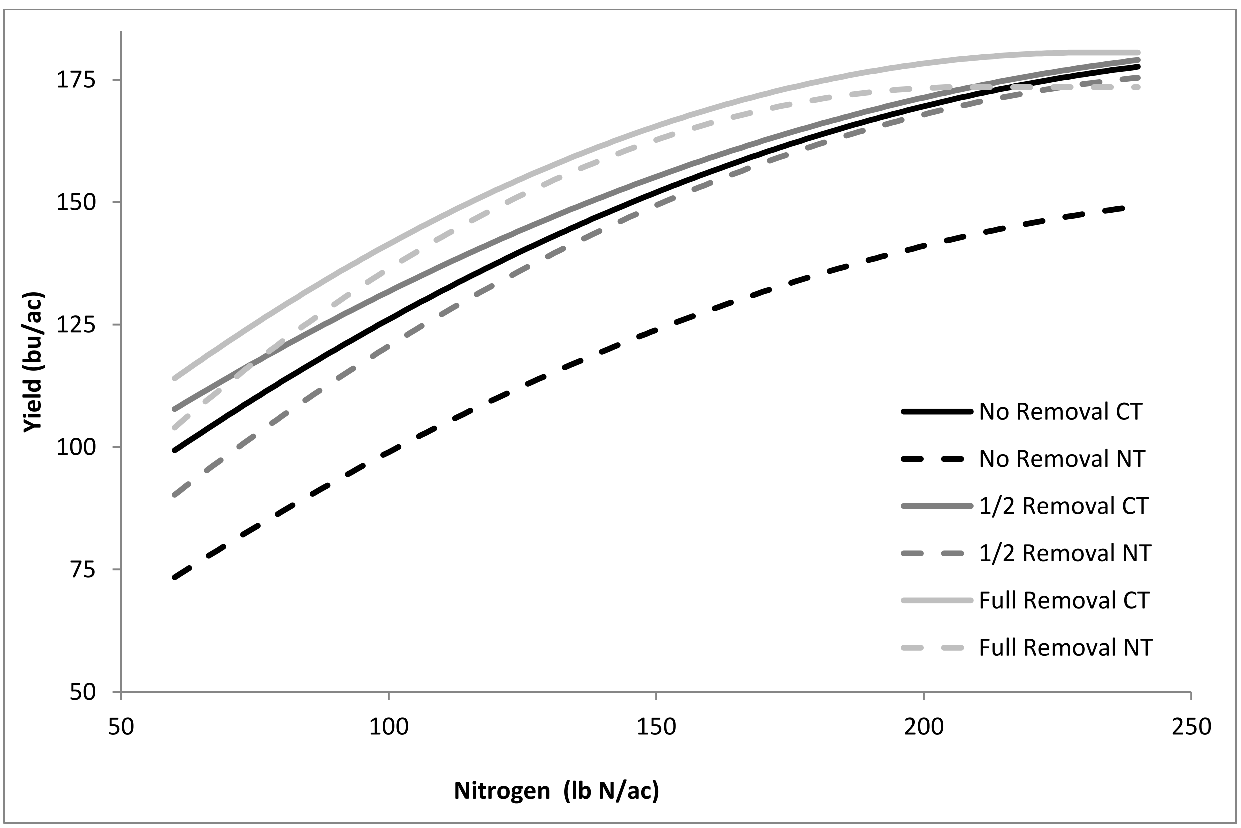


Figure 4 Yield response to N rate for combinations of residue removal and tillage, DeKalb, 2008-2010.

Table 2 Test of fixed effects on grain yield in at DeKalb across 180 and 240 lb N/acre , 2008-2010.

| | | 2008 | | 2009 | | 2010 | | 2008-2010 | |
|---|---|---|---|---|---|---|---|---|---|
| Source | DF | F | Pr>F | F | Pr>F | F | Pr>F | F | Pr>F |
| R | 2 | 17.11 | 0.003 | 6.56 | 0.031 | 1.91 | 0.228 | 8.43 | 0.018 |
| T | 1 | 12.55 | 0.006 | 5.70 | 0.041 | 4.04 | 0.075 | 15.01 | 0.004 |
| N | 1 | 12.00 | 0.003 | 2.65 | 0.121 | 15.44 | 0.001 | 20.57 | 0.000 |
| R x T | 2 | 5.95 | 0.023 | 0.63 | 0.555 | 3.36 | 0.081 | 6.45 | 0.018 |
| R x N | 2 | 1.98 | 0.167 | 0.10 | 0.907 | 0.15 | 0.861 | 0.71 | 0.506 |
| T x N | 1 | 4.19 | 0.056 | 0.04 | 0.844 | 0.00 | 0.981 | 1.40 | 0.252 |
| R x T x N | 2 | 0.33 | 0.721 | 1.26 | 0.309 | 0.67 | 0.524 | 0.62 | 0.552 |

Table 3 Treatment means at DeKalb across 180 and 240 lb N/acre, 2008-2010.

| | | 2008 | | 2009 | | 2010 | | 2008-2010 | |
|---|---|---|---|---|---|---|---|---|---|
| Residue | Tillage | Mean | | Mean | | Mean | | Mean | |
| Averages over tillage | | | ---------------------bushels per acre--------------------------- | | | | | | |
| No Removal | | 160.2 | b | 140.6 | b | 168.2 | a | 156.4 | b |
| Partial Removal | | 187.6 | a | 142.35 | b | 183.4 | a | 171.1 | a |
| Full Removal | | 190.6 | a | 151.25 | a | 180.9 | a | 174.3 | a |
| Averages over Residue Treatments | | | | | | | | | |
| | No-till | 171.2 | b | 140.5 | b | 173.0 | b | 161.6 | b |
| | Chisel | 187.8 | a | 149.0 | a | 182.0 | a | 172.9 | a |
| Residue and tillage treatment combinations | | | | | | | | | |
| No Removal | Chisel | 179.9 | a | 147.58 | ab | 180.9 | a | 169.5 | a |
| No Removal | No-till | 140.6 | b | 133.63 | c | 155.5 | b | 143.3 | b |
| Partial Removal | Chisel | 191.0 | a | 144.64 | b | 183.8 | a | 173.1 | a |
| Partial Removal | No-till | 184.1 | a | 140.05 | bc | 182.9 | a | 169.1 | a |
| Full Removal | Chisel | 192.4 | a | 154.7 | a | 181.3 | a | 176.1 | a |
| Full Removal | No-till | 188.8 | a | 147.81 | ab | 180.5 | a | 172.4 | a |

Table 4 Coefficients for best-fit model (linear, quadratic, quadratic + plateau) for N responses at DeKalb, 2008-2010. EONR values are based on an N cost:corn price ration of 0.1 ($/lb N:$/bu corn).

| Residue | Tillage | Coefficients A | B | C | $R^2$ | Model | Predicted Maximum Yield | N Rate for Max Yield | EONR |
|---|---|---|---|---|---|---|---|---|---|
| 2008 | | | | | | | (bu/ac) | (lbN/ac) | (lbN/ac) |
| No Removal | Chisel | 66.2 | 0.558 | | 0.857 | Linear | 200.1 | 240.0 | 240.0 |
| No Removal | No-till | 22.8 | 0.900 | -0.0016 | 0.871 | Q | 146.7 | 240.0 | 240.0 |
| 1/2 Removal | Chisel | 56.3 | 1.062 | -0.0019 | 0.863 | Q | 199.4 | 240.0 | 240.0 |
| 1/2 Removal | No-till | 37.7 | 1.264 | -0.0027 | 0.897 | Q+P | 187.9 | 237.6 | 218.8 |
| Full Removal | Chisel | 29.7 | 1.887 | -0.0055 | 0.885 | Q+P | 192.5 | 172.5 | 163.4 |
| Full Removal | No-till | 72.2 | 1.092 | -0.0025 | 0.669 | Q+P | 189.9 | 215.8 | 196.0 |
| 2009 | | | | | | | | | |
| No Removal | Chisel | 43.7 | 1.125 | -0.0031 | 0.794 | Q+P | 147.5 | 184.5 | 168.1 |
| No Removal | No-till | 75.4 | 0.277 | | 0.680 | Linear | 141.9 | 240.0 | 240.0 |
| 1/2 Removal | Chisel | 92.9 | 0.245 | | 0.583 | Linear | 151.8 | 240.0 | 240.0 |
| 1/2 Removal | No-till | 13.1 | 1.209 | -0.0028 | 0.923 | Q+P | 143.1 | 215.1 | 197.3 |
| Full Removal | Chisel | 52.8 | 1.181 | -0.0034 | 0.805 | Q+P | 154.5 | 172.2 | 157.6 |
| Full Removal | No-till | 13.6 | 1.567 | -0.0046 | 0.882 | Q+P | 147.9 | 171.5 | 160.5 |
| 2010 | | | | | | | | | |
| No Removal | Chisel | 77.5 | 0.491 | | 0.850 | Linear | 195.3 | 240.0 | 240.0 |
| No Removal | No-till | 34.2 | 0.566 | | 0.833 | Linear | 170.1 | 240.0 | 240.0 |
| 1/2 Removal | Chisel | 83.6 | 0.462 | | 0.782 | Linear | 194.5 | 240.0 | 240.0 |
| 1/2 Removal | No-till | 59.6 | 0.579 | | 0.923 | Linear | 198.4 | 240.0 | 240.0 |
| Full Removal | Chisel | 82.7 | 0.471 | | 0.773 | Linear | 195.7 | 240.0 | 240.0 |
| Full Removal | No-till | 16.6 | 1.442 | -0.0031 | 0.778 | Q+P | 185.3 | 234.1 | 217.8 |
| 2008-2010 | | | | | | | | | |
| No Removal | Chisel | 49.1 | 0.936 | -0.0017 | 0.743 | Q | 177.6 | 240.0 | 240.0 |
| No Removal | No-till | 25.7 | 0.889 | -0.0016 | 0.778 | Q | 149.1 | 240.0 | 240.0 |
| 1/2 Removal | Chisel | 62.9 | 0.834 | -0.0015 | 0.621 | Q | 179.0 | 240.0 | 240.0 |
| 1/2 Removal | No-till | 32.5 | 1.085 | -0.0020 | 0.736 | Q | 175.4 | 240.0 | 240.0 |
| Full Removal | Chisel | 59.3 | 1.047 | -0.0023 | 0.670 | Q+P | 180.6 | 231.6 | 209.5 |
| Full Removal | No-till | 36.5 | 1.314 | -0.0032 | 0.599 | Q+P | 173.5 | 208.6 | 192.7 |

Monmouth

As the result of good growing conditions and excellent soil productivity, yields at the higher N rates averaged more than 220 bu/acre each year at this location, and were exceptionally high, at more than 250 bu/acre, in 2008 (Table 6). Soils at this location are highly productive, with both good water-holding capacity and the ability to drain excess water relatively well. Temperatures were also quite different among years, with May temperatures below normal in 2008 and 2009 and above normal in 2010, and July and August below normal in 2008, and much below normal in 2009 (Table 1).

Because there were significant N rate interactions with residue and tillage treatments, both across all N rates and across the highest two N rates, the effects of residue and tillage were examined only at the highest N rate. At 240 lb N/acre, the main effect of residue was not significant in any year, or across years (Table 5).

At 240 lb N/acre and averaged across residue treatments, chisel-till produced higher yields than no-till in only one individual year, 2010 (Table 6). In 2010, chisel-till yielded 13 bu/acre (6%) higher than no-till. Across years, chisel-till yielded 9 bu/acre (4 percent) more than no-till. There was a significant residue x tillage interaction in 2009, 2010, and across years. Averaged over years, removing all or part of the residue increased yields by 7 and 3.5%, respectively, under no-till, but removing all or part of the residue lowered yields in chisel-till by three and seven percent, respectively.

