SOIL CHARACTERISTICS AND SUBSEQUENT CORN DEVELOPMENT FOLLOWING PARTIAL CORN RESIDUE REMOVAL IN A NO-TILL, CORN-SOYBEAN ROTATION

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By

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The undersigned, appointed by the dean of the Graduate School, have examined the Dissertation entitled

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A candidate for the degree of Doctor of Philosophy

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CHAPTER I

LITERATURE REVIEW

A rise in population and a thriving world economy have increased the demand for energy. A large portion of the world's energy is provided by finite fossil fuels such as oil, coal and natural gas. Fossil fuels release greenhouse gases into the atmosphere originally sequestered underground (Offermann, 2011). Oil is anticipated to be the first major non-renewable fuel to deplete within 35 to 40 years (Administration, 2006; Shafiee and Topal, 2008). Natural gas and coal are anticipated to deplete in approximately 40 and 107 years, respectively (Shafiee and Topal, 2008). Alternative energy sources are needed in large quantities to replace diminishing fossil fuels. Focus has been placed on renewable energy, such as solar, wind, water and bioenergy, to provide solutions to the impending energy crisis. Slow incorporation of alternative energy allows time to evaluate the effects to the environment and economy, while establishing a smooth transition from old to new energy sources.

Bioenergy is a renewable energy source made from living or recently deceased organisms. The primary organic feedstock used for bioenergy is generated from plants and animals including, but not limited to: grain, agricultural residues, forest residues and municipal solid wastes (Offermann et al., 2011). Currently, 10% of the world's energy needs are met by bioenergy, primarily used for heating and cooking (Agency, 2009).

Biofuel, also known as renewable fuel, can be generated from domestic organic feedstocks to replace a portion of transportation fuel produced from imported oil

(U.S.Government, 2007). According to the Energy Independence and Security Act of 2007 (U.S.Government, 2007), “the term renewable fuel means fuel that is produced from renewable biomass and that is used to replace or reduce the quantity of fossil fuel present in a transportation fuel.” Biofuels provide opportunity to enhance America’s economic, social, and environmental sustainability while reducing dependence on foreign oil (U.S.DOE, 2011b). Some countries from which the USA imports oil have unstable governments and/or economies. International oil prices can be affected by these countries to increase the price of gasoline at fuel stations. Increasing the consumption of biofuels produced domestically could reduce and stabilize transportation fuel prices, while stimulating the nationwide economy (U.S.DOE, 2005).

Concern for national energy independence and environmental responsibility led President George W. Bush to sign the Energy Independence and Security Act of 2007 (U.S.Government, 2007). The act requires an increased supply and efficiency of domestic energy sources with low greenhouse gas emissions. *Title II - Energy Security through Increased Production of Biofuels* set specific national standards and stipulations for biofuels. *Title II* of the act mandates 36 billion gallons of biofuel to be sold in the United States by 2022; 21 billion gallons must come from advanced sources other than corn (*Zea mays* L.*)* starch. A minimum of 16 billion gallons of advanced biofuel must come from cellulosic sources. All greenhouse gas emissions from advanced biofuels must have a lifecycle length at least 50% less than the fossil fuel baseline, as determined by the United States government. Cellulosic biofuel must provide at least 60% less greenhouse gas emissions than fossil fuels (U.S.Government, 2007).

Ethanol made from biomass feedstock can be mixed with gasoline for a liquid transportation fuel. According to the Merriam-Webster Dictionary (2013), ethanol is, “a colorless volatile flammable liquid C_2H_5OH that is the intoxicating agent in liquors and is also used as a solvent and in fuel.” Tank mixes of 90% gasoline and 10% ethanol are currently available at fuel stations across the USA and are consumable by most combustion engines. Older vehicles are limited to a lower percentage of ethanol in a tank mix with gasoline, while newer flex fuel vehicles can consume up to 85% ethanol (U.S.DOE, 2013). As vehicles advance to withstand greater tank mixes of ethanol, production of ethanol will need to increase with demand.

For the past several decades in the USA, corn grain has been the predominant feedstock for national ethanol production. Corn grain is composed of over 85% starch based carbohydrates (Earle et al., 1946), providing roughly 2.55 gallons of ethanol per bushel (Wang, 2000). Demand for corn grain is great among many industries. Overuse of corn grain in ethanol production creates a strain on supply for the food and feed industries (Perlack et al., 2005; Sanderson, 2006). A short supply of corn grain could drive up prices in livestock markets and cause apprehension for food security. As a result, the Energy Independence and Security Act of 2007 limited ethanol production from corn starch to 15 billion gallons annually (U.S.Government, 2007).

An extended goal of the legislative mandate is to displace 30 percent of the national gasoline consumption by 2030 with ethanol (U.S.Government, 2007). To accomplish this goal, one billion dry tons of domestic cellulosic feedstock would be required annually, assuming the 2005 cellulosic ethanol conversion rate of 85 gallons per dry ton (Perlack et al., 2005; U.S.DOE, 2005). The 2005 *Billion Ton Study* (U.S.DOE, 2005), found the annual collection of a billion dry tons of domestic cellulosic feedstock attainable from forest and agricultural land (368 and 998 million dry tons, respectively)(Graham et al., 2007; Perlack et al., 2005; U.S.DOE, 2005). The 2011 *Billion Ton Update* (U.S.DOE, 2011b) assessed the accuracy of potential cellulosic feedstock from the 2005 study concluding potential forest and agriculture allocations were less than originally predicted. However, the 2011 *Billion Ton Update* added pastureland to the model and projected greater potential for dedicated energy crops. Cellulosic feedstocks were still estimated to be greater than one billion tons annually by 2030 with high yield scenarios peaking at 1.5 billion tons per year (U.S.DOE, 2011b).

Economic value and environmental impact determine the best cellulosic feedstocks for ethanol conversion. Dedicated energy crops, forest residues and crop residues are the three primary feedstocks anticipated for cellulosic biofuel in the USA (Parveen et al., 2009). The biomass of dedicated energy crops has large carbohydrate content and is grown solely for energy production, but energy crop potential depends on available land (Offermann et al., 2011). Premium production land is used primarily for row crops. Energy crops are expected to be grown on land that is marginal for crop production (Dhugga, 2007). Energy crop biomass is harvested annually, with some feedstocks producing up to 30,000 kg ha^{-1} each year (McLaughlin et al., 2006).

Residues are “residual material from a primary production process” (Offermann et al., 2011). Residues are essentially by-products or wastes from a separate production income. Forests can provide two sources of revenue. Favorable wood is primarily made into lumber, while residues can be made into ethanol or another by-product. Forests produce large amounts of cellulosic feedstock, but require a long growth period. Forest residues have large lignin composition causing difficulty and expense in biomass conversion to ethanol (Sjostrom, 1993). Most agricultural crops could also provide two sources of revenue from collection of seed and residue. Agricultural residues have great carbohydrate content and are vastly abundant within the USA (Perlack et al., 2005; Reddy and Yang, 2005). Most agricultural crops are annual plants, so large amounts of residue can be harvested each year. Crop residues generate smaller environmental footprints than dedicated energy crops by reducing the conversion of marginal crop land into production (Dhugga, 2007).

Crops favorable for cellulosic ethanol have large residue production (Perlack et al., 2005; Reddy and Yang, 2005). Corn is the largest producer of crop residue in the USA, producing more than half (75 of the 144 million dry tons per year) of the total residue available (Perlack et al., 2005; Reddy and Yang, 2005). Corn residue, also known as corn stover, is the non-grain remains of a corn plant consisting of the stalk, leaves, husk, cob, tassel, and silks. Roughly 5% of corn residue in the USA is removed for silage, bedding or industrial processing following grain harvest. The remaining 95% of corn residue left in the field to decompose (Glassner et al., 1999) remains available to the cellulosic ethanol industry.

Corn residue has large carbohydrate content, providing a promising ethanol feedstock. Cellulose and hemicellulose are the structural carbohydrates used for ethanol conversion, and together they comprise 65% of corn residue on a dry matter basis. The chemical composition of corn residue is approximately 25% hemicellulose, 40% cellulose, 20% lignin, 5% protein and 5% soluble solids (Pordesimo et al., 2005). Chemical composition determines the mechanical strength of plant tissues, as well as the ability of a plant to withstand environmental stresses to remain freestanding until grain harvest (Ching et al., 2006; Hatfield and Fukushima, 2005; Pedersen et al., 2005). Cellulose and hemicellulose are found within primary and secondary plant cell walls to provide structural support. Secondary cell walls have additional structural support from lignin, a polymer with a non-repetitive chemical structure (Dickison, 2000). Lignin interlinks with cellulose and hemicellulose in a matrix within secondary cell walls, inhibiting enzymes access to the carbohydrate macromolecules. Both cellulose and hemicellulose must be broken into their component monomers before yeasts can convert them to ethanol. Therefore, an expensive pretreatment must be applied to loosen cell wall components and allow access for enzymes (Parveen et al., 2009). Development of efficient and cost effective conversion methods is essential for the future of cellulosic ethanol production.

Corn production provides an equilibrium for atmospheric carbon capture and release, or possibly even a net carbon sequestration into the soil (U.S.DOE, 2011a). The Environmental Protection Agency (U.S.EPA, 2010) examined the carbon footprint of ethanol feedstocks and other renewable bioenergy sources. Corn residue converted to ethanol by thermochemical conversion resulted in a 93% carbon reduction from the petroleum baseline. Corn residue converted to ethanol by biochemical conversion resulted in a 130% reduction from the petroleum baseline. Both conversion methods surpass the requirement set by the government to reduce greenhouse gas emissions from biofuels by 60% from the fossil fuel baseline.

Approximately 30 to 60% of corn residue is needed to remain in the field to maintain soil quality (Kim and Dale, 2004; Nelson, 2002). The percentage depends upon residue yield, management practices, and field conditions (Linstrom et al., 1981). Mowers, rakes and balers are typical equipment accessible to producers for corn residue collection. It is not feasible to collect much more than 60% of corn residue, since commercial balers are limited to approximately 70% removal (Glassner et al., 1998).