The N rate effect was large and significant, accounting for 39% of total variation across years at Monmouth. In 2008, all of the no-till plots showed a Q+P response to N rate (Table 7).

That year, chisel till with no residue removal and chisel till with full residue removal showed linear responses, and chisel-till with partial residue removal showed a quadratic response, with yields dropping slightly at the highest N rate (240 lb N/acre) (Figure 5). All responses were Q+P in 2009, but in 2010, predicted yields at zero N were very low, and the crop was responsive to N across the full range of rates in three of the residue-tillage treatments: no removal with chisel- or no-till and full removal with chisel-till (Figure 7). Such response to higher N rates was likely related to the high rainfall in both May and June, along with warm temperatures in June, likely leading to some N loss. It's possible that chisel-tilled plots had more water infiltration and greater N loss, though tilled treatments yielded more at low N, and at the highest N rate all yields were relatively good.

Across the three years at Monmouth, N responses were described by Q+P functions for all residue-tillage treatments except no-till with no residue removed, which was quadratic (Table 7). Residue removal had little effect on N responses in tilled plots; N rates required for maximum yields and predicted yields at these N rates were similar for all residue treatments under chisel-till. Removing part or all of the residue under no-till, however, lowered the N rate required for maximum yield, from 240 for no residue removal to 149 and 176 for partial and full residue removal, respectively (Table 7). Maximum yield under no-till increased as more residue was removed, from 225 with no residue removal to 230 and 240 bu/acre, respectively, for partial and full residue removal.

Continuous corn at Monmouth was less responsive to N rate in this study than expected, especially in 2008 (Figure 5) and across years (Figure 8). In 2008, yields of 250 bu/acre or more were reached at N rates of only 120 to 160 lb/acre, and EONR values for chisel-till treatments were only 110 to 150 lb N/acre (Table 7). In contrast, it required 160 to 240 lb N/acre to maximize yields in 2010, while in 2009, intermediate N rates produced yields similar to those in 2010. Across all three years, chisel-tilled treatments required only 165 to 170 lb N to produce yields of 239 to 245 bu/acre. No-till with no residue removed had the highest response to N rate across years, with the maximum yields being produced at 240 lb N/ac compared to a range of 149 to 176 lb N/ac for all other treatments.

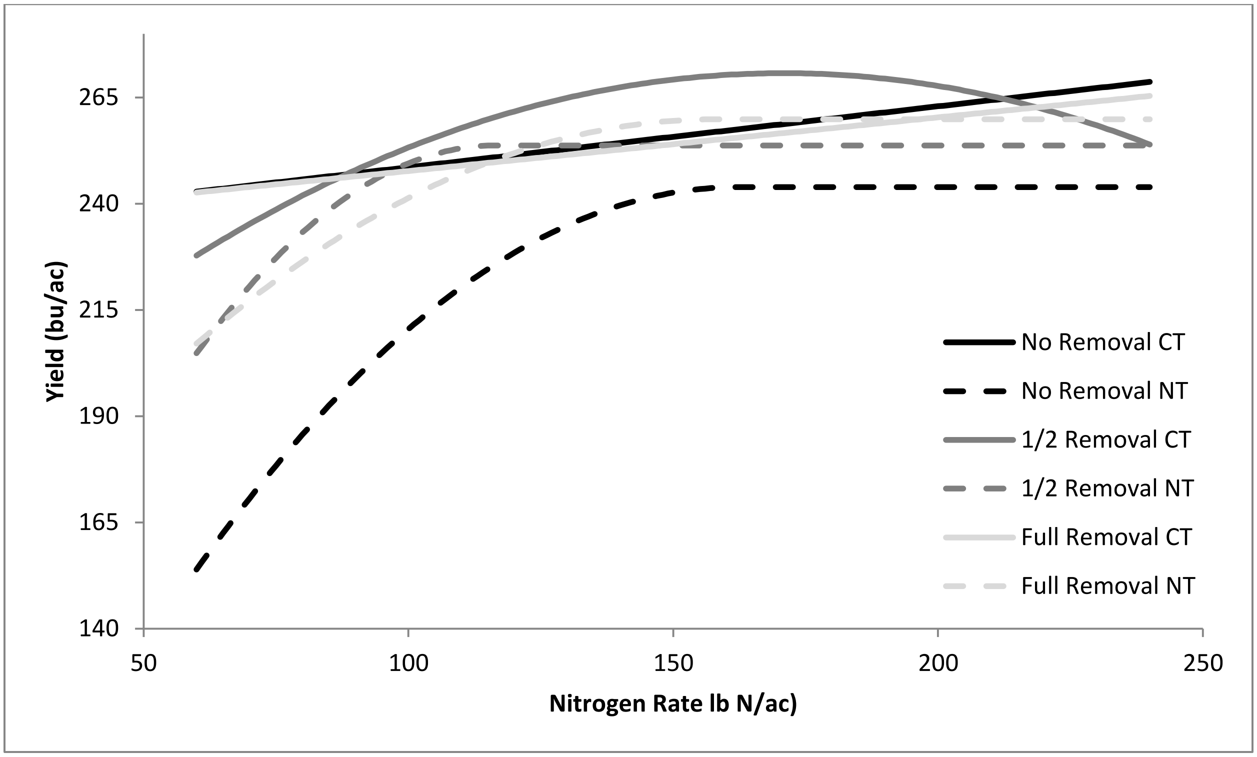


Figure 5 Yield response to N for combinations of residue removal and tillage, Monmouth, 2008.

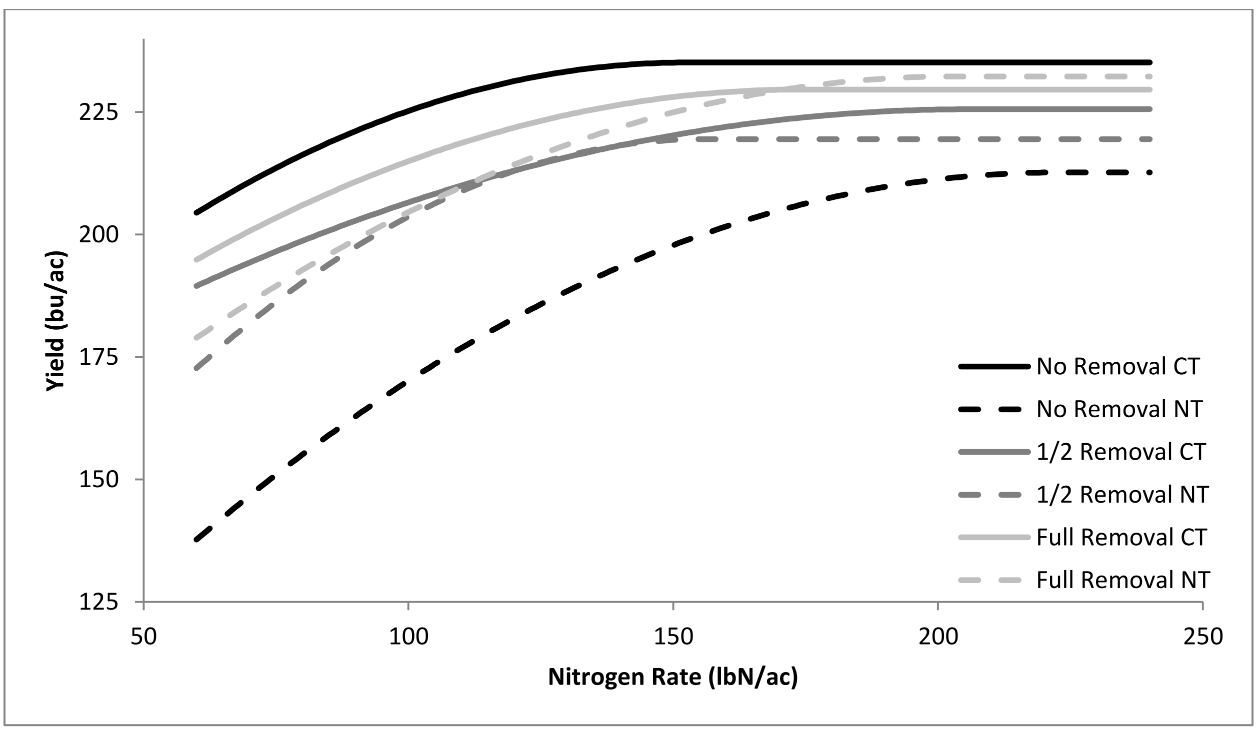


Figure 6 Yield response to N for combinations of residue removal and tillage, Monmouth, 2009.

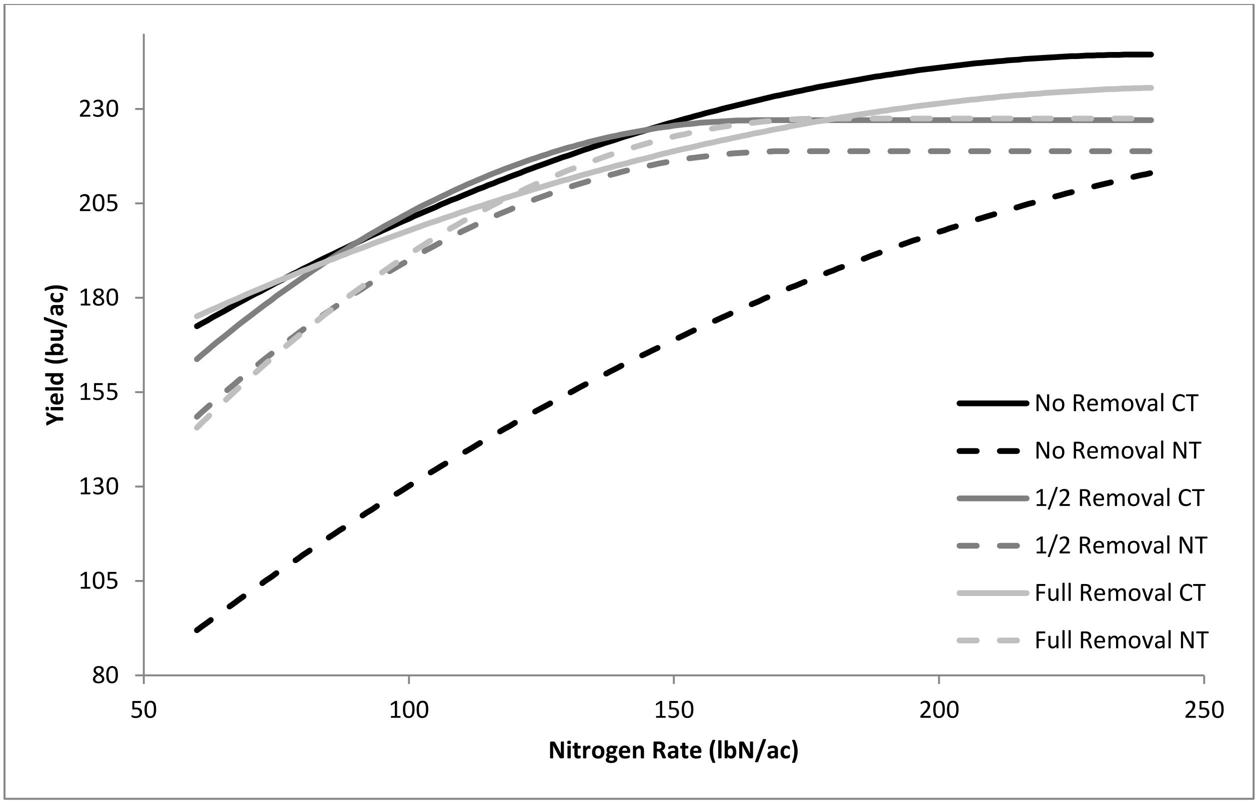

Figure 7 Yield response to N for combinations of residue removal and tillage, Monmouth, 2010.