There is potential to collect only corn cobs as an ethanol feedstock. Cobs are readily available after grain harvest and have no direct link to the food or feed industry. Cob collection would be relatively easy to implement. As corn ears are harvested, grain and cobs are separated within the combine; grain enters the hopper and cobs exit the rear. Equipment could attach to the combine and collect cobs as they exit, increasing the efficiency of cob collection (Halvorson and Johnson, 2009; Lorenz et al., 2009) and limiting passages of equipment through the field. Cobs only compose 15% of corn residues, leaving 85% of residues to remain in the field. (Hanway, August 2007). With only cob removal, there is less need to develop residue management strategies. On the other hand, the small amount of biomass collected from cobs would not convert to significant volumes of ethanol.

Soil characteristics affected by residue removal

Crop biomass is by far the dominant input of organic matter into the soil of production fields (Allison, 1973). If residues are removed, soil organic matter (SOM) and soil organic carbon (SOC) decrease near the soil surface (Moebius-Clune et al., 2008). Graham et al. (2007) and Perlack et al. (2005) estimated two-thirds of corn residue could be removed annually from a no-till field without significantly decreasing SOM. The remaining corn residue and root system provided sufficient biomass to maintain SOM. Wilts et al. (2004) estimated corn roots accounted for as much as threefold the amount of soil carbon than above ground biomass and these results were supported by Campbell et al. (1991). Not all research supports the contention that up to 67% of the corn residue could be removed without reducing SOC. Blanco-Canqui and Lal (2009) found that SOC decreased with residue removal rates as little as 25%.

Corn residue that remains in the field provides fertility to the soil upon decomposition. A portion of organic nutrients within corn residue mineralize in the spring as soil temperatures and microbial activity increase (Alberts and Neibling, 1994; Kumar and Goh, 2000). Released mineral nutrients are then available to the subsequent crop during rapid vegetative growth (VanEs et al., 2007). Harvesting corn residue would likely cause soil fertility to decline unless augmented with additional fertilizer inputs. Residue removal rates as little as 40% have caused soil nutrient concentrations to decrease near the soil surface (Fixen, 2007). On the other hand, Blanco-Canqui and Lal (2009) and Karlen et al. (1984) both concluded nearly 100% corn residue removal was needed to significantly affect all macronutrient levels near the soil surface.

Increased water runoff and erosion caused by corn residue removal may result in mineral nutrient loss from the field. Surface residues inhibit water movement within a field to increase water ponding and infiltration (Alberts and Neibling, 1994). When residues are removed from a field, water runoff usually increases. Nitrogen is relatively mobile with mass water flow, so it can be easily transported from the field with water. Phosphorus and potassium establish strong adhesive bonds with soil particles and are relatively immobile within the soil. Soil particles with bound phosphorus and potassium may become detached and picked up by running water to be transported out of the field, resulting in nutrient loss. Soil erosion is nearly eliminated when at least 50% of corn residue remains in a no-till field (Gilley et al., 1997). Nutrient loss by erosion and water runoff could be reduced with only partial corn residue removal.

Corn residue removal can affect soil physical characteristics near the soil surface. The direct impact of raindrops can splash soil particles from original surface aggregates into pores, forming soil crusts (Alberts and Neibling, 1994). Within one year, complete corn residue removal can significantly increase crust strength of the top 5 cm of soil (Blanco-Canqui et al., 2006). Soil crusting can cause inadequate gas exchange for roots (Kladivko, 1994), less water infiltration (Bajracharya and Lal, 1998; Wells et al., 2003), restricted seedling emergence (Baumhardt et al., 2004) and decreased plant growth (Maiorana et al., 2001). Quick transitions from wet soil to dry soil, increase the likelihood of soil crusting in areas with silt soils (Or and Ghezzehei, 2002). The soil of central Missouri has a large silt concentration, supporting the need for a portion of corn residues to remain on the soil surface to prevent soil crusting.

As plant biomass is left to degrade in production fields, typically SOM increases and soil bulk density decreases (Kladivko, 1994). In a long term, no-till study, Moebius-Clune et al. (2008) measured a 5% difference in soil bulk density between 100% and 0% residue removal treatments, with 100% removal having the denser soil. In a one year study by Blanco-Canqui et al. (2006), soil bulk density was measured from a 0 to 6 cm soil depth following corn residue removal of 0, 25, 50, 75 and 100% from three locations in Ohio. After one year, a positive relationship was found between soil bulk density and corn residue removal rate, but only treatments of 0% and 100% residue removal were significantly different

Surface residues reflect a large portion of solar radiation and inhibit soil moisture evaporation, keeping soil surface temperatures lower than when residue is removed (Doran et al., 1984; Kumar and Goh, 2000). Removal of surface residues exposes bare soil to environmental elements (e.g. sunlight and wind), causing the soil to warm more quickly in the spring (Zhai et al., 1990). Doran et al. (1984) found a positive relationship between the percentage of corn residue removed and soil temperature at a 5 cm soil depth. At the hottest point in the summer, treatments with 0% and 50% corn residue removal had soil surface temperatures 8.6 ^{o}C and 4.2 ^{o}C cooler than 100% removal. Contradictory conclusions were provided from research by Flerchinger et al. (2003) that compared bare soil to soil covered by residue. They found remaining surface residues can significantly increase soil surface temperatures by absorbing, trapping and retaining more heat from solar radiation.

Surface residues increase soil water content and may provide protection against drought stress. Water evaporation and runoff in a production field reduces the water available to crops. Restricting water movement with surface residues increases water ponding and infiltration of water into the soil (Alberts and Neibling, 1994). Blanco-Canqui et al. (2006) and Moebius-Clune et al. (2008) found a negative correlation between soil water content and corn residue removal rate. Doran et al. (1984) measured soil water content every 0.3 m, up to a 1.8 m depth for 0, 50 and 100% corn residue removal treatments. At each depth, soil water content was greatest for residue removal treatments of 0%, followed by 50%, and then 100%.

Plant development affected by residue removal

An abundance of research has been conducted to evaluate the effects of residue removal on corn grain yield, but results vary considerably (Blanco-Canqui and Lal, 2007; Doran et al., 1984; Moranchan et al., 1972; Swan et al., 1994; Wilhelm et al., 2004). Doran et al. (1984) found a 21% corn grain yield reduction the following year with complete residue removal compared to no residue removal. Swan et al. (1994) found a positive correlation between corn grain yield and the amount of corn residue on the soil surface. In contrast, Barber (1979) found no significant differences for grain yield in continuous corn for treatments with 1) residue completely removed, 2) all residues remaining or 3) residue doubled. In continuous corn, Blanco-Canqui et al. (2006) and Wilhelm et al. (1986) calculated that corn residue removal rates explained 93% and 80% of grain yield variability in the following corn crop.

Weather conditions can influence the effects of corn residue removal on subsequent corn grain yield. In dry years of a continuous corn study, Linden et al. (2000) found treatments with all corn residue remaining produced larger grain yields than treatments with all residue removed. Sims et al. (1998) determined if spring temperatures were cool or below average, corn grain yield was reduced when corn residue remained. If several years of drought have occurred, producers may consider limiting residue removal to conserve soil moisture (Linden et al., 2000; Sims et al., 1998). The producer can alter the corn planting date accordingly to accomodate for soil temperatures.

Corn residue removal rate can influence the residue yield of the following corn crop. Power et al. (1998) found complete residue removal reduced corn residue yield the following year by 12% compared to all residue remaining; roughly half of the overall 23% biomass reduction. Power et al. (1986) and Swan et al. (1994) found a negative relationship between corn residue removal rate and residue yield of the following corn crop. In continuous corn, Blanco-Canqui et al. (2006) and Wilhelm et al., (1986) calculated that residue removal rates explained 95% and 86% of the variability in residue yield for the following corn crop. It is unknown if the decline in corn grain and corn residue yield is a result of changes in chemical composition, plant morphology and/or stalk strength characteristics.

Corn emergence is the first plant development characteristic to present differences from corn residue removal treatments. Emergence can be affected in three ways: 1) the number of plants to emerge, 2) number of days from planting to emergence and 3) length of emergence period. Burgess et al. (1996) found a decrease in corn stand density when planting into treatments with all corn residue remaining from the previous year. Blanco-Canqui et al. (2006) reported that corn emergence in treatments with 0% corn residue removal was delayed by three days compared to 100% residue removal. Residue removal led to faster corn emergence by increasing soil temperature (Ford and Hicks, 1992; Sharratt, 2002). Corn that emerges earlier would have a competitive advantage over late emerging corn for access to resources.

Fortin and Pierce (1990) evaluated the effects of complete and no residue removal on the number of days after emergence for corn plants to reach developmental stages. The first year, plants in the no residue removed treatment reach V8, V12 and VT four days later than plants in treatments with residue completely removed. The second year more growth stages were evaluated. Corn plants in treatments with no residue removed resulted in a delay of four days at V3, six days at V6, seven days at V12 and eight days at R1 compared to plants in treatments with complete residue removal. Variation in the number of days to reach each growth stage was attributed to soil temperature differences among residue treatments.

Fortin and Pierce (1990) compared the height of corn plants in 0% and 100% residue removal treatments. Although maximum corn plant heights were the same among residue treatments, plants in treatments with 100% residue removed grew more quickly. Corn plants from 100% residue removal reached their maximum heights 60 days after emergence versus 68 days for plants in 0% residue removal treatments. Blanco-Canqui et al. (2006) found similar results as 100% residue removal treatments had earlier emerging corn plants that grew consistently taller than plants within 0% residue removal treatments until 50 days after emergence. Residue removal treatments did not affect maximum corn plant height. It is unknown if corn plants that reached a maximum height early then transitioned growth to other development characteristics, such as, increased leaf coverage or enhanced stalk strength.