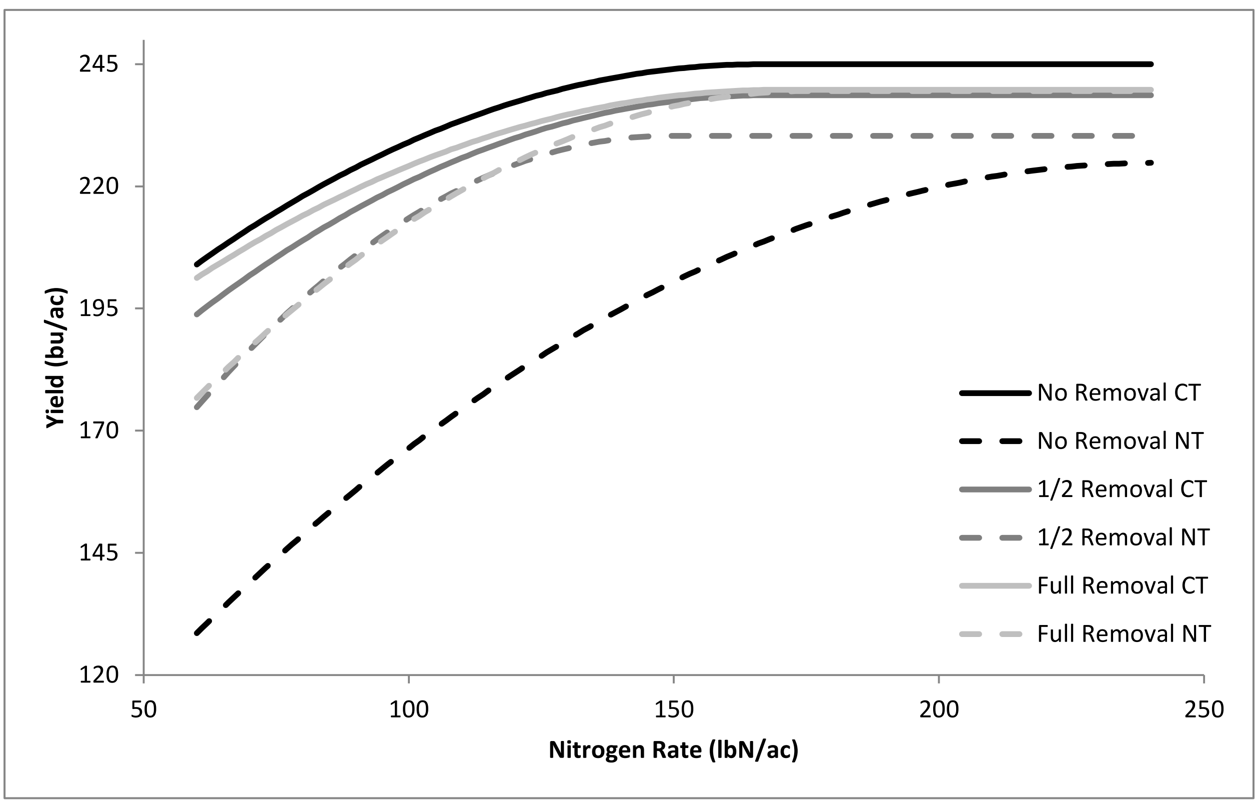

Figure 8 Yield response to N for combinations of residue removal and tillage, Monmouth, 2008-2010.

Table 5 Test of fixed effects on grain yield in at Monmouth at 240 lb N/acre, 2008-2010.

| | | 2008 | | 2009 | | 2010 | | 2008-2010 | |
|---|---|---|---|---|---|---|---|---|---|
| Source | DF | F | Pr>F | F | Pr>F | F | Pr>F | F | Pr>F |
| R | 2 | 0.53 | 0.595 | 0.72 | 0.498 | 2.34 | 0.125 | 2.73 | 0.144 |
| T | 1 | 0.72 | 0.407 | 2.68 | 0.119 | 8.31 | 0.010 | 18.92 | 0.002 |
| R x T | 2 | 1.17 | 0.334 | 2.97 | 0.077 | 5.22 | 0.016 | 16.61 | 0.001 |

Table 6 Treatment means at Monmouth at 240 lb N/acre, 2008-2010.

| | | 2008 | | 2009 | | 2010 | | 2008-2010 | |
|---|---|---|---|---|---|---|---|---|---|
| Residue | Tillage | Mean | | Mean | | Mean | | Mean | |
| Averages over tillage | | ---------------------bushels per acre--------------------------- | | | | | | | |
| No Removal | | 261.0 | a | 224.5 | a | 231.0 | ab | 238.8 | ab |
| Partial Removal | | 256.6 | a | 223.6 | a | 222.8 | b | 234.3 | b |
| Full Removal | | 262.0 | a | 231.7 | a | 234.0 | a | 242.6 | a |
| Averages over Residue Treatments | | | | | | | | | |
| | No-till | 257.9 | a | 221.7 | a | 222.9 | b | 234.2 | b |
| | Chisel | 261.8 | a | 231.6 | a | 235.6 | a | 243.0 | a |
| Residue and tillage treatment combinations | | | | | | | | | |
| No Removal | Chisel | 267.9 | a | 239.6 | a | 247.0 | a | 251.5 | a |
| No Removal | No-till | 254.2 | a | 209.5 | b | 215.0 | d | 226.2 | e |
| Partial Removal | Chisel | 255.7 | a | 225.6 | ab | 222.1 | cd | 234.5 | cd |
| Partial Removal | No-till | 257.4 | a | 221.7 | ab | 223.5 | cd | 234.2 | d |
| Full Removal | Chisel | 261.8 | a | 229.5 | a | 237.6 | ab | 243.0 | b |
| Full Removal | No-till | 262.2 | a | 233.9 | a | 230.3 | bc | 242.1 | bc |

Table 7 Coefficients for best-fit model (linear, quadratic, quadratic + plateau) for N responses at Monmouth, 2008-2010. EONR values are based on an N cost:corn price ration of 0.1 ($/lb N:$/bu corn).

| | | Coefficients | | | | | Predicted Maximum | N Rate for Max | |
|---|---|---|---|---|---|---|---|---|---|
| Residue | Tillage | A | B | C | $R^2$ | Model | Yield | Yield | EONR |
| 2008 | | | | | | | (bu/ac) | (lbN/ac) | (lbN/ac) |
| No Removal | chisel | 234.2 | 0.143 | | 0.596 | Linear | 268.6 | 240.0 | 240.0 |
| No Removal | no-till | 14.8 | 2.804 | -0.00858 | 0.870 | Q+P | 243.9 | 163.4 | 157.6 |
| 1/2 Removal | chisel | 168.7 | 1.195 | -0.00350 | 0.856 | Q | 270.7 | 170.7 | 156.4 |
| 1/2 Removal | no-till | 42.3 | 3.597 | -0.01530 | 0.826 | Q+P | 253.7 | 117.5 | 114.3 |
| Full Removal | chisel | 235.1 | 0.126 | | 0.427 | Linear | 265.3 | 240.0 | 240.0 |
| Full Removal | no-till | 120.9 | 1.747 | -0.00549 | 0.741 | Q+P | 259.9 | 159.1 | 150.0 |
| 2009 | | | | | | | | | |
| No Removal | chisel | 151.8 | 1.092 | -0.00358 | 0.616 | Q+P | 235.1 | 152.6 | 138.6 |
| No Removal | no-till | 72.0 | 1.266 | -0.00285 | 0.817 | Q+P | 212.7 | 222.2 | 204.6 |
| 1/2 Removal | chisel | 153.8 | 0.697 | -0.00169 | 0.609 | Q+P | 225.6 | 206.1 | 176.5 |
| 1/2 Removal | no-till | 95.5 | 1.593 | -0.00512 | 0.790 | Q+P | 219.5 | 155.6 | 145.8 |
| Full Removal | chisel | 148.6 | 0.932 | -0.00268 | 0.541 | Q+P | 229.6 | 173.8 | 155.2 |
| Full Removal | no-till | 124.7 | 1.060 | -0.00261 | 0.750 | Q+P | 232.3 | 203.0 | 183.9 |
| 2010 | | | | | | | | | |
| No Removal | chisel | 116.2 | 1.072 | -0.00224 | 0.891 | Q | 244.5 | 239.3 | 217.0 |
| No Removal | no-till | 22.5 | 1.279 | -0.00202 | 0.925 | Q | 213.1 | 240.0 | 240.0 |
| 1/2 Removal | chisel | 71.9 | 1.869 | -0.00563 | 0.883 | Q+P | 227.0 | 166.0 | 157.1 |
| 1/2 Removal | no-till | 52.1 | 1.948 | -0.00569 | 0.937 | Q+P | 218.8 | 171.2 | 162.4 |
| Full Removal | chisel | 131.0 | 0.835 | -0.00166 | 0.794 | Q | 235.7 | 240.0 | 221.2 |
| Full Removal | no-till | 41.8 | 2.079 | -0.00582 | 0.900 | Q+P | 227.5 | 178.6 | 170.0 |
| 2008-2010 | | | | | | | | | |
| No Removal | chisel | 144.8 | 1.204 | -0.00362 | 0.399 | Q+P | 244.9 | 166.3 | 152.5 |
| No Removal | no-till | 54.2 | 1.417 | -0.00294 | 0.633 | Q | 224.8 | 240.0 | 223.9 |
| 1/2 Removal | chisel | 129.9 | 1.297 | -0.00387 | 0.378 | Q+P | 238.6 | 167.6 | 154.7 |
| 1/2 Removal | no-till | 74.6 | 2.089 | -0.00701 | 0.540 | Q+P | 230.3 | 149.0 | 141.9 |
| Full Removal | chisel | 147.7 | 1.084 | -0.00319 | 0.319 | Q+P | 239.8 | 169.9 | 154.2 |
| Full Removal | no-till | 94.8 | 1.646 | -0.00468 | 0.571 | Q+P | 239.5 | 175.9 | 165.2 |

Urbana

The weather conditions at Urbana in 2010 were much less favorable for corn growth and development than in 2008 and 2009 (Table 1). In 2008, both July and September had higher than normal rainfall, but August rainfall was much lower than normal, and temperatures were very close to normal for the entire growing season. In 2009, the cooler temperatures in July and August helped to mitigate the yield loss from lower rainfall in July. Because of this, yields in 2008 and 2009 were very similar, and both yielded more than 180 bu/acre when averaged across residue and tillage treatments at the two highest N rates. In 2010, heavy rainfall in June caused standing water in many of the plots, which may have resulted in denitrification and damage to roots. Yields from all treatment combinations were closely grouped and showed a strong, linear response to N rate. Therefore, data from 2010 were not used when performing the analysis across years.

When averaged across the two highest N rates, the main effect of residue removal was not significant in 2008, 2009, 2010, or across 2008-2009 (Table 8). Averaged across residue removal treatments, the tillage effect was significant in 2008 and across 2008-2009, with chisel-till yielding nine and five percent (15 and 9 bu/acre) more than no-till in 2008 and across 2008-2009, respectively (Table 9). The residue x tillage interaction was significant in 2009, due in part to the fact that removing all of the residue slightly decreased yields (by 2%) in chisel-till plots, but greatly increased yields (by 11%) in no-till plots.

Nitrogen rate accounted for 68 and 88% of the total variation in yield across 2008-2009 and in 2010, respectively. The N responses were all quadratic + plateau in 2008. That year, predicted maximum yields for chisel-till with no residue removal, chisel-till with full residue removal, no-till with partial residue removal, and no-till with full residue removal were all between 188 and 194 bu/acre, and the predicted maximum yields for chisel-till with partial residue removal and no-till with no residue removal were 174 and 169 bu/acre, respectively (Table 10). The EONR values at Urbana differed widely, from 125 lb N/acre (no-till with partial residue removal) to 173 lb N/acre (chisel-till with partial residue removal).

In 2009, the N responses were all quadratic + plateau except no-till with full residue removal, which showed a linear response (Table 10). Chisel-till with partial residue removal had the lowest predicted maximum yields at 176 bu/acre, and chisel-till with no residue removal had the highest yield at 201 bu/acre. Chisel-till with partial residue removal had the lowest EONR value at 144 lb N/acre, chisel-till with no residue removal, no-till with no residue removal, and no-till with partial residue removal all had EONR values above 200 lb N/acre, and for no-till with full residue removal, the EONR was 240 lb N/acre, the highest N rate used. The N rate response for no-till with no residue removed was unusual for Urbana in 2009, showing a quadratic + plateau curve similar to conventional tillage (Figure 9). The predicted maximum yields for no-till with no residue removal in 2009 was 187 bu/acre, 11 bu/acre more than chisel-till with partial residue removal. This was unique to Urbana, as no-till with no residue removed had the lowest predicted maximum yields at DeKalb and Monmouth in 2009, and Perry showed a linear relationship between N rate and yields.

In 2010, the predicted maximum yields were much lower than in 2008 and 2009, with the highest being chisel-till with no residue removal (162 bu/acre), which was lower than the lowest maximum yield in 2008 (no-till with no residue removal, 169 bu/acre) and 2009 (chisel-till with partial residue removal, 176 bu/acre) (Table 10). No-till with partial residue removal had the lowest predicted maximum yields at 138 bu/acre, and no-till with no residue removal, chisel-till with full residue removal, and no-till with full residue removal all had predicted maximum yields between 146 and 153 bu/acre. With linear responses, the maximum N used (240 lb N/acre) was required to reach maximum yields and also serves as the EONR, though clearly the addition of even more N would likely have increased yields. Due to weather conditions, tillage and residue removal treatments were not done until the spring of 2010, shortly before planting. Coupled with the wet weather after planting which most likely promoted denitrification, this left very little available N for the corn crop. Because of this, all of the treatment combinations showed a very similar, linear N rate response, with lower than average yields (Table 10).

When averaged across 2008 and 2009, all of the N rate response functions were Q+P (Table 10). The predicted maximum yields were all between 176 and 196 bu/acre, and the N rate required to achieve the maximum yields differed little among residue-tillage treatments, with the lowest N rate for maximum yields (chisel-till with partial residue removal) being only 27 lb N/acre less than the highest N rate for maximum yields (no-till with full residue removal).

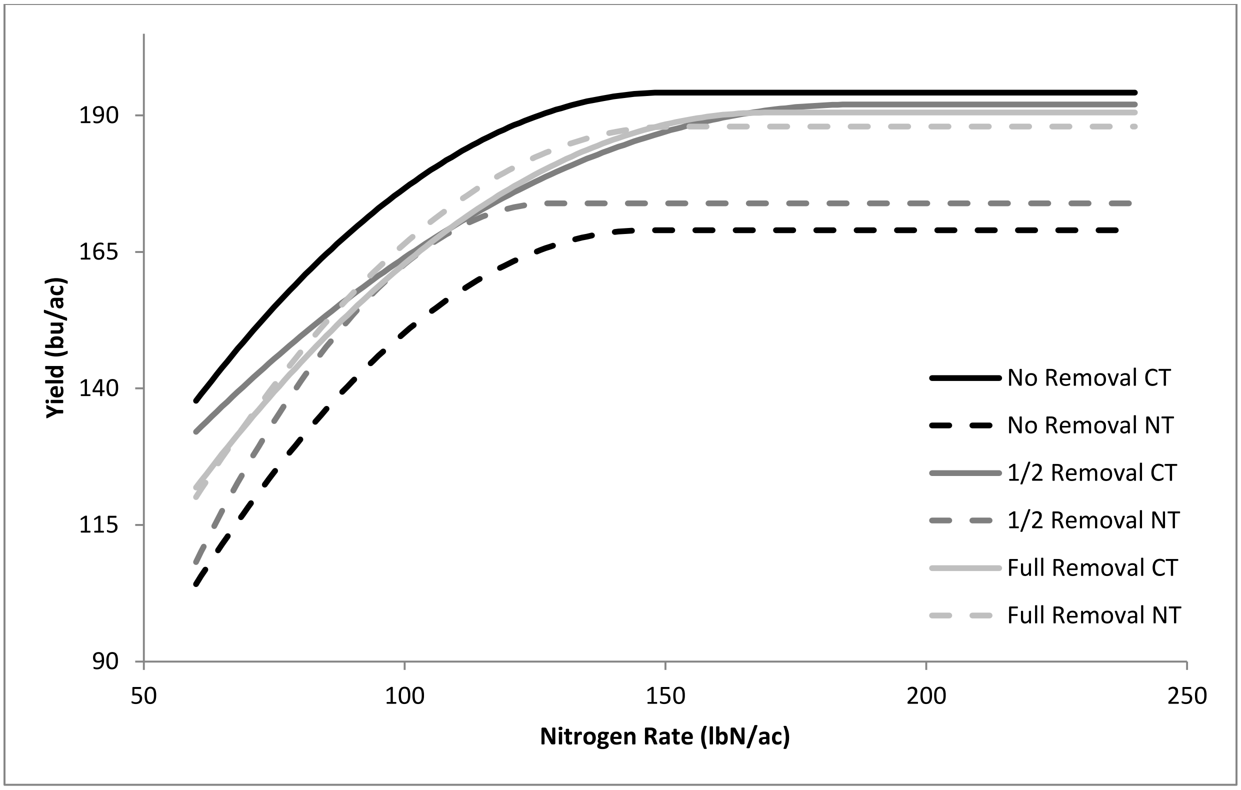


Figure 9 Yield response to N for combinations of residue removal and tillage, Urbana, 2008.

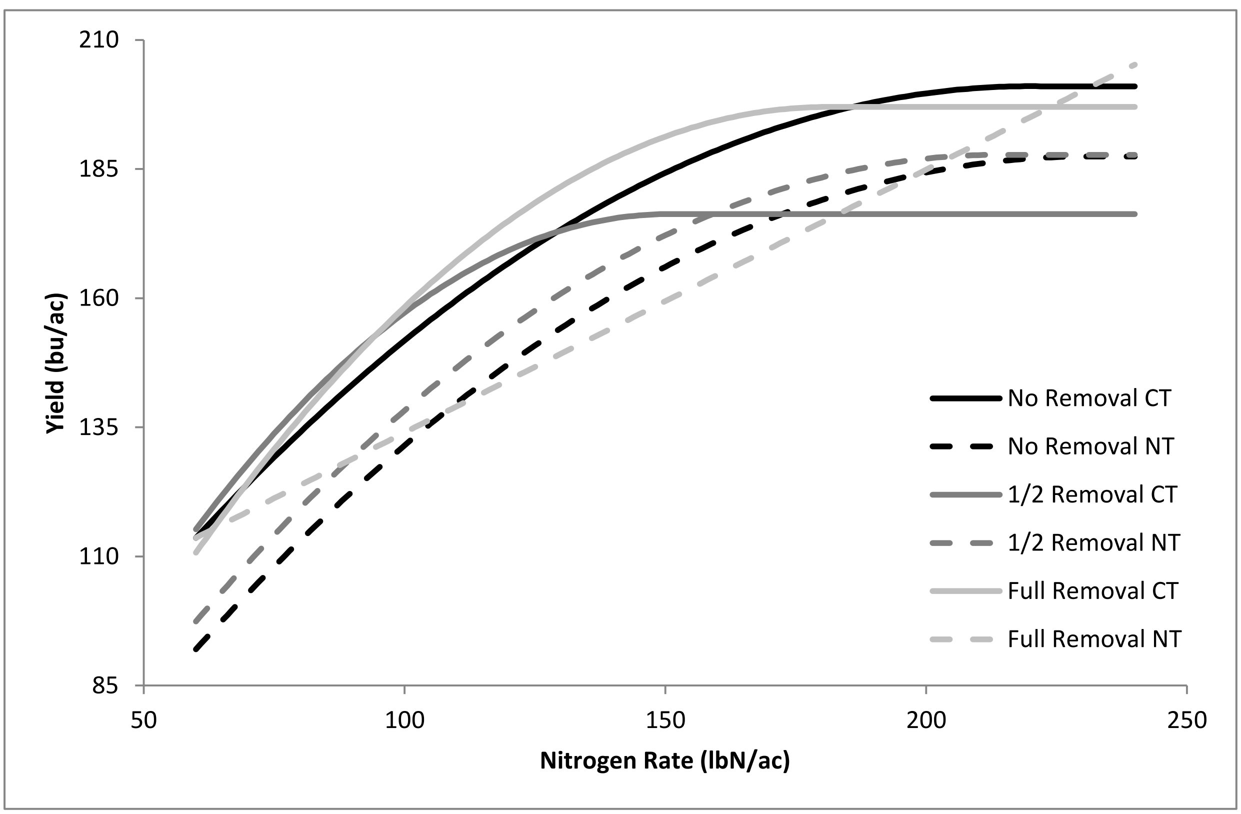


Figure 10 Yield response to N for combinations of residue removal and tillage, Urbana, 2009.

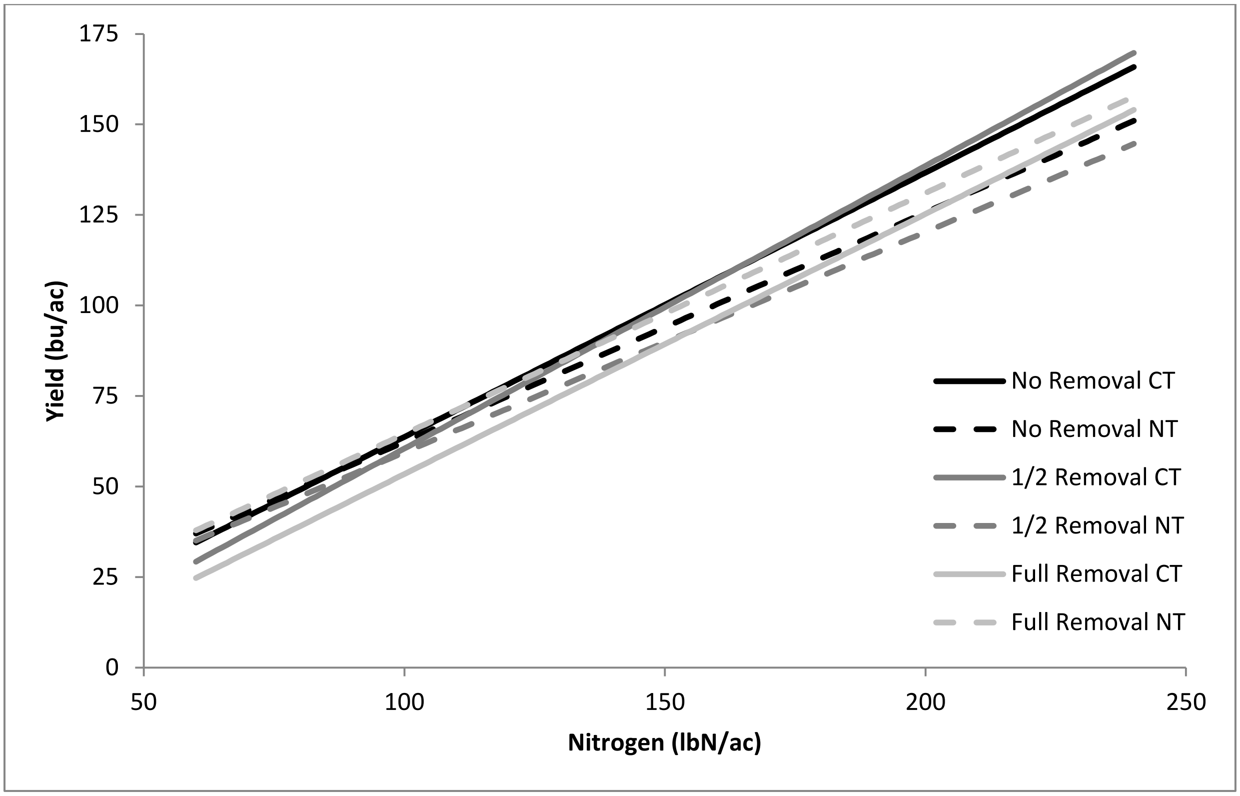


Figure 11 Yield response to N for combinations of residue removal and tillage, Urbana, 2010.