Management practices used with residue removal

Profitability of corn production was once strictly associated with grain yield. The legislative mandate requiring 36 billion gallons of ethanol to be sold in the USA by 2022 has expanded the cellulosic ethanol industry, creating a demand for corn residue. In some areas of the country, producers can harvest both corn grain and corn residue for profit. Management strategies implemented by the producer should strive to attain the greatest yield for both. If corn residue removal becomes a common practice, soil and crop productivity may be affected. Management practices used in a production system can influence the effect corn residue removal has on soil and subsequent corn productivity. Such practices include: crop rotation, tillage practices and use of cover crops.

Most research evaluating the effects of corn residue removal to soil and plant productivity compare residue removal rates in a continuous corn system. Crop rotation implements the planting of a succession of different crops (e.g. corn-soybean). Alternating years of corn and soybean (*Glycine max* L.) is a common crop rotation in the Midwest and especially in Missouri. Theoretically, a corn-soybean rotation should cause fewer effects on soil and plant characteristics since corn residue is only removed in alternating years and soybean biomass would remain in the field.

The tillage practice applied to a production system can influence soil chemical, physical and microclimate characteristics. The two primary seedbed preparation practices include no-tillage (no-till) and tillage. In a no-till system, soil is only disrupted to plant seed and plant residues remain on the soil surface. No-till systems cause the soil to increase in soil organic matter, aggregate stability, and water infiltration, while decreasing soil bulk density and erosion (Havlin et al., 2005; Liebig et al., 2004; Pierce and Rice, 1988). Harvesting crop residues in no-till could make planting more efficient by increasing the seed-to-soil contact for greater seed germination rates and uniform emergence.

Tillage disrupts the soil to a desired depth, usually incorporating a portion of surface residues into the soil. Tillage causes faster decomposition of surface residues and provides a relatively clean seedbed for improved seed-to-soil contact. Faster decomposition of crop residues with tillage is beneficial if residues are overabundant and burdensome for future planting. Most tillage practices expose soil from under surface residues and soil erosion becomes a concern. Erosion from tillage is an issue that can be compounded when surface residues are removed. A 32-year study by Moebius-Clune et al. (2008) studied the effects of residue management and tillage on soil characteristics. Tillage had more significant effects on soil characteristics (affecting 15 out of 25 soil characteristics measured) than complete corn residue removal (affecting 8 out of 25 soil characteristics measured) at the end of the study. Of the soil characteristics affected by both tillage and corn residue removal, most had greater change with tillage. The study drew two major conclusions: 1) tillage results in more dramatic changes to soil characteristics than harvesting corn residue and 2) harvesting corn residue is feasible under a no-till practice.

Cover crops can contribute organic matter to the soil and provide ground cover during fallow periods (Sarrantonio and Gallandt, 2008). The use of cover crops could mitigate soil changes associated with residue removal and function as a substitute for crop residues. Their above ground biomass shields the soil surface from external agents, such as rainfall, wind and sunlight. (Network, 1998). Cover crops contribute biomass to the soil decreasing bulk density, increasing soil water infiltration and increasing SOM (Mendes et al., 1999; Reeves, 1994; Villamil et al., 2006). They improve soil fertility by releasing absorbed or fixed mineral nutrients upon termination (Pierce and Rice, 1988). Approximately 30% to 60% of mineral nutrients released by cover crops become available to the summer crop during intensive growth periods (Network, 1998). Cover cropping is becoming more common due to soil quality benefits and the increased cost of fertilizers (Network, 1998; Sarrantonio and Gallandt, 2008). A need exists to determine if cover crops can mitigate soil changes associated with corn residue removal.

Most research on corn residue removal has evaluated soil characteristics and corn yield results for 1) complete residue removal versus no residue removal, 2) residue removal in various tillage systems and 3) residue removal in continuous corn (Doran et al., 1984; Kumar and Goh, 2000; Moebius-Clune et al., 2008). Complete residue removal is not feasible since commercial balers are limited to a 70% corn residue removal rate (Glassner et al., 1998). A no-till system would minimize disruptions to the soil to improve soil quality (Moebius-Clune et al. 2008). Partial corn residue removal in a corn-soybean rotation should reduce the negative effects of residue removal on soil and crop productivity. Cover crops can be added to a system to further mitigate changes to soil characteristics caused by corn residue removal.

Objectives

The Energy Independence and Security Act of 2007 mandates 21 billion gallons of cellulosic biofuel to be sold in the USA by 2022 (U.S.Government, 2007). The cellulosic ethanol industry will require vast amounts of domestic biomass feedstock to meet such a demand. Corn residue will be a primary cellulosic feedstock as the most abundant agricultural residue in America with a large carbohydrate content (Perlack et al., 2005; Reddy and Yang, 2005). These greatly desired attributes can lead to corn residue removal on an unprecedented scale. An urgent need exists to understand how corn residue removal affects soil and corn productivity to establish reliable management recommendations for producers. The objectives of this study include: 1) determine the effects of partial corn residue removal on selected soil chemical, physical and microclimate characteristics, 2) determine the effects of partial corn residue removal on corn development 3) determine how emergence order and emergence variation caused by partial corn residue removal and cover crop use affects plant development and 4) determine if cover crops can mitigate potential negative effects caused by corn residue removal on soil and corn productivity.

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CHAPTER II

EFFECT OF CORN RESIDUE REMOVAL AND USE OF A COVER CROP ON SOIL CHARACTERISTICS

ABSTRACT

Corn *(Zea mays* L.*)* residue removal for ethanol production can affect soil chemical, physical and microclimate characteristics. Little research has evaluated partial corn residue removal from baling followed by the use of a cover crop to mitigate potential changes to soil characteristics. Research is needed to determine the effects of corn residue removal and establish residue management recommendations for producers to prevent a decline in soil productivity. This three year study evaluated the effects of Baled (60% residue removal) and Not Baled (0% residue removal) corn residue treatments in combination with None and Rye (*Secale cereal* L.) cover crop treatments on fourteen soil characteristics in a no-till, corn-soybean rotation. The Baled treatment reduced magnesium concentrations at the 0 to 5 cm and 5 to 20 cm soil depths and increased soil water content at corn silking (R1). The Rye treatment increased soil ammonium-N concentration, soil water content at R1, minimum and average soil temperature at corn emergence (VE). Only calcium concentration at the 5 to 20 cm soil depth had a significant residue X cover crop interaction. The results of this study show 60% corn residue removal is feasible in a no-till, corn-soybean rotation, causing minimal short-term effects to soil chemical, physical or microclimate

characteristics. Small amounts of biomass were established with rye as a winter cover crop, providing few benefits to soil characteristics.

INTRODUCTION

Thriving domestic and world economies have given rise to large demands for fossil fuels such as coal, oil and natural gas. Oil supplies most of the world's transportation fuel, but is anticipated to diminish within the next 40 years (Administration, 2006). Ethanol provides opportunity as a renewable biofuel to enhance national economic growth and environmental responsibility while reducing dependence on foreign oil (Grassley, 2011; U.S.DOE, 2011b). The Energy Independence and Security Act of 2007 mandates 36 billion gallons of biofuels to be sold in the USA by 2022 (U.S.Government, 2007). Of that amount, 21 billion gallons must be derived from cellulosic feedstock or other advanced forms. An extended goal of the legislative mandate is to displace approximately 30% of the national petroleum consumption by 2030 (U.S.Government, 2007). One billion dry tons of cellulosic feedstock would be required annually to accomplish this goal (Perlack et al., 2005; U.S.DOE, 2005). The annual collection of a billion dry tons of cellulosic feedstock will be difficult, but is attainable from agricultural residues, forest residues and energy crops (Graham et al., 2007; Perlack et al., 2005; U.S.DOE, 2005; U.S.DOE, 2011b). Corn residue has large carbohydrate content, is readily available for collection and produces more residue than any other agricultural crop in the USA (Perlack et al., 2005; Reddy and Yang, 2005).

The federal mandate will expand the cellulosic ethanol market, requiring an abundance of corn residue to be collected from production fields.

If corn residue removal becomes part of a cropping system, soil chemical, physical and microclimate characteristics may be affected from a reduction of both soil coverage and organic inputs. Less organic inputs to the soil could decrease soil organic matter (SOM), soil organic carbon (SOC) and soil fertility. A decrease in soil coverage from residue removal could affect near-surface soil physical properties within one year following removal, including crust strength and bulk density(Blanco-Canqui et al., 2006). Microclimate at the soil surface is influenced by the presence of residue acting as a barrier to reflect sunlight and decrease soil surface temperatures (Larson et al., 1978). The soil surface barrier created by residue decreases water evaporation (Kumar and Goh, 2000) and reduces water runoff for greater water infiltration (Alberts and Neibling, 1994).

It is important to evaluate corn residue removal under conditions that producers would apply in their own production systems. Residue collection equipment is limited to far less than 100% removal. Commercial balers are capable of 70% corn residue removal rate from production fields (Glassner et al., 1999). Much of the previous research for corn residue removal has focused on a continuous corn cropping system. Impacts from corn residue removal may be less in a system with crop rotation because corn residue is only removed in alternate years. Winter cover crops can add organic matter and sequester mineral nutrients. It is important to determine if cover crops can counter the potential negative effects on soil characteristics resulting from corn residue removal. The objectives of this study include: 1) determine the effects of partial corn residue removal on soil physical, chemical and microclimate characteristics in a corn-soybean rotation and 2) determine how cover crops influence soil characteristics that could be affected by corn residue removal.

MATERIALS AND METHODS

Field experiments were conducted at the University of Missouri - Bradford Research Center. The predominant soil resource at this location was a Mexico silt loam (montmorillonitic, mesic, aeric, Vertic Epiaqualfs). These soils are classified by the USDA-NRCS as Major Land Resource area 113 - central claypan till plains. The parent materials for this resource are primarily loess, over pedisediment, over glacial till.

Although data were collected in 2010 and 2011, site preparation for the experiment began in the fall of 2008. In 2008, the entire plot area was planted to corn. Randomized strips of corn and soybean were planted in 2009 and a corn-soybean rotation was implemented from that year forward. Data were not collected in 2009, but residue removal and cover crop treatments were applied after corn harvest in the fall.

Experimental design for this research study was a randomized complete block with four replications. Treatment combinations were arranged in a split plot. Whole plots were two residue treatments, Baled and Not Baled. Corn residue for Not Baled treatments remained undisturbed following grain harvest. Collection of corn residue for the Baled treatment was a three step process consisting of mowing residue, raking residue into windrows and baling residue for transport from field. Approximately 60% of corn residue was removed in the Baled treatment immediately following grain harvest each fall. Percentage of corn residue removal by the three step baling process was determined by residue biomass collection within four random 0.3 m^2 areas before and after baling within each plot. Subplots were two winter cover crop treatments, None and Rye. In the Rye treatment, cereal rye (*Secale cereal* L.) was planted each fall at a seeding rate of 78 kg ha^{-1}. In plots of maturing soybean (will be corn the following year), rye was broadcast seeded prior to soybean leaf drop with a hand held seed spreader. In plots of corn (will be soybean the following year), rye was planted following corn residue baling with an 8-row Almaco no-till plot drill (ALMACO, Nevada, IA). Plot size was 6.1 m wide and 7.6 m long.

In early spring of each year, phosphorus as triple super phosphate was applied at 85.5 kg P ha^{-1} and potassium as KCl was applied at 142.5 kg K ha^{-1} to the entire field. One week before corn planting, the field was sprayed with a tank mix of S-metolachlor and glyphosate to kill all existing vegetation, including the rye cover crop. Additional pre-emergence weed control was provided by a tank mix of 2,4-dichlorophenoxyacetic acid, glyphosate, and mesotrione.

On 15 April 2010 and 4 May 2011, Dekalb brand 62-54 was planted at a seeding rate of 73,500 seeds ha^{-1} with a Kinze model 2100 row planter (Kinze Manufacturing, Inc., Williamsburg, IA). Plot size for corn was equal to the plot size for cover crops. Row spacing was 0.76 m, so plots contained eight rows of corn. Broadcast ammonium nitrate was applied using a hand held fertilizer spreader at a rate of 205 kg N ha^{-1} following corn emergence. Glyphosate was applied as necessary for post emergence weed control. Irrigation was applied with a lateral irrigator when soil moisture was low, as determined by visual inspection. Irrigation was not needed in 2010. In 2011, approximately 25 mm of water was applied on four different dates following corn tasseling. On 3 July 2011, a hailstorm struck the study location, one week before the corn reached R1 stage. Although there was roughly a 15% plant loss, the experiment was continued.

Soil cores were collected from the center of each plot from within a 4.0 m^2 area. Six deep soil cores were collected to analyze soil ammonium-N and nitrate-N as recommended by the University of Missouri Soils Testing Laboratory. The claypan at the experiment location was present at a soil depth of 46 cm, so deep soil cores were taken from 0 to 46 cm. Eight soil cores used to determine organic carbon, organic matter, phosphorus, potassium, calcium, magnesium, sulfur and pH characteristics were separated into two soil depths: 0 to 5 cm and 5 to 20 cm. All soil samples were collected following corn planting, but prior to ammonium nitrate application. Samples were placed in a forced ventilation dryer at 15^{o}C for 48 hours then ground through a 2-mm screen.

All soil analyses except SOC were conducted at the University of Missouri Soil and Plant Testing Laboratory. Ammonium-N and nitrate-N were extracted with a 2 M potassium chloride solution. Nitrogen concentrations were measured using a Lachet Flow Injection Autoanalyzer (Hach Company, Loveland, CO) by standard colorimetric Berthelot (NH_4^+) and Griess-Ilosvay (NO_3^-) methods as described by Mulvaney (1996). SOM was estimated by weight loss resulting from ignition in a 360 ^{o}C oven. Phosphorus was evaluated by mixing with the color reagent ascorbic acid to develop color based on phosphorus content of the sample. A spectrophotometer measured transmittance at 660 nm which was compared to a standard curve to estimate phosphorus concentration. Potassium, calcium and magnesium were determined using 1N ammonium acetate (NH_4OA_c) at a pH of 7.0 to extract basic exchangeable cations. Sulfur was extracted by 2 N acetic acid containing 500 mg kg^{-1}. Soil pH was determined by a pH meter with a glass electrode that measured H^+ concentration (Nathan et al., 2012). SOC concentrations were assessed from soil samples by the dry combustion method (925^oC) using a LECO C-144 carbon analyzer (LECO Corporation, St. Joseph, MI) (Nelson and Sommers, 1996).

On the day of corn planting, StowAway Tidbit Temperature Data Loggers (Onset Computer Corp., Bourne, MA) were placed 6 cm below the soil surface within the fourth row of each corn plot. For the duration of the corn season, the data loggers recorded soil temperature every hour. Prior to harvest, the data loggers were removed from the soil. The daily minimum, maximum, and average temperatures were transferred to Windows Excel by HOBOware Lite 3.0 software (Onset Computer Corp, Bourne, MA).

An Imko TRIME-FM instrument (MESA Syst. Co, Medfield, MA) with a TRIME-P3 3 rod probe using time domain reflectometry (TDR) was used to measure the volumetric water content. One moisture reading at the center of each plot was recorded from a 15 cm soil depth at corn VE and R1. Soil crust strength was measured with a Soil Test CL-700 pocket penetrometer (Soil Test Incorporated, Evanston, IL) to determine the compressive strength (kg cm^{-2}) of the top 0.65 cm of the soil surface.

Five random penetration readings per plot were averaged for one compression value at corn VE and R1.

Soil bulk density was measured at the beginning and end of the study to determine the change in bulk density. A 7.62 cm diam. x 7.62 cm length soil ring was used to remove a soil core from each plot. Collected density cores were weighed and then dried at 45°C in an oven with forced ventilation for four days. Upon oven removal, core samples were weighed for soil density values.

Data was analyzed using the SAS statistical software package (SAS Inst., 2001). Proc Mixed was used to perform the analysis of variance. Replication was considered random whereas all other sources of variation were considered fixed. Statistical significance was evaluated at $P \leq 0.05$. When treatment effects were significant, means were separated using least significant difference (LSD).

RESULTS AND DISCUSSION

Crop Residue

Residues are important contributors of organic matter and mineral nutrients to the soil. Crop biomass is by far the dominant source of organic matter and organic carbon for soil of production fields. Corn residue removal deprives soil near the surface of significant organic inputs. It is likely that changes to soil characteristics may occur more quickly near the soil surface than deeper into the soil profile. For this reason, soil samples were divided into 0 to 5 cm and 5 to 20 cm soil depths for analysis of SOM, SOC, pH, potassium, phosphorus, calcium, magnesium and sulfur.

The residue removal treatments, Baled and Not baled, did not differ at either depth for SOM or SOC (Table 2-1). These results are supported by Graham et al. (2007), Perlack et al. (2005), and Wilhelm et al. (2004) who estimated that two-thirds of corn residue could be removed using no-till soil management without causing significant reductions to SOM. With corn residue removal, a reduction was expected for SOM and SOC in the Baled treatment, at least in the 0 to 5 cm soil depth. Reductions in SOM and SOC may occur beyond the scope of this three year study. The Baled treatments removed 60% of corn residue in alternating years, while the soybean residue in the rotation was not removed. Apparently, the remaining 40% corn residue, corn roots, and soybean biomass were able to maintain the SOM and SOC concentrations in the soil. Wilts et al. (2004) reported that corn roots accounted for threefold the amount of SOC in the plow layer than above ground vegetation. The findings of Wilts et al. (2004) provide an explanation for no reduction in SOC found in my short-term corn residue removal study.

Decomposing corn residues release mineral nutrients into the soil that are available to succeeding crops (Network, 1998). The concentrations of K, P, Ca, Mg, and S were evaluated at the 0 to 5 and 5 to 20 cm soil depths while ammonium-N and nitrate-N were evaluated at the 0 to 46 cm depth. The only soil mineral nutrient affected by residue removal was Mg concentration (Table 2-1, 2-2). At both soil depths, the Baled treatment resulted in 18% smaller Mg concentrations than the Not Baled treatment. These results from 60% residue removal were similar to the 20% decline in soil Mg reported by Moebius-Clune et al. (2008) with complete corn residue removal.

With the exception of soil Mg, the results of my study support Blanco-Canqui et al. (2006) and Karlen et al. (1984) who concluded close to 100% corn residue removal is needed to significantly reduce concentrations of soil mineral nutrients. Harvesting corn residue removes organic nutrients and should eventually cause the soil fertility to decline unless augmented with additional fertilizer inputs. Overall, partial corn residue removal caused limited effects on soil macronutrients concentrations within the time frame of this three year study.

Residue treatment did not affect soil pH at either the 0 to 5 cm or 5 to 20 cm soil depths (Table 2-3). Changes in soil pH occur relatively slowly and can result from production practices such as fertilizer application and organic input source (Blevins et al., 1983; Clark et al., 1998). Changes to soil pH from applied treatments are likely to occur beyond the time frame of this study.

Residue treatment did not affect final bulk density or change in bulk density from the beginning of the study to the end (Table 2-4). Blanco-Canqui et al. (2006) found treatments with 100% corn residue removal caused greater soil bulk density after just one year compared to treatments with 0% corn residue removal. Baling corn residue removed only 60% of the residue. Perhaps, this explains part of the difference between my results and those of Blanco-Canqui et al. (2006). Soil bulk density usually decreases as plant biomass degrades and SOM increases (Kladivko, 1994).

Residue treatments did not affect soil crust strength of the top 0.65 cm of soil surface (Table 2-4). The soil type at the study location was a Mexico silt loam. Soils that contain a large proportion of silt are prone to crusting (Or and Ghezzehei, 2002).