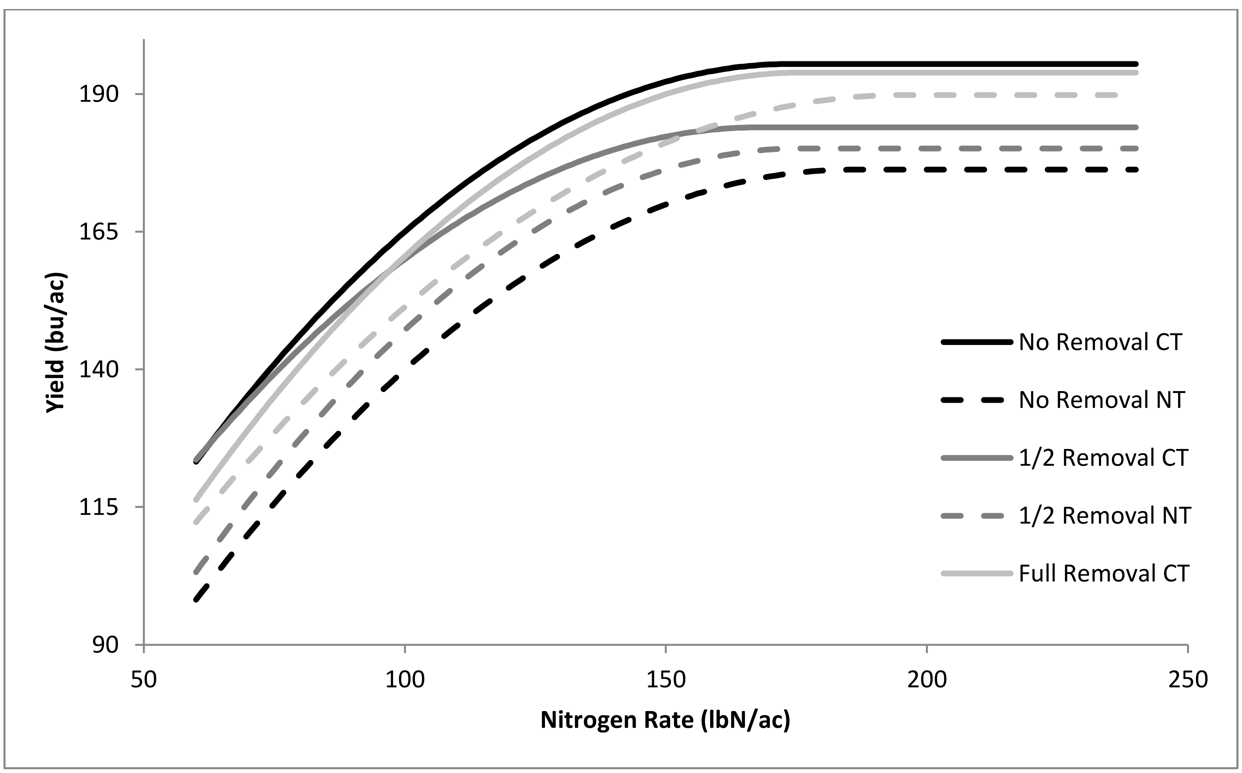


Figure 12 Yield response to N for combinations of residue removal and tillage, Urbana, 2008-2009.

Table 8 Test of fixed effects on grain yield in at Urbana across high N rates, 2008-2010.

| | | 2008 | | 2009 | | 2010 | | 2008-2009 | |
|---|---|---|---|---|---|---|---|---|---|
| Source | DF | F | Pr>F | F | Pr>F | F | Pr>F | F | Pr>F |
| R | 2 | 0.86 | 0.471 | 2.82 | 0.137 | 0.02 | 0.983 | 1.45 | 0.307 |
| T | 1 | 9.92 | 0.012 | 1.15 | 0.312 | 2.17 | 0.174 | 5.74 | 0.040 |
| N | 1 | 0.32 | 0.580 | 2.77 | 0.113 | 67.13 | <.0001 | 2.88 | 0.107 |
| R x T | 2 | 1.85 | 0.212 | 4.36 | 0.047 | 1.12 | 0.367 | 1.56 | 0.261 |
| R x N | 2 | 1.16 | 0.337 | 0.35 | 0.710 | 0.07 | 0.934 | 0.12 | 0.884 |
| T x N | 1 | 1.14 | 0.300 | 0.01 | 0.905 | 3.59 | 0.075 | 0.22 | 0.644 |
| R x T x N | 2 | 0.03 | 0.966 | 1.09 | 0.358 | 0.94 | 0.410 | 0.61 | 0.555 |

Table 9 Treatment means at Urbana across high N rates, 2008-2010.

| | | 2008 | | 2009 | | 2010 | | 2008-2009 | |
|---|---|---|---|---|---|---|---|---|---|
| Residue | Tillage | Mean | | Mean | | Mean | | Mean | |
| Averages over tillage | | | | ---------------------bushels per acre--------------------------- | | | | | |
| No Removal | | 181.6 | a | 190.0 | ab | 138.7 | a | 185.8 | a |
| Partial Removal | | 182.7 | a | 181.3 | b | 137.4 | a | 182.0 | a |
| Full Removal | | 189.2 | a | 193.4 | a | 136.3 | a | 191.3 | a |
| Averages over Residue Treatments | | | | | | | | | |
| | No-till | 176.9 | b | 186.4 | a | 133.2 | a | 181.7 | b |
| | Chisel | 192.2 | a | 190.0 | a | 141.8 | a | 191.1 | a |
| Residue and tillage treatment combinations | | | | | | | | | |
| No Removal | Chisel | 194.2 | a | 196.8 | a | 144.5 | a | 195.5 | a |
| No Removal | No-till | 169.1 | c | 183.3 | bc | 133.0 | a | 176.2 | b |
| Partial Removal | Chisel | 191.7 | a | 176.3 | c | 146.2 | a | 184.0 | ab |
| Partial Removal | No-till | 173.7 | bc | 186.3 | abc | 128.6 | a | 180.0 | b |
| Full Removal | Chisel | 190.6 | a | 197.1 | a | 134.7 | a | 193.8 | a |
| Full Removal | No-till | 187.9 | ab | 189.7 | ab | 137.9 | a | 188.8 | ab |

Table 10 Coefficients for best-fit model (linear, quadratic, quadratic + plateau) for N responses at Urbana, 2008-2010. EONR values are based on an N cost:corn price ration of 0.1 ($/lb N:$/bu corn).

| Residue | Tillage | Coefficients A | B | C | $R^2$ | Model | Predicted Maximum Yield | N Rate for Max Yield | EONR |
|---|---|---|---|---|---|---|---|---|---|
| 2008 | | | | | | | (bu/ac) | (lbN/ac) | (lbN/ac) |
| No Removal | chisel | 37.8 | 2.081 | -0.00692 | 0.596 | Q+P | 194.2 | 150.4 | 143.1 |
| No Removal | no-till | -16.8 | 2.536 | -0.00865 | 0.696 | Q+P | 169.0 | 146.6 | 140.8 |
| 1/2 Removal | chisel | 61.6 | 1.399 | -0.00375 | 0.785 | Q+P | 192.0 | 186.5 | 173.1 |
| 1/2 Removal | no-till | -58.8 | 3.636 | -0.0142 | 0.896 | Q+P | 173.9 | 128.0 | 124.5 |
| Full Removal | chisel | 26.0 | 1.942 | -0.00573 | 0.695 | Q+P | 190.5 | 169.5 | 160.8 |
| Full Removal | no-till | 1.5 | 2.466 | -0.00815 | 0.732 | Q+P | 187.9 | 151.3 | 145.1 |
| 2009 | | | | | | | | | |
| No Removal | chisel | 35.7 | 1.502 | -0.00341 | 0.802 | Q+P | 201.0 | 220.2 | 205.5 |
| No Removal | no-till | 13.2 | 1.509 | -0.00327 | 0.933 | Q+P | 187.4 | 230.8 | 215.5 |
| 1/2 Removal | chisel | 7.9 | 2.234 | -0.00741 | 0.718 | Q+P | 176.3 | 150.7 | 144.0 |
| 1/2 Removal | no-till | 13.3 | 1.631 | -0.00381 | 0.820 | Q+P | 187.8 | 214.0 | 200.9 |
| Full Removal | chisel | 4.2 | 2.128 | -0.00587 | 0.826 | Q+P | 197.0 | 181.2 | 172.7 |
| Full Removal | no-till | 83.1 | 0.509 | | 0.659 | Linear | 205.2 | 240.0 | 240.0 |
| 2010 | | | | | | | | | |
| No Removal | chisel | -9.2 | 0.730 | | 0.938 | Linear | 165.9 | 240.0 | 240.0 |
| No Removal | no-till | -1.0 | 0.633 | | 0.912 | Linear | 151.0 | 240.0 | 240.0 |
| 1/2 Removal | chisel | -17.5 | 0.781 | | 0.926 | Linear | 169.8 | 240.0 | 240.0 |
| 1/2 Removal | no-till | -1.4 | 0.608 | | 0.763 | Linear | 144.6 | 240.0 | 240.0 |
| Full Removal | chisel | -18.4 | 0.781 | | 0.898 | Linear | 169.0 | 240.0 | 240.0 |
| Full Removal | no-till | -2.1 | 0.666 | | 0.897 | Linear | 157.7 | 240.0 | 240.0 |
| 2008-2009 | | | | | | | | | |
| No Removal | chisel | 27.2 | 1.933 | -0.00555 | 0.691 | Q+P | 195.5 | 174.1 | 165.1 |
| No Removal | no-till | 5.8 | 1.835 | -0.00494 | 0.793 | Q+P | 176.2 | 185.7 | 175.6 |
| 1/2 Removal | chisel | 37.9 | 1.738 | -0.00517 | 0.704 | Q+P | 183.9 | 168.0 | 158.4 |
| 1/2 Removal | no-till | 2.8 | 2.018 | -0.00574 | 0.805 | Q+P | 180.1 | 175.8 | 167.1 |
| Full Removal | chisel | 15.5 | 2.026 | -0.00575 | 0.760 | Q+P | 193.9 | 176.2 | 167.5 |
| Full Removal | no-till | 28.2 | 1.656 | -0.00424 | 0.680 | Q+P | 189.8 | 195.3 | 183.5 |

Perry

At the Perry location, the weather was relatively consistent among years, with only small deviations from the average temperature and rainfall (Table 1). Because of this, overall yields at the highest N rate were consistent among years, ranging from 193 bu/acre in 2008 to 213 bu/acre in 2009. The lower yields in 2008 may have been due to the fact that August was drier than normal. In 2009, rainfall was fairly normal for most of the growing season, but late season temperatures were much cooler than normal.