With partial corn residue removal, the physical barrier between the soil surface and raindrops is reduced. As a result, the soil surface should have been more susceptible to crust formation, but such an event did not occur (Alberts and Neibling, 1994). A quick transition from wet soil to dry soil that encourages soil crusting may not have transpired around the time of crusting strength sampling. In addition, 40% of corn residue remaining in the Baled treatment could have sufficiently intercepted raindrops to prevent soil particle movement.

Microclimate of the soil surface should change almost immediately with corn residue removal, especially soil water content and soil temperature. Soil water content at VE, was not affected by residue treatments (Table 2-3). This outcome contradicts results of Blanco-Canqui et al (2006) and Doran et al. (1984) who found a negative relationship between soil water content and percentage of corn residue removal. At R1, Baled treatments had greater soil water content (0.28 $m^3 m^{-3}$) than Not Baled (0.26 $m^3 m^{-3}$). The increase in soil water content from removing residue was the opposite of the results expected and not easily explained. The presence of corn residue generally prevents soil moisture evaporation (Doran et al., 1984; Kumar and Goh, 2000), which should have caused Not Baled treatments to have higher soil water content.

Soil temperature near the surface is influenced by the quantity of corn residue remaining and weather conditions. Residues reflect solar radiation and prevent soil moisture evaporation, keeping underlying soil temperatures cooler than when surface residues are removed (Doran et al., 1984; Kumar and Goh, 2000). Partial corn residue removal will expose a portion of the soil surface, causing the soil to warm more quickly in the spring (Zhai et al, 1990). Residue treatments did not affect maximum, minimum or average soil temperatures measured at VE or R1. Lack of soil temperature differences among residue treatments suggests the remaining 40% of corn residue on the soil surface after baling inhibits the soil from warming earlier than when all residues remain. My results conflict with those of Doran et al. (1984) who found that 50% corn residue removal increased soil temperatures at a 5 cm soil depth by 4.4 ^{o}C over treatments with no residue removal at R1.

Cover Crops

An expressed concern for harvesting corn residue is the deprivation of organic matter from the field that leaves bare soil exposed to environmental elements. My results, using partial corn residue removal in a corn-soybean rotation, indicate that this concern may not be valid, at least not in the short term. However, continuing research needs to investigate methods that could ameliorate possible negative consequences of removing corn residue. Cover crops could be incorporated into a production system to add organic matter, recycle mineral nutrients, and provide soil coverage to protect from the action of raindrops. A common cover crop, rye, was studied for this purpose. Weather conditions and the length of cover crop growth period influenced rye biomass accumulation. Rye biomass yield in 2010 was 287 kg ha^{-1} after 169 days of over winter growth. Rye biomass yield nearly doubled in 2011 to 595 kg ha^{-1} after 192 days of over winter growth. These numbers are only 10% or less of the corn residue removed with the Baled treatment. The small amount of cover crop biomass accumulation could impact cover crop treatment effects on soil characteristics.

The cover crop treatments, None and Rye, did not affect SOM, SOC or pH at either the 0 to 5 cm or the 5 to 20 cm soil depth (Table 2-1). The only soil macronutrient concentration affected by cover crop treatment was ammonium-N (Tables 2-1, 2-2). Rye had a greater soil ammonium-N concentration (15.1 mg kg^{-1}) than None (13.4 mg kg^{-1}). Microbial activity and soil temperature may have been greater in Rye treatments for increased nutrient mineralization from SOM by the time of soil sampling. Soil sample timing may not have accurately presented the benefit rye could provide to soil fertility. Termination of rye took place prior to corn planting, but the time lapse from termination to soil sampling may not have been sufficient to allow for organic nutrient mineralization from rye. It is difficult to determine the ideal time for soil sampling to evaluate the contributions of the rye cover crop to soil fertility.

Soil crust strength and bulk density were not affected by cover crop treatment (Tables 2-4). The lack of a cover crop effect on soil physical characteristics may have occurred for several reasons. The amount of rye biomass may not have been sufficient to intercept raindrops from directly impacting the soil. By corn R1, rye biomass would have significantly degraded, rendering the rye cover crop useless for intercepting the direct impact of rainfall. Soil bulk density of cover crop treatments remained virtually unchanged for the three year time frame between samplings. The accumulated rye biomass by termination may not have been enough to decrease bulk density.

Cover crop treatments had an effect on several soil microclimate characteristics measured. Soil water content at VE was not affected by cover crop treatment, but a significant cover crop effect was found for soil water content at R1 (Table 2-3). Soil water content at R1 for Rye and None averaged 0.28 $m^3 m^{-3}$ and 0.26 $m^3 m^{-3}$, respectively. Rye could have allowed for greater water content at R1 in two ways: 1) added plant residue at the soil surface reduced evaporation and water runoff and/or 2) the root system of rye created more soil surface openings for increased water infiltration.

A year X cover crop treatment effect occurred for maximum, minimum and average soil temperature at VE and maximum soil temperature at R1(Table 2-5). Rye increased all three measures of soil temperature at VE in 2010, but did not increase soil temperature at VE in 2011. At VE in 2010, the maximum, minimum and average soil temperature of the Rye treatment was 21.6, 9.2 and 14.5^{o}C, while the None treatment was 20.3, 8.2 and 13.6^{o}C, respectively. Rye biomass caused the soil to increase earlier in the spring in 2010. The 2010 corn planting was approximately 20 calendar days earlier than corn planting in 2011, which explains much of the temperature differences between years. Cool soil temperatures generally come with early planting (Havlin et al., 2005). Rye also increased the maximum soil temperature at R1 in 2011, but not in 2010. At R1 in 2011, the maximum soil temperature of Rye was 29.7^{o}C, while None was 28.8^{o}C.

SUMMARY AND CONCLUSIONS

Baling 60% of corn residue in a no-till, corn-soybean rotation had few short term effects on soil characteristics in this three year study. Residue treatments, Baled and Not Baled, did not affect SOM, SOC or concentrations of potassium, phosphorus, calcium or sulfur at either the 0 to 5 cm or 5 to 20 cm soil depth. Residue treatments did not affect soil ammonium-N or nitrate-N from a 46 cm depth. Magnesium was the only soil chemical characteristic affected by partial corn residue removal. Baled treatments resulted in an 18% decline in magnesium concentration at both the 0 to 5 cm and 5 to 20 cm depth from that of Not Baled. Residue treatments did not affect soil crust strength or bulk density. Soil water content differed between residue treatments at R1, but not VE. At R1, the Baled treatment had greater soil water content (0.28 $m^3\ m^{-3}$) than Not Baled (0.26 $m^3\ m^{-3}$). Residue treatments did not affect soil temperature at either VE or R1.

Cover crop treatments, None and Rye, caused few significant differences among soil characteristics. Ten soil chemical characteristics were measured (SOM, SOC, potassium, phosphorus, calcium, magnesium, sulfur, ammonium-N, nitrate-N and pH), but only soil ammonium-N was affected by cover crop treatments. The Rye treatment had greater ammonium-N (15.1 mg kg^{-1}) than the None treatment (13.4 mg kg^{-1}). Cover crop treatments did not affect soil crust strength or bulk density. Cover crop treatments differed for soil water content at R1, but not VE. Rye had greater soil water content (0.28 $m^3\ m^{-3}$) than None (0.26 $m^3\ m^{-3}$). A year X cover crop interaction occurred for maximum, minimum and average soil temperature at VE and maximum soil temperature at R1(Table 2-5). Rye increased all three measures of soil temperature at VE in 2010, but did not increase soil temperature at VE in 2011. At VE in 2010, the maximum, minimum and average soil temperature of the Rye treatment was 21.6, 9.2 and 14.5^{o}C, while the None treatment was 20.3, 8.2 and 13.6^{o}C, respectively. Rye also increased the maximum soil temperature at R1 in 2011, but not in 2010. At R1 in 2011, the maximum soil temperature of Rye was 29.7^{o}C, while None was 28.8^{o}C.

Based on the results from this study, soil characteristics undergo minimal short term changes from 60% corn residue removal in a two-year, corn-soybean rotation under no-till. The remaining residues and root systems of alternating corn and soybean crops were sufficient to maintain soil chemical, physical, and microclimate characteristics after partial corn residue removal. Since residue treatments caused few significant effects on soil characteristics, a cover crop was not needed to mitigate effects associated with partial corn residue removal. Biomass accumulated by rye replaced only 10% of the corn residue mass removed by baling. The small biomass accumulated by rye contributed little to organic matter input, soil fertility or a protective barrier over soil. This study demonstrates corn residue can be removed in a no-till, corn-soybean rotation and used for biofuel if residue removal does not exceed recommended rates.

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Table 2-1: Treatment means within residue and cover crop main effects for soil organic matter (SOM), soil organic carbon (SOC) and the concentration of five mineral nutrients in the soil measured within two depths †.

Depth	Main effect	Treatment	SOM	SOC	K	P	Ca	Mg	S
cm			----- g kg^{-1}------		--------------- mg kg^{-1} ---------------				
0 to 5	Residue	Baled	24.3a‡	14.3a	129a	45a	1568a	118a	8a
		Not Baled	23.9a	13.5a	132a	39a	1670a	144b	10a
	Cover crop	None	23.2a	14.0a	131a	44a	1608a	130a	10a
		Rye	24.9a	13.8a	129a	41a	1630a	132a	8a
5 to 20	Residue	Baled	17.2a	10.0a	48a	11a	-	113a	5a
		Not Baled	17.0a	9.6a	51a	11a	-	137b	5a
	Cover crop	None	16.5a	9.6a	52a	12a	-	122a	5a
		Rye	17.7a	10.0a	47a	11a	-	128a	5a

†Year X cover crop, year X residue, residue X cover crop and year X residue X cover crop interactions were not significant except for Ca at the 5 to 20 cm soil depth.

‡Means within a column, within a main effect and within a soil depth followed by the same letter are not significantly different (F-test, P=0.05).

Table 2-2: Treatment means within a year and within a residue and cover crop main effects for soil calcium concentrations in the 5 to 20 cm depth †.

Main effect	Treatment	2010	2011
		------------- mg kg^{-1}	-------------
Residue	Baled	1783a‡	1595a
	Not Baled	2000a	1582a
Cover crop	None	1920a	1511a
	Rye	1863a	1666b

†Year X cover crop interaction was significant.

‡Means within a column and within a main effect followed by the same letter are not significantly different (LSD, P=0.05).

Table 2-3: Treatment means within residue and cover crop main effects for soil ammonium and nitrate concentrations, soil pH at the 0 to 5 cm and 5 to 20 cm depths and soil water content at corn plant emergence (VE) and silking (R1) stages †.

				Soil pH		Soil water content	
Main effect	Treatment	Ammonium -N	Nitrate -N	0 to 5 depth	5 to 20 depth	VE	R1
		-------- mg kg^{-1} -------				--- $m^3 m^{-3}$ ---	
Residue	Baled	14.5a‡	11.9a	5.8a	6.1a	0.32a	0.28b
	Not Baled	14.0a	9.9a	5.7a	6.0a	0.33a	0.26a
Cover crop	None	13.4a	12.0a	5.8a	6.0a	0.33a	0.26a
	Rye	15.1b	9.8a	5.7a	6.1a	0.33a	0.28b

†Year X cover crop, year X residue, residue X cover crop and year X residue X cover crop interactions were not significant.

‡Means within a column and within a main effect followed by the same letter are not significantly different (F-test, P=0.05).

Table 2-4: Treatment means within residue and cover crop main effects for beginning, end and change in soil bulk density and soil crusting strength at emergence (VE) and silking (R1) †.

		Bulk density			Soil crust strength	
Main effect	Treatment	Beginning	End	Change	VE	R1
		---------------- g cm^{-3}	------------		----- kg cm^{-2}	----
Residue	Baled	1.46a‡	1.42a	-0.03a	1.89a	2.37a
	Not Baled	1.45a	1.40a	-0.05a	1.73a	2.35a
Cover crop	None	1.45a	1.40a	-0.05a	1.80a	2.38a
	Rye	1.45a	1.42a	-0.03a	1.82a	2.33a

†Year X cover crop, year X residue, residue X cover crop and year X residue X cover crop interactions were not significant.

‡Means within a column and within a main effect followed by the same letter are not significantly different (F-test, P=0.05).

Table 2-5: Treatment means within a year and within residue and cover crop main effects for soil temperatures at corn plant emergence (VE) and silking (R1) †.

			VE			R1		
Year	Main effect	Treatment	Max.	Min.	Av.	Max.	Min.	Av.
			---------------------------- °C -------------------------------					
2010	Residue	Baled	21.0a‡	8.7a	14.1a	26.0a	23.4a	24.4a
2010		Not Baled	20.8a	8.7a	14.0a	25.6a	23.3a	24.3a
2010	Cover crop	None	20.3a	8.2a	13.6a	25.9a	23.4a	24.4a
2010		Rye	21.6b	9.2b	14.5b	25.7a	23.3a	24.3a
2011	Residue	Baled	27.0a	19.6a	22.6a	29.6a	24.3a	26.6a
2011		Not Baled	26.7a	19.6a	22.5a	28.9a	24.2a	26.2a
2011	Cover crop	None	27.0a	19.5a	22.5a	28.8a	24.2a	26.2a
2011		Rye	26.7a	19.7a	22.5a	29.7b	24.3a	26.6a

† Year X cover crop interactions were significant for all characteristics except minimum and average temperatures at R1.

‡ Means within a year, within a column, and within a main effect followed by the same letter are not significantly different (LSD, P=0.05).

CHAPTER III

EFFECT OF CORN RESIDUE REMOVAL AND USE OF A COVER CROP ON CORN DEVELOPMENT

ABSTRACT

Little research has evaluated the effects of partial corn *(Zea mays* L.*)* residue removal on corn development or use of a cover crop to mitigate corn development changes associated with residue removal. Research is needed to determine the effects of corn residue removal on corn productivity and establish management recommendations for producers. This three year study evaluated the effects of Baled (60% residue removal) and Not Baled (0% residue removal) residue treatments in combination with None and Rye (*Secale cereal* L.) cover crop treatments on 25 corn development characteristics in a no-till, corn-soybean rotation. Year affected 15 of the 25 corn development characteristics measured, speculated to result from soil temperature associated with planting dates or hail damage in 2011. Baled treatments had less nitrogen in corn residue the following spring and accumulated more rye biomass than Not Baled treatments. A year X residue X cover crop interaction was found for corn height at 6 weeks after emergence, fall residue yield, total corn yield and harvest index. A cover crop X year interaction occurred for corn stand density. In 2010, Rye had a greater corn stand density (68, 214 plants ha^{-1}) than None (63,352 plants ha^{-1}). A difference between cover

crop treatments did not occur in 2011.The results of this study demonstrate that 60% corn residue removal is feasible in a no-till, corn-soybean rotation causing minimal affects to corn development characteristics. A small amount of biomass was established with rye as a winter cover crop, providing few benefits to corn development.

INTRODUCTION

A thriving world economy places a heavy demand on the finite oil supply producing most of the transportation fuel in the USA (Administration, 2006). Domestic ethanol production provides a clean, renewable alternative transportation fuel, reducing dependence on foreign oil (Grassley, 2011). The Energy Independence and Security Act of 2007 mandates the use of 36 billion gallons of biofuels in the United States by 2022, of which, 21 billion gallons must be generated from cellulosic or other advanced feedstock (U.S.Government, 2007). Energy crops, forest residues and agricultural residues are expected to supply most of the feedstock for cellulosic ethanol production (Parveen et al., 2009). Corn residue is the most abundant crop residue in the USA and contains a large carbohydrate content (Perlack et al., 2005; Reddy and Yang, 2005). Traditionally, corn residue remains in the field to provide organic matter, fertility and a protective barrier to the soil. Corn residue removal could affect the development and potential yield of the following corn crop. Many studies have been conducted to evaluate the effects of residue removal on grain yield, but results vary considerably (Barber, 1979; Doran et al., 1984; Moranchan et al., 1972; Power et al., 1998).

A majority of research studying the effects of corn residue removal on following corn plant development has focused on complete removal of corn residue. Residue collection equipment is limited to far less than 100% removal. Commercial balers available to producers for corn residue removal are only capable of a 70% residue removal rate (Glassner et al., 1998). In addition, much of the previous research has focused on a continuous corn cropping system, but a two-year, corn-soybean rotation is common in the Midwest. It is important to evaluate corn residue removal under conditions that producers would perform in their own systems. Impacts from corn residue removal may be less in a production system that incorporates crop rotation because corn residue is only removed in alternate years. Finally, cover crops produce organic matter and provide a barrier over the soil surface. It is important to determine if cover crops can counter negative effects on corn development caused by corn residue removal. Understanding how corn residue removal affects corn productivity is essential to develop management recommendations for producers. The objectives of this study include: 1) determine the effects of partial corn residue removal in a no-till, corn soybean rotation on subsequent corn development and 2) determine if a cover crop can mitigate potential negative effects on subsequent corn plant productivity caused by partial corn residue removal.

MATERIALS AND METHODS

Field experiments were conducted at the University of Missouri - Bradford Research Center. The predominant soil resource at this location was a Mexico silt loam (montmorillonitic, mesic, aeric, Vertic Epiaqualfs). These soils are classified by the USDA-NRCS as Major Land Resource area 113 - central claypan till plains. The parent materials for this resource are primarily loess, over pedisediment, over glacial till.

Experiment site management was discussed in Chapter 2. In summary, data were collected in 2010 and 2011, but site preparation for the experiment began in 2008. As described in Chapter 2, the experimental design for this research study was a randomized complete block with four replications. Treatment combinations were arranged in a split plot. Whole plots were two residue treatments: Baled and Not Baled. The Baled treatment removed approximately 60% of corn residue by mowing, raking and baling residue immediately following grain harvest each fall. Subplots were two winter cover crop treatments: None and Rye. Plot size was 6.1 m wide and 7.6 m long. On 15 April 2010 and 4 May 2011, Dekalb brand 62-54 was planted at a seeding rate of 73,500 seeds ha^{-1} with a Kinze model 2100 row planter (Kinze Manufacturing, Inc., Williamsburg, IA). Plot size for corn was equal to the plot size for cover crops. Corn row spacing was 0.76 m, so plots contained eight corn rows.

Prior to corn emergence, 3.0 m sections in rows six and seven of each plot were marked. Marked sections were observed every day to identify new corn seedling emergence. Color coded skewers for the date of emergence was placed next to each newly emerged seedling. Emergence (VE) was defined as the coleoptile visible above the soil surface (Extension, 2009). Plots were observed each day until no new seedlings were observed for at least two days. After VE was complete, VE dates for all seedlings were converted to number of days after planting. VE dates of all seedlings within a plot were averaged to calculate mean emergence date. Length of emergence period was the number of days between VE dates for the first and last emerged seedlings in each plot. The coefficient of variability for emergence date was calculated as the ratio of the standard deviation and mean emergence date. Stand density was calculated using the total number of plants in a 6.1 m section of rows two and three determined soon after VE.

Dates of R1 were recorded when 50% of all corn plants in a plot had silks visible outside of the husk (Extension, 2009). Dates of physiological maturity (R6) were recorded when 50% of all corn plants in a plot exhibited ear leaf senescence of 80%. Dates for R1 and R6 were converted to number of days after planting. These dates were used to calculate the length of vegetative (R1-VE) and reproductive (R6-R1) phases of corn development. Length of life cycle was calculated as R6-VE.

Corn canopy images were taken 3.0 m above the soil at three, five, seven and nine weeks after emergence (WAE). Images were taken with an Olympus C-740 Ultra Zoom, 3.2 megapixel digital camera (Olympus, Center Valley, PA). SigmaScan Pro 5 (Aspire Software International, Ashburn, VA) divided the number of green pixels in each image by the total number of pixels to calculate percent canopy coverage.