At the highest N rate, the main effect of residue removal was not significant in any year or across years. When averaged across residue removal rates, tillage was significant only in 2009 (Table 11). In 2009, chisel-till yielded nine percent more than no-till (Table 12). The residue x tillage interaction was highly significant in each year, as well as across years. Across years, no-till with no residue removal yielded less than all other treatment combinations at the highest N rate. This contrasts with findings from this location under two dry years by Coulter and Nafziger (2008), who found lower yields when residue was removed and soil was tilled. No-till with no residue removal and chisel-till with full residue removal were the lowest yielding treatments yielding 185 and 194 bu/acre, respectively.

The effect of N rate was significant each year and across years, and accounted for 65% of the total variation in yields across years (Table 11). The application of 23 lb N/acre with fall-applied P fertilizer was not included in the analysis, so the EONR and N rate for predicted maximum yields were probably higher than indicated. In 2008, yields were fairly consistent, with all treatment combinations except for no-till with no residue removal having predicted maximum yields between 193 and 208 bu/acre (Table 13). All of these treatment combinations reached their maximum yields at relatively low N rates, ranging from 152 to 175 lb N/acre. No-till with no residue removal showed a linear response to N rate, and had a predicted maximum yield of 166 bu/acre at the highest N rate (240 lb N/acre). The EONR values for the non-linear functions were also low in 2008, ranging from 146 lb N/acre (chisel-till with partial residue removal) to a high of 169 lb N/acre (no-till with partial residue removal). No-till with no residue removal, which had the only linear function in 2008, had an EONR value of 240.

In 2009, the predicted maximum yields were grouped even closer, ranging from 202 to 224 bu/acre (Table 13). No-till with no residue removal again showed a linear response to N rate, but had the highest predicted maximum yields – 224 bu/acre at 240 lb N/acre – of all residue-tillage treatment combinations. This is in contrast to the other years at Perry, and may have been due to surface residue preserving soil moisture during a drier than normal July. The EONR values for non-linear functions were slightly higher in 2009, ranging from 173 bu/acre (no-till with full residue removal) to 240 bu/acre (no-till with partial residue removal).

In 2010, the range of predicted maximum yields was again relatively high, with the exception of no-till with no residue removal, with a maximum yield of only 143 bu/acre (Table 13). This was likely due in part to the extremely high rainfall in June and July of that year removing any moisture conservation benefits of residue. The rest of the treatment combinations ranged from 205 bu/acre (chisel-till with full residue removal) to 225 bu/acre (chisel-till with no residue removal). The EONR values in 2010 were higher than in either 2008 or 2009, with all treatment combinations having EONR values above 185 lb N/acre.

Across years at this location, predicted maximum yields ranged widely between no-till with no residue removal (176 bu/acre) and the rest of the treatments, which ranged between

205 bu/acre and 216 bu/acre. The EONR values across years for all residue treatments in chisel tillage ranged between 182 and 189 lb N/acre. The no-till treatments had much more variation, with no-till with full residue removal having an EONR of 190 lb N/acre, no-till with partial residue removal at 223 lb N/acre, and no-till with no residue removal having an EONR of 240 lb N/acre due to its linear N response.

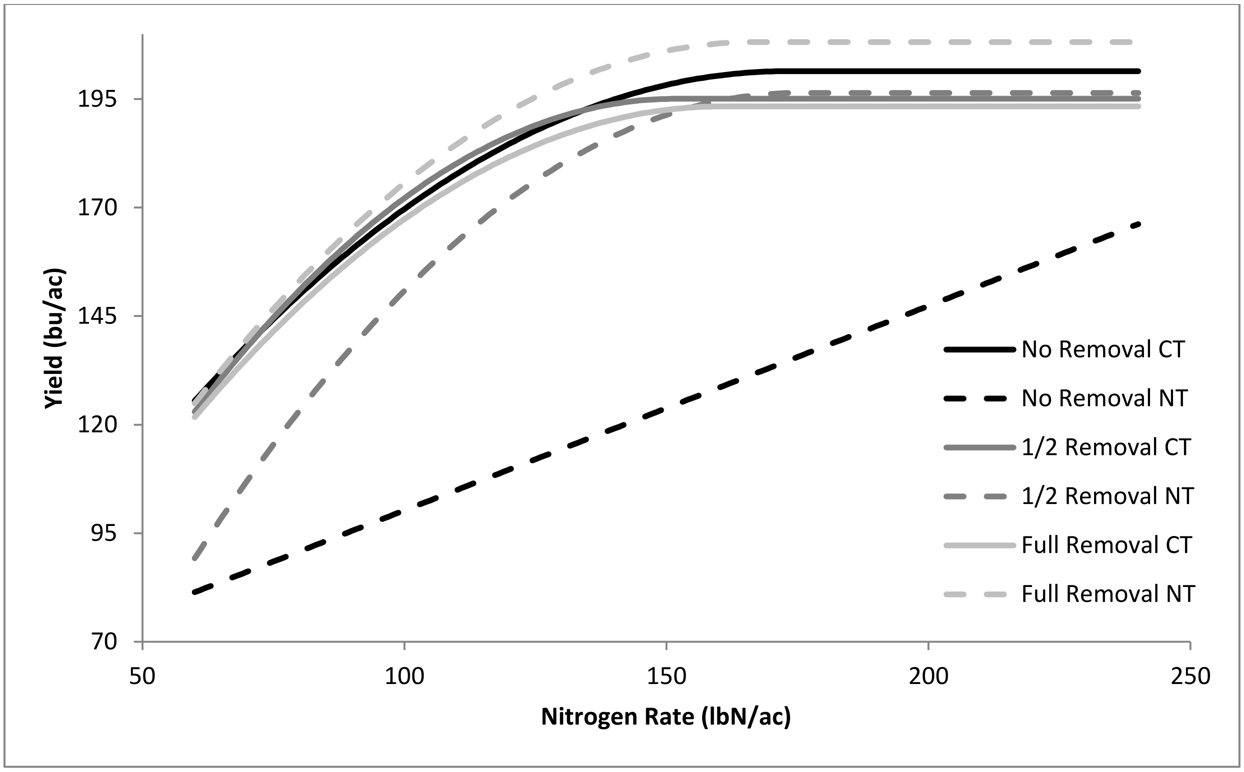


Figure 13 Yield response to N rate for combinations of residue removal and tillage, Perry, 2008.

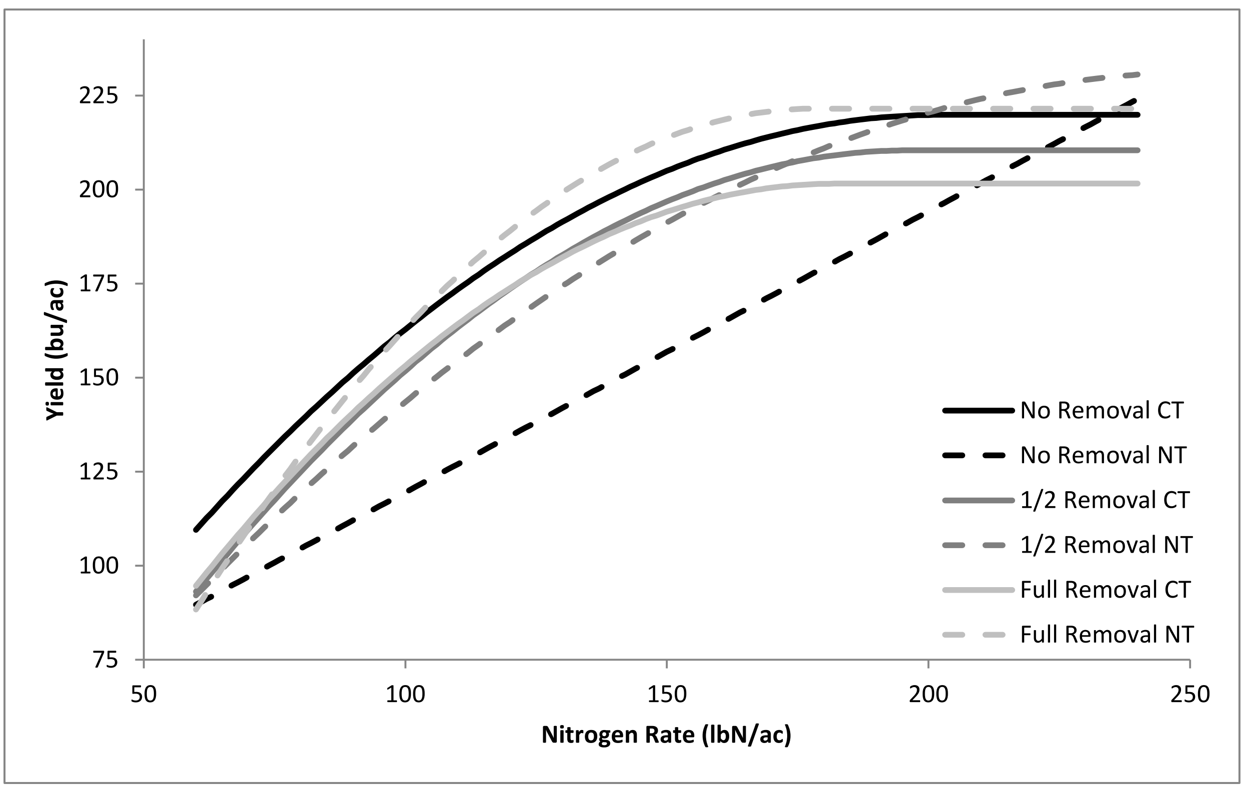


Figure 14 Yield response to N rate for combinations of residue removal and tillage, Perry, 2009.