Corn plant height was recorded four, six, eight and ten WAE. Ten plants per plot were measured from the soil surface to the tallest point with all leaves pulled upward. The last height measurement was taken once the plant tassel was fully extended.

Prior to grain harvest, row two and three were end trimmed to 6.1 m. Grain was harvested with a Massey Ferguson 8XP plot combine (AGCO Corporation, Duluth, GA) on 29 September in 2010 and 23 September in 2011. Grain yields were corrected to 15.5% moisture.

Following grain harvest, corn residue within four random 0.3 m^2 areas within each plot was collected and dried at 45°C in an oven with forced ventilation for four days. Corn residue yield was calculated from samples. The same procedure also took place after corn baling to calculate removal percentage and the following spring to determine the amount of corn residue present at soybean planting.

Rye biomass was collected one week following spring burn down herbicide application. Rye was cut at the soil line from within four random 0.3 m^2 areas within each plot. Rye was dried at 45°C in an oven with forced ventilation for four days and above ground rye biomass weight was calculated.

Fall and spring corn residue samples were ground using a three step process. Residue was shredded using a 10 horse power, 1450 Intek series Troybilt chipper/shredder (Briggs & Stratton, Milwaukee, WI) to make the samples manageable. A residue subsample was ground through a 1-mm screen using a Thomas Wiley Mill (Thomas Scientific, Swedesboro, NJ) and through a 1-mm screen using a Udy Mill (Udy Corporation, Fort Collins, CO). Rye was ground through a 1-mm screen using a Thomas Wiley Mill and through a 1-mm screen using a Udy Mill.

Residue and rye samples were analyzed using a 6500 Near-Infrared Reflectance Spectrometer (FOSS NIRSystems, Inc, Laurel, MD) to determine hemicellulose and cellulose concentrations. Operating software of the NIR was designed by Infrasoft International (Port Matilda, PA). All tissue samples were scanned with infrared radiation from 1100 to 2500 nm at 2-nm increments to develop reflectance values. Predicted concentrations of hemicellulose and cellulose were developed from relationships between reflectance and calibration data. Approximately 20% of residue samples and 50% of rye samples were selected for wet chemistry calibration. Samples for calibration were processed by wet chemistry using the ANKOM Filter Bag method (ANKOM Technology, Macedon, NY, USA) and an ANKOM-200 Fiber Analyzer. Analysis of total nitrogen was conducted by a LECO nitrogen analyzer (LECO Corp., St. Joseph, MI) then multiplied by 6.25 to determine protein as determined by the Kjeldahl method (McClements, 2003).

Data were analyzed using the SAS statistical software package (SAS Inst., 2001). Proc Mixed was used to perform the analysis of variance. Replication was considered random, whereas, all other sources of variation were considered fixed. Statistical significance was evaluated at $P \leq 0.05$. When treatment effects were significant, means were separated using least significant difference (LSD).

RESULTS AND DISCUSSION

Corn Development

Corn planting occurred as soon as field conditions would allow on 15 April 2010 and 4 May 2011. A year effect occurred for mean emergence, length of emergence period and coefficient of variation. In 2010 and 2011, mean emergence was 17 and 7 days after planting, length of emergence period was 8 and 4 days and the coefficient of variation for emergence was 3% and 4% (Table 3-1), respectively. Despite a 20 day difference in planting date between years, mean emergence occurred on 2 May 2010 and 12 May 2011. Year differences in emergence characteristics are attributed to soil temperature associated with planting date. Cool soil temperatures associated with early corn planting can delay corn emergence (Havlin et al., 2005). On the first day of corn emergence in 2010 and 2011, average soil temperature at a 6 cm soil depth was 14.0^{o}C and 22.5^{o}C, respectively.

Early emergence is desired for extensive vegetative growth before the greater temperatures and lesser precipitation common in later summer months (Nafziger, 2009).

Residue treatment did not affect mean emergence, length of emergence period or coefficient of variation (Table 3-1). Exposing a portion of the soil surface from partial corn residue removal was predicted to increase soil temperature, resulting in earlier corn emergence (Zhai et al, 1990); however, soil temperature of Baled and Not Baled treatments did not differ at VE (Table 2-5). Blanco-Canqui et al. (2006) concluded that 100% residue removal in a continuous corn system caused corn to emerge three days earlier than treatments with 0% residue removal from soil temperature differences. The results of my study show Baled treatments in a corn-soybean rotation did not cause earlier corn emergence than Not Baled.

Cover crop treatments, Rye and None, did not differ for corn mean emergence, length of emergence period or emergence coefficient of variation. It was anticipated that rye biomass would provide additional soil surface coverage, decreasing soil temperature near the surface and delaying corn emergence. Surprisingly, soil temperature at VE was 0.5^{o}C warmer in Rye than None.

A cover crop X year interaction occurred for corn stand density, but no affect was caused by residue treatment (Table 3-2). In 2010, Rye had a greater corn stand density (68, 214 plants ha^{-1}) than None (63,352 plants ha^{-1}). That same year, Rye had greater minimum and average soil temperature at VE than None (Table 2-5). Increased soil temperature in Rye may have caused a greater germination percentage and, in turn, a greater stand density. In 2011, None and Rye treatments did not differ with stand densities of 70,781 and 70,106 plants ha^{-1}, respectively. In continuous corn, Burgess et al. (1996) found greater stand densities when corn was planted into bare soil compared to all residue remaining. Burgess et al. (1996) assumed corn seed and residue was pushed into the ground together for poor seed-to-soil contact causing a lower germination rate. A corn-soybean rotation has less soil surface residue to hinder the efficiency of corn planting that is common when planting through heavy crop residue.

Neither residue nor cover crop treatments affected the number of days from planting to R1 or R6 (Table 3-3). My results contradict results from a study by Fortin and Pierce (1990) in which removing 100% of the residue in a continuous corn system decreased the number of days from planting to R1.

Neither residue nor cover crop treatment had an effect on length of vegetative development, reproductive development or lifecycle (Table 3-4). Year differences occurred for lengths of vegetative development and reproductive development, but not length of lifecycle (Table 3-4). Length of vegetative development in 2010 and 2011 was 69 and 59 days. Length of reproductive development in 2010 and 2011 was 46 and 58 days. In 2010, corn spent roughly 33% more time in vegetative development than reproductive development. Temperature regulates corn maturation (Nafziger, 2009), so cooler weather during vegetative development in 2010 may have slowed corn development. In 2011, length of vegetative development and reproductive development were approximately the same.

Vegetative imagery from above the corn canopy provides a quantitative evaluation of biomass coverage within a field (Martin et al., 2007) and is a strong predictor of biomass accumulation (Lukina et al., 2008). Neither residue nor cover crop treatment had a significant effect on corn vegetative coverage at 3, 5, 7 or 9 WAE (Table 3-5). In 2010, average maximum vegetative coverage reached 96%. In 2011 prior to 9 WAE, hail caused 15% of the corn stand to lodge. After the hail damage, expansion of the corn vegetation ceased, resulting in a final vegetative coverage of approximately 76% for all treatments by R1. Statistical analysis of vegetative coverage at 9 WAE in 2011 was not conducted.

No significant differences in corn height resulted from residue or cover crop treatment at 4, 8 or 10 WAE (Table 3-6). A year X residue X cover crop interaction occurred for corn height 6 WAE (Table 3-7). At 6 WAE in 2010, the Not Baled X None treatment had taller corn plants than Not Baled X Rye. At 6 WAE in 2011, the Not Baled X None treatment produced shorter plants than the Not Baled X Rye. The exact reason for this interaction is unknown. Year could influence weather conditions while residue and cover crop treatments could influence soil characteristics. Decomposing rye could have released allelopathic compounds to temporarily hinder corn development around 6WAE. Before 10 WAE in 2011, hail affected corn height. Statistical analysis of plant height for 10 WAE in 2011 was not conducted. Fortin and Pierce (1990) found complete corn residue removal caused corn plants to grow taller more quickly than corn in treatments with no residue removed; however, maximum of corn height within each treatment was the same. Partial corn removal used in our study did not cause variation in height from that of 0% corn residue removal.

Neither residue nor cover crop treatment had an effect on grain yield. My results are consistent with Doran et al. (1984) who determined grain yields of treatments with 0% and 50% corn residue removal were not significantly different in continuous corn. However, when Doran et al. (1984) removed 100% of corn residue, grain yield was lowered by 21% from that of 0% corn residue removal. Yearly differences occurred for corn grain yield. Corn in 2010 produced an average grain yield of 10,939 kg ha^{-1}, whereas corn in 2011 produced an average yield of 8,699 kg ha^{-1} (Table 3-8). Hail caused 15% of the corn plants to lodge a week prior to R1 in 2011, reducing the number of corn plants to survive until maturity and produce an ear with grain. In addition, plants were partially defoliated. Corn grain production is particularly sensitive to stresses that occur near R1.

A year X residue X cover crop interaction occurred for corn residue yield (Table 3-9). In 2010, the four residue X cover crop treatment combinations did not differ for residue yield. In 2011, the Baled X None (6,243 kg ha^{-1}) and Not Baled X Rye (7,145 kg ha^{-1}) treatments yielded significantly less residue than Not Baled X None (12,338 kg ha^{-1}). Corn residue removal took place almost two years prior to corn residue yield assessment in this corn-soybean rotation, so the effects of 60% corn residue removal is still evident two years after partial corn removal.

There are several possible reasons for the year X residue X cover crop interaction for corn residue yield. Weather conditions could have varied by year. Lodged and defoliated portions of the corn plants from hail damage may have significantly degraded before residue yield assessment was completed in the fall to affect 2011 residue yield. In

2010, vegetative development (69 days) lasted 33% longer than reproductive development (46 days). In 2011, length of vegetative and reproductive development was approximately the same (59 and 58 days). Yearly corn residue yield and the presence of rye could have affected soil characteristics, such as temperature or water content, in turn, influencing corn development. When Doran et al. (1984) compared treatments of 0% and 50% corn residue removal in continuous corn, no significant difference was found.