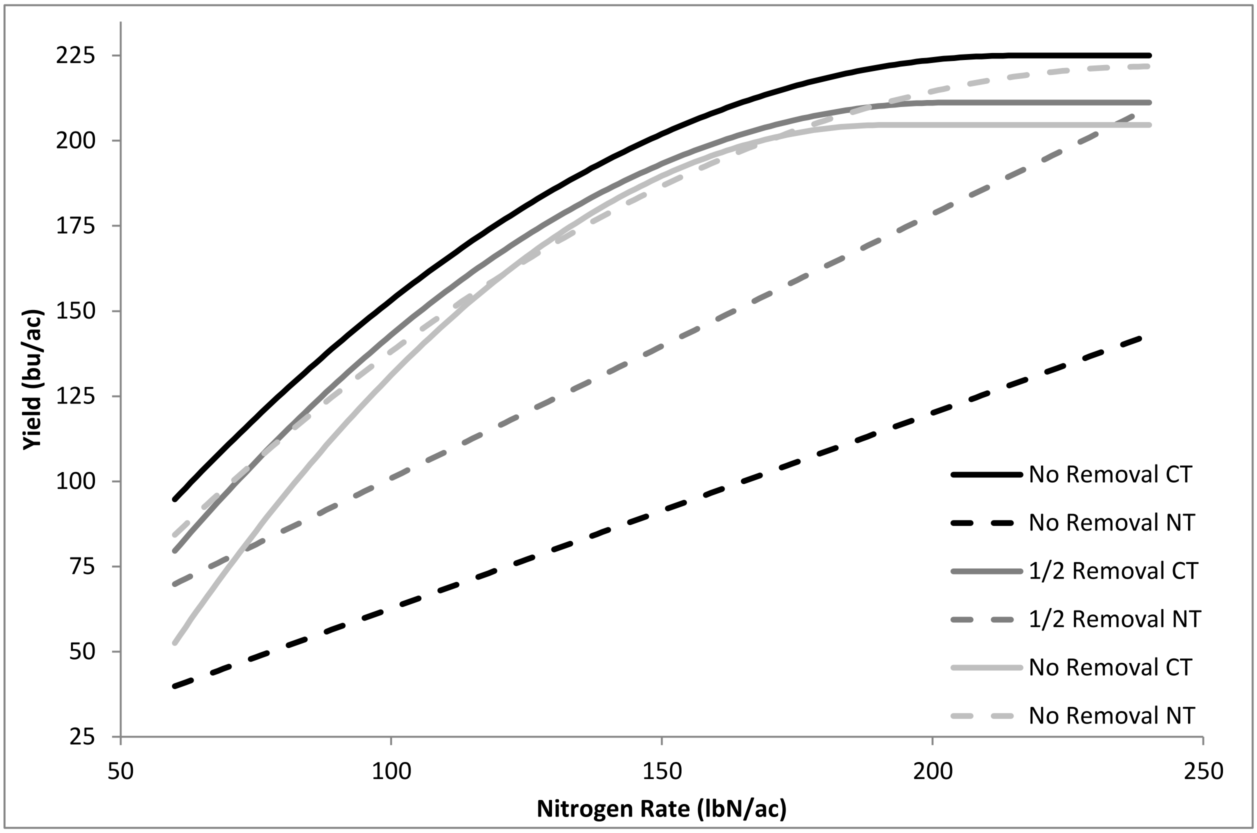

Figure 15 Yield response to N rate for combinations of residue removal and tillage, Perry, 2010.

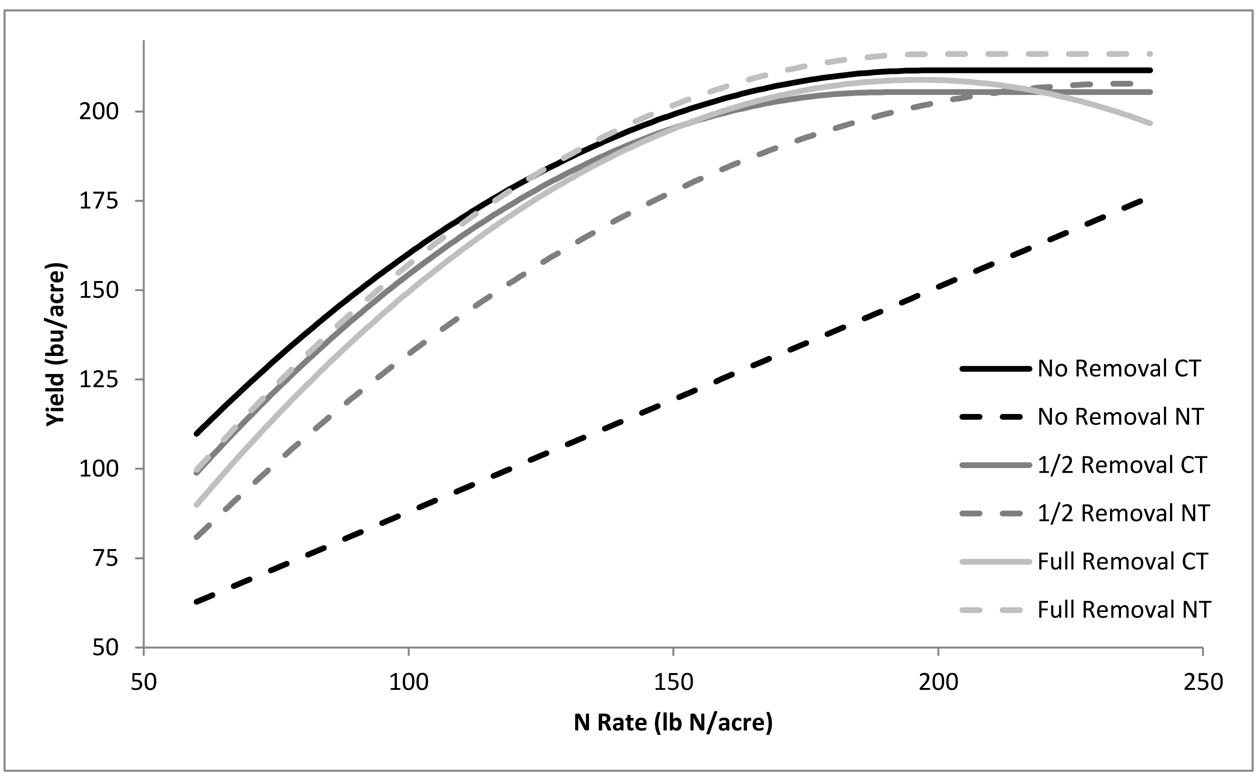

Figure 16 Yield response to N rate for combinations of residue removal and tillage, Perry, 2008-2010.

Table 11 Test of fixed effects on grain yield in at Perry at 240 lb N/acre, 2008-2010.

| | | 2008 | | 2009 | | 2010 | | 2008-2010 | |
|---|---|---|---|---|---|---|---|---|---|
| Source | DF | F | PF>F | F | Pr>F | F | Pr>F | F | PR>F |
| R | 2 | 1.49 | 0.2521 | 1.51 | 0.2468 | 1.03 | 0.3776 | 0.74 | 0.4827 |
| T | 1 | 0.006 | 0.8172 | 19.19 | 0.0004 | 1.57 | 0.2256 | 0.05 | 0.8282 |
| R x T | 2 | 4.16 | 0.0326 | 4.78 | 0.0216 | 7.05 | 0.0055 | 9.92 | 0.0002 |

Table 12 Treatment means at Perry at 240 lb N/acre, 2008-2010.

| | | 2008 | | 2009 | | 2010 | | 2008-2010 | |
|---|---|---|---|---|---|---|---|---|---|
| Residue | Tillage | Mean | | Mean | | Mean | | Mean | |
| Averages over tillage | | | ---------------------bushels per acre-------------------------- | | | | | | |
| No Removal | | 192.0 | a | 217.1 | a | 188.9 | a | 199.3 | a |
| Partial Removal | | 193.5 | a | 218.8 | a | 202.1 | a | 204.8 | a |
| Full Removal | | 201.4 | a | 210.6 | a | 207.0 | a | 206.3 | a |
| Averages over Residue Treatments | | | | | | | | | |
| | No-till | 195.1 | a | 224.4 | a | 192.6 | a | 204.0 | a |
| | Chisel | 196.2 | a | 206.6 | b | 206.0 | a | 202.9 | a |
| Residue and tillage treatment combinations | | | | | | | | | |
| No Removal | Chisel | 201.9 | ab | 216.2 | bc | 222.3 | a | 213.5 | ab |
| No Removal | No-till | 182.1 | c | 217.9 | abc | 155.4 | b | 185.1 | d |
| Partial Removal | Chisel | 191.7 | bc | 209.1 | c | 203.4 | a | 201.4 | bc |
| Partial Removal | No-till | 195.3 | abc | 228.5 | a | 200.8 | a | 208.2 | abc |
| Full Removal | Chisel | 195.0 | abc | 194.5 | d | 192.3 | a | 193.9 | cd |
| Full Removal | No-till | 207.8 | a | 226.7 | ab | 221.6 | a | 218.7 | a |

Table 13 Coefficients for best-fit model (quadratic or quadratic + plateau) for N responses at Perry, 2008-2010. EONR values are based on an N cost:corn price ration of 0.1 ($/lb N:$/bu corn).

| Residue | Tillage | Coefficients A | Coefficients B | Coefficients C | $R^2$ | Model | Predicted Maximum Yield | N Rate for Max Yield | EONR |
|---|---|---|---|---|---|---|---|---|---|
| 2008 | | | | | | | (bu/ac) | (lbN/ac) | (lbN/ac) |
| No Removal | chisel | 23.6 | 2.054 | -0.00593 | 0.948 | Q+P | 201.5 | 173.0 | 164.8 |
| No Removal | no-till | 53.1 | 0.471 | | 0.427 | Linear | 166.2 | 240.0 | 240.0 |
| 1/2 Removal | chisel | -2.4 | 2.605 | -0.00859 | 0.884 | Q | 195.1 | 152.0 | 145.8 |
| 1/2 Removal | no-till | -51.9 | 2.838 | -0.00811 | 0.969 | Q+P | 196.4 | 175.0 | 168.8 |
| Full Removal | chisel | 10.9 | 2.271 | -0.00707 | 0.779 | Q+P | 193.3 | 161.0 | 153.6 |
| Full Removal | no-till | 4.8 | 2.440 | -0.00732 | 0.941 | Q+P | 208.1 | 167.0 | 159.8 |
| 2009 | | | | | | | | | |
| No Removal | chisel | -3.1 | 2.205 | -0.00545 | 0.944 | Q+P | 219.9 | 202.0 | 193.1 |
| No Removal | no-till | 44.8 | 0.747 | | 0.926 | Linear | 224.1 | 240.0 | 240.0 |
| 1/2 Removal | chisel | -32.7 | 2.476 | -0.00630 | 0.901 | Q+P | 210.4 | 196.0 | 188.5 |
| 1/2 Removal | no-till | -7.2 | 1.876 | -0.00369 | 0.947 | Q | 230.6 | 240.0 | 240.0 |
| Full Removal | chisel | -35.8 | 2.604 | -0.00714 | 0.939 | Q+P | 201.6 | 182.0 | 175.4 |
| Full Removal | no-till | -80.6 | 3.385 | -0.00948 | 0.958 | Q+P | 221.6 | 179.0 | 173.3 |
| 2010 | | | | | | | | | |
| No Removal | chisel | -25.5 | 2.328 | -0.00541 | 0.952 | Q+P | 225.0 | 215.0 | 206.0 |
| No Removal | no-till | 5.4 | 0.573 | | 0.639 | Linear | 143.0 | 240.0 | 240.0 |
| 1/2 Removal | chisel | -54.3 | 2.620 | -0.00646 | 0.773 | Q+P | 211.2 | 203.0 | 195.0 |
| 1/2 Removal | no-till | 23.3 | 0.761 | | 0.795 | Linear | 205.9 | 240.0 | 240.0 |
| Full Removal | chisel | -118.4 | 3.380 | -0.00884 | 0.868 | Q+P | 204.6 | 191.0 | 185.5 |
| Full Removal | no-till | -21.3 | 2.009 | -0.00415 | 0.983 | Q | 221.8 | 240.0 | 230.0 |
| 2008-2010 | | | | | | | | | |
| No Removal | chisel | 2.2 | 2.115 | -0.00534 | 0.906 | Q+P | 211.5 | 196.3 | 188.6 |
| No Removal | no-till | 25.0 | 0.629 | | 0.484 | Linear | 176.0 | 240.0 | 240.0 |
| 1/2 Removal | chisel | -22.2 | 2.397 | -0.00631 | 0.783 | Q+P | 205.4 | 189.9 | 182.0 |
| 1/2 Removal | no-till | -20.7 | 1.941 | -0.00412 | 0.817 | Q+P | 207.8 | 235.5 | 223.4 |
| Full Removal | chisel | -37.8 | 2.513 | -0.00640 | 0.794 | Q | 208.9 | 196.3 | 188.5 |
| Full Removal | no-till | -22.9 | 2.407 | -0.00606 | 0.901 | Q+P | 216.1 | 198.6 | 190.3 |

Across Site-Years

When averaged across years and locations, residue, tillage, and residue x tillage interaction were all significant at the two highest N rates (Table 14). Full and partial residue removal increased yields by six and four percent over no residue removal, respectively (Table 15). Chisel tillage yielded six percent more than no-till. The large residue x tillage interaction was due to yields increasing as more residue was removed on no-till, and no residue removed having higher yields than partial or full residue removal on chisel tillage. No-till with no residue removal had lower yields than all of the other treatment combinations, at 179.8 bu/acre. No-till with partial residue removal yielded higher than no-till with no residue removal, but lower than the other four treatment combinations.

N rate accounted for 39% of the total variation across locations and years. The predicted maximum yields were all very similar, in a range from 202 to 211 bu/acre, with the exception of no-till with no residue removal, which had a maximum yield of 189 (Table 16). Both the N rate necessary to reach the maximum yields and EONR were always lower for chisel till than no-till within each residue treatment. All of the treatment combinations had a Q+P response except for no residue removal on no-till, which had a quadratic response. All of the chisel-till plots showed a similar response to N rate. Within chisel-till, full residue removal reached its maximum predicted yields at a lower nitrogen rate than either of the other plots, but its predicted maximum yield (209 bu/acre) was between partial and no residue removal (203 and 211 bu/acre, respectively). No-till with full residue removal showed a similar response to N rate as the chisel-till plots, and its predicted maximum yield was 210 bu/acre. No-till with partial residue removal reached its predicted maximum yields at a slightly higher N rate than the chisel-till and no-till with full residue removal plots, but those maximum yields (202 bu/acre) were lower than those treatments. No-till with no residue removal showed a much different N rate response than any of the other treatments, with yields continuing to increase with increased N rate up to 240 lb N/acre. However, its predicted maximum yields (189 bu/acre) were lower than all of the other treatment combinations

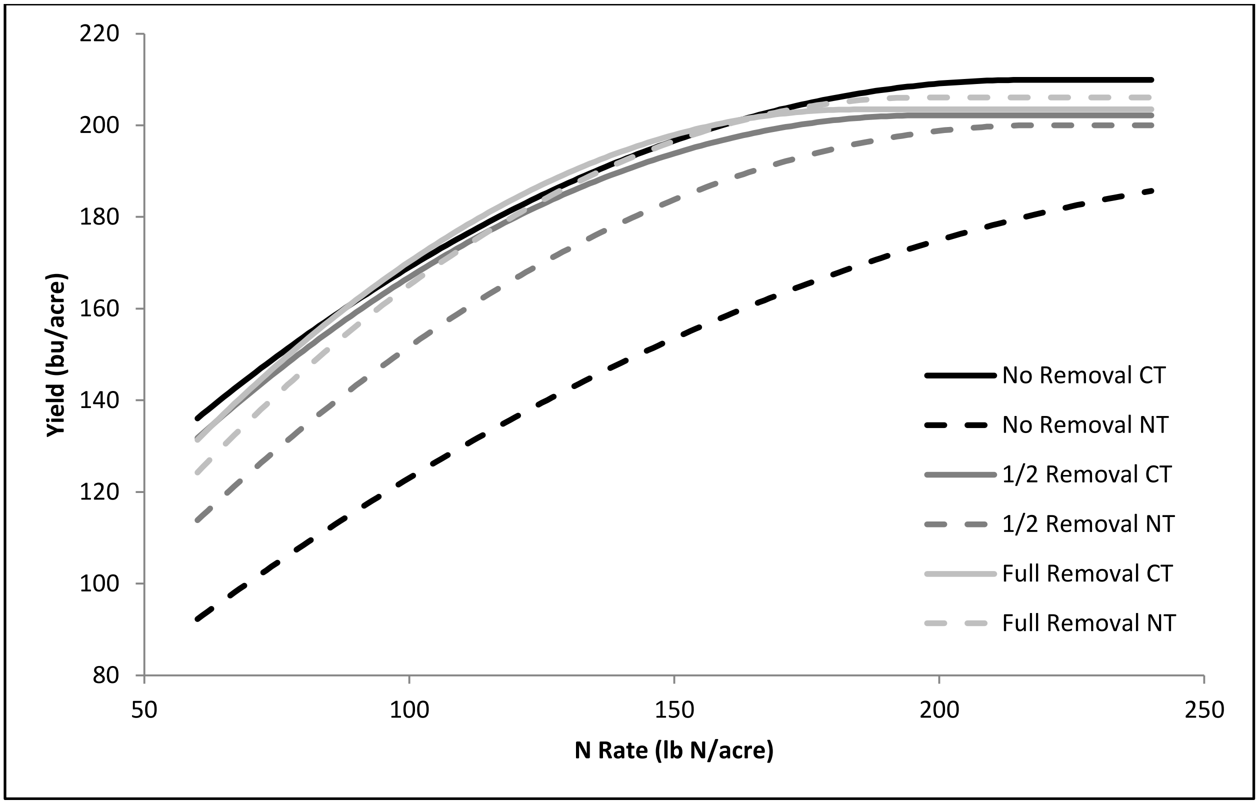

Figure 17 Yield Response to N for combinations for residue removal and tillage, across locations, 2008-2010.

Table 14 Test of fixed effects on grain yield across locations at high N rates, 2008-2010.

| | | 2008-2010 | |
|---|---|---|---|
| Source | DF | F | PR>F |
| R | 2 | 8.10 | 0.0011 |
| T | 1 | 22.45 | 0.0001 |
| N | 1 | 20.87 | 0.0001 |
| R x T | 2 | 7.99 | 0.0008 |
| R x N | 2 | 2.24 | 0.1106 |
| T x N | 1 | 7.29 | 0.0079 |
| R x T x N | 2 | 0.43 | 0.6486 |

Table 15 Treatment means across locations at high N rates in bu/acre, 2008-2010.

| Residue | Tillage | 2008-2010 | |
|---|---|---|---|
| Averages over tillage | | | |
| No Removal | | 193.1 | b |
| Partial Removal | | 200.8 | a |
| Full Removal | | 205.0 | a |
| Averages over residue treatments | | | |
| | No-till | 193.4 | b |
| | Chisel | 205.8 | a |
| Residue and tillage treatment combinations | | | |
| No Removal | Chisel | 206.4 | a |
| No Removal | No-till | 179.8 | c |
| Partial Removal | Chisel | 205.2 | a |
| Partial Removal | No-till | 196.4 | b |
| Full Removal | Chisel | 205.9 | a |
| Full Removal | No-till | 204.1 | a |

Table 16 Coefficients for best-fit model (linear, quadratic, quadratic + plateau) for N responses across locations, 2008-2010. EONR values are based on a N cost:corn price ration of 0.1 ($/lb N:$/bu corn).

| | | Coefficients | | | | | Predicted Maximum | N rate for Max | |
|---|---|---|---|---|---|---|---|---|---|
| Residue | Tillage | A | B | C | R | Model | Yield | Yield | EONR |
| | | | | | | | (bu/ac) | (lbN/ac) | (lbN/ac) |
| No Removal | Chisel | 71.5 | 1.249 | -0.0028 | 0.3596 | Q+P | 210.7 | 223.0 | 205.1 |
| No Removal | No-till | 35.2 | 1.060 | -0.0018 | 0.4374 | Q | 188.7 | 240.0 | 240.0 |
| 1/2 Removal | Chisel | 60.7 | 1.391 | -0.0034 | 0.3587 | Q+P | 202.9 | 204.5 | 189.8 |
| 1/2 Removal | No-till | 38.8 | 1.447 | -0.0032 | 0.4534 | Q+P | 202.4 | 226.1 | 210.4 |
| Full Removal | Chisel | 57.7 | 1.455 | -0.0035 | 0.3735 | Q+P | 208.8 | 207.8 | 193.5 |
| Full Removal | No-till | 45.8 | 1.537 | -0.0036 | 0.4674 | Q+P | 209.8 | 213.4 | 199.5 |

# SUMMARY AND CONCLUSIONS

During years three through five of this experiment, six of the twelve site-years did not have a significant difference in yields between chisel-till and no-till. Of the six site-years in which there was a difference, chisel-till had higher yields than no-till in five of them; the only location where no-till yielded more was Perry in 2009, the same location Coulter and Nafziger (2008) found higher yields with no-till.

In four of the seven site-years in which no-till had yields equal to or greater than chisel-till, rainfall for July and August was lower than average. Of the five site-years in which chisel-till produced higher yields than no-till, three had cooler than normal early growing season temperatures (April and May). This observation is similar to that by Vyn and Raimbault's (1993). Removing all of the residue from no-till plots increased yields compared to no residue removal in eight years, and early season temperatures were below normal during five of them. Interestingly, in years with less than average rainfall for July and August, no-till with no residue removed never yielded higher than no-till with full residue removed. This was in contrast to the finding of Coulter and Nafziger (2008) that in low rainfall conditions, removing residue on no-till reduced yields. Under chisel-till, only one site-year showed a yield difference between full and no residue removal. This indicates that residue management is more important in no-till systems than under tillage. This may involve effects of both tillage and residue removal on soil water and temperature, and is supported by the fact that effects were somewhat dependent on both weather conditions and soil type.

Averaged across three years (only two years at Urbana), chisel-till produced higher yields than no-till at three of four locations. At two of the locations (Urbana and Perry), there was no effect of residue removal on yield when averaged across years and tillage treatments. At DeKalb and Perry, leaving all of the residue in place decreased yields on no-till plots when averaged across years. Interestingly, there was no difference between residue treatments across years at Urbana and Perry.

Across years and locations, chisel tillage produced higher corn yields than did no-till. Increasing the amount of residue removed increased yields, although the difference between full and partial residue removal was not significant. All of the chisel-till treatments and no-till with full residue removal had similar yields (204 to 206 bu/acre). No-till with partial residue removal was somewhat lower at 196 bu/acre, and no-till with no residue removed was the lowest, yielding 180 bu/acre. The predicted maximum yields of no-till and chisel-till were very similar within full and partial residue removal treatments, but without residue removal, the predicted maximum yield was 22 bu/acre higher for chisel-till than for no-till. The N rate for predicted maximum yields and the EONR values were always lower for chisel tillage than for no-till within residue treatments.

The trends that we found in this study indicate that whether removing residue has a positive or negative effect on grain yields depends on the tillage treatment. Removing all or part of the residue lowered yields in conventional tillage. However, growing corn under no-till management in Illinois benefits from having the residue removed from the fields. This finding is in contrast to Doran et al. (1984) who found that completely removing crop residues decreased corn yields by 22%. In their studies, yield gains from leaving residue in the fields came in years or locations in which water was limiting. In years that water was a limiting factor, such as Perry in 2009, as well as some years observed by Coulter and Nafziger (2008), the same response was observed, although water limitations were relatively rare among our sites. Residue management may increase yields in no-till systems in areas that are colder for longer early in the growing season, such as northern locations.

Adding twelve more site-years of data to those reported by Coulter and Nafziger (2008) clearly confirmed that the response to residue removal and tillage that they observed under dry conditions at the Perry location were mostly a function of the weather, not the soil; results at this location from 2008 through 2010 were quite similar to results at other sites when water was adequate. With the exception of several sites (DeKalb in 2009 and 2010, Urbana in 2010) where cool temperatures and high rainfall prevailed, responses to residue removal and tillage, and to N rates within these combinations, were rather consistent. It is clear that residue removal has only minor effects on yield and response to N of continuous corn that is conventionally tilled. Under no-till, however, removal of residue makes higher yields possible under reasonable N fertilizer rates, especially in fields with cooler, wetter soils. We do not know if there are effects of long-term removal of residue on soil properties, but there do not appear to be cumulative yields effects – negative or positive – after five years of residue removal.

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