A year X residue X cover crop interaction occurred for total corn yield (grain + residue) and HI (Table 3-10). In 2010, residue X cover crop treatment combinations did not affect total corn yield or HI. Total corn yield in 2011was greater for Not Baled X None (21,587 kg ha^{-1}) than both Baled X None (14,888 kg ha^{-1}) and Not Baled X Rye (15,170 kg ha^{-1}). HI in 2011 was significantly greater for Baled X None (0.59) than Not Baled X None (0.44). These interactions could have occurred from yearly weather conditions, including an early planting date in 2010 and hail damage in 2011and/or treatments affecting soil characteristics to influence corn development. Power et al. (1998) concluded a positive correlation between the quantity of corn residue on the soil surface and total yield of corn the following year.

According to Pordesimo et al. (2005), weight of corn residue on a dry matter basis is comprised of approximately 25% hemicellulose, 40% cellulose, 20% lignin, 5% protein, and 5% soluble solids. Cellulose and hemicellulose are the structural carbohydrates of corn residue that can be converted to ethanol (McKendry, 2002). Neither residue nor cover crop treatment had an effect on hemicellulose or protein content of corn residue. For unknown reasons, a year X residue interaction occurred for cellulose content in fall residue. In 2010, the cellulose content of corn residue in the Not Baled treatment was significantly greater (376 g kg^{-1}) than the cellulose content of corn residue in the Baled treatment (311 g kg^{-1}) (Table 3-11). In 2011, cellulose content of corn residue was not different between residue treatments. Cover crop treatment did not affect cellulose content of corn residue.

Corn residue present on the soil surface at the time of soybean planting was evaluated for N concentration. A year X residue interaction was found for spring residue N concentration (Table 3-12). In 2010, N concentration of spring residue in the Not Baled treatment was greater (1.5 g kg^{-1}) than the Baled treatment (1.0 g kg^{-1}). A significant difference did not occur between residue treatments in 2011. Only a one day difference existed between years for number of days between fall and spring residue sampling. There are several possible reasons for this interaction. Winter weather conditions could have varied. The 40% of remaining residue in the Baled treatment may be more accessible to microorganism for decomposition. Mowing fall corn residue for the easement of baling reduced the size of remaining residue for faster decomposition.

Cover Crop Development

Residue treatment did not affect the amount of biomass accumulated by rye at spring termination. Rye biomass at termination could have been influenced by length of overwinter growth and winter weather conditions. For this study, rye biomass at termination in 2010 was 287 kg ha^{-1} after 169 days of over winter growth. Rye biomass nearly doubled in 2011 to 595 kg ha^{-1} after 192 days of over winter growth. These numbers are only 10% or less of the corn residue removed with the Baled treatment.

Residue treatment did not affect the concentration or kg ha^{-1} of nitrogen, phosphorus or potassium within rye biomass a week after termination. The nitrogen, phosphorus and potassium concentration of rye was 22.0, 4.0 and 24.4 g kg^{-1} (Table 3-13). These concentrations are slightly greater than Hoyt (1987) found for nitrogen (16.0 g kg^{-1}), phosphorus (3.0 g kg^{-1}) and potassium (19.0 g kg^{-1}) within rye at the onset of reproductive development. In 2010, nitrogen, phosphorus and potassium concentrations in rye were great, while rye biomass accumulation was small. In 2011, nitrogen phosphorus and potassium concentrations in rye were small, while rye biomass accumulation was twice that of 2010. As a result, the kg ha^{-1} of nitrogen, phosphorus and potassium within rye biomass upon termination did not vary by year.

SUMMARY AND CONCLUSIONS

Year affected 15 out of 25 corn development characteristics measured, speculated to be a result of either soil temperature associated with planting dates or hail damage before R1 in 2011. Residue treatment only had an effect on N concentration of corn residue sampled in the spring and rye biomass. Baled treatments had significantly less N concentration of corn residue in the spring and accumulated significantly more rye biomass than Not Baled treatments. A year X residue X cover crop interaction was found for 4 of the 25 corn development characteristics including: corn height at 6 WAE, fall residue yield, total corn yield and HI. A cover crop X year interaction occurred for corn stand density (Table 3-2). In 2010, Rye had a higher corn stand density (68, 214 plants ha^{-1}) than None (63,352 plants ha^{-1}). A difference between cover crop treatments did not occur in 2011.

A cover crop was not needed to mitigate negative effects associated with partial corn residue removal, since corn residue removal had limited effects on subsequent corn development. The small amount of biomass produced by rye presented few benefits to corn development characteristics and only replaced 10% of the corn residue mass removed by baling. The 40% of corn residue present after baling and soybean biomass were sufficient to minimize the effects of 60% corn residue removal on following corn plant development. The results of this study show that 60% corn residue removal in a no-till, corn-soybean rotation has minimal effects on following corn development. These short-term results demonstrate corn residue can be collected in a no-till, corn soybean rotation if residue removal does not exceed recommended rates, providing support for corn residue harvest for additional production profit.

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Table 3-1: Treatment means within a year and within residue and cover crop main effects for corn mean emergence, length of emergence period, and coefficient of variation of emergence †.

		Mean emergence		Length of emergence period		Coefficient of variability	
Main effect	Treatment	2010	2011	2010	2011	2010	2011
		days after planting		------ days--------		------- % --------	
Year		17b	7a	8b	4a	3a	4b
Residue	Baled	17a	7a	8a	4a	3a	4a
	No Baled	17a	7a	8a	4a	3a	4a
Cover crop	None	17a	7a	7a	4a	3a	4a
	Rye	17a	7a	8a	4a	3a	4a

†Year X cover crop, year X residue, residue X cover crop and year X residue X cover crop interactions were not significant.

‡ Means within the main effect year and within an emergence characteristic followed by the same letter are not significantly different (F-test, P=0.05).

§ Means within a column and within a main effect followed by the same letter are not significantly different (LSD, P=0.05).

Table 3-2: Treatment means within a year and within residue and cover crop main effects for corn stand density †.

Main effect	Treatment	2010	2011
		---------- plants ha^{-1}-----------	
Year		65,783a‡	70,443b
Residue	Baled	64,567a§	71,051a
	Not Baled	66,999a	69,835a
Cover crop	None	63,352a	70,781a
	Rye	68,214b	70,106a

†Year X cover crop interaction was significant.

‡ Means within the main effect year followed by the same letter are not significantly different (F-test, P=0.05).

§ Means within a column and within a main effect followed by the same letter are not significantly different (LSD, P=0.05).

Table 3-3: Treatment means within a year and within residue and cover crop main effects for days after planting for corn to reach emergence (VE), silking (R1) and physiological maturity (R6) growth stage†.

		VE		R1		R6	
Main effect	Treatment	2010	2011	2010	2011	2010	2011
		---------------------- days after planting ---------------------					
Year		17b‡	7a	85b	67a	131b	124a
Residue	Baled	16a§	7a	83a	66a	129a	124a
	Not Baled	17a	7a	87a	67a	134a	125a
Cover crop	None	17a	7a	84a	67a	131a	123a
	Rye	16a	7a	86a	67a	132a	126a

†Year X cover crop, year X residue, residue X cover crop and year X residue X cover crop interactions were not significant.

‡ Means within the main effect year and within a growth stage followed by the same letter are not significantly different (F-test, P=0.05).

§ Means within a column and within a main effect followed by the same letter are not significantly different (LSD, P=0.05).

Table 3-4: Treatment means within a year and within residue and cover crop main effects for length of vegetative development, reproductive development and life cycle of corn †.

		Vegetative‡		Reproductive		Life cycle	
Main effect	Treatment	2010	2011	2010	2011	2010	2011
		----------------------------	no. of days	----------------------------			
Year		69b§	59a	46a	58b	115a	117a
Residue	Baled	68a¶	59a	46a	57a	114a	116a
	Not Baled	70a	59a	47a	58a	117a	118a
Cover crop	None	67a	59a	47a	57a	114a	116a
	Rye	70a	59a	46a	59a	116a	118a

†Year X cover crop, year X residue, residue X cover crop and year X residue X cover crop interactions were not significant.

‡ Vegetative = corn silking (R1) – corn emergence (VE); reproductive = corn physiological maturity (R6) – R1; life cycle = R6 – VE.

§ Means within main effect year and within a development phase followed by the same letter are not significantly different (F-test, P=0.05).

¶ Means within a column and within a main effect followed by the same letter are not significantly different (LSD, P=0.05).

Table 3-5: Treatment means within a year and within residue and cover crop main effects for corn vegetative coverage 3, 5, 7 and 9 weeks after emergence (WAE) †.

		3 WAE		5 WAE		7 WAE		9 WAE	
Main effect	Treatment	2010	2011	2010	2011	2010	2011	2010	2011‡
		%							
Year		14a§	14a	36a	49a	61a	76b	96	-
Residue	Baled	15a¶	16a	38a	50a	65a	74a	96	-
	Not Baled	14a	13a	34a	48a	58a	79a	97	-
Cover crop	None	15a	15a	40a	52a	64a	76a	97	-
	Rye	14a	13a	32a	46a	59a	77a	95	-

†Year X cover crop, year X residue, residue X cover crop and year X residue X cover crop interactions were not significant.

‡ Prior to 2011week 9, hail damage affected corn vegetative coverage so statistical analysis was not conducted.

§ Means within main effect year and within a WAE followed by the same letter are not significantly different (F-test, P=0.05).

¶ Means within a column and within a main effect followed by the same letter are not significantly different (F-test, P=0.05).

Table 3-6: Treatment means within a year and within residue and cover crop main effects for average plant height of corn at 4, 8 and 10 weeks after emergence (WAE) †.

		4 WAE		8 WAE		10 WAE	
Main effect	Treatment	2010	2011	2010	2011	2010	2011‡
		m					
Year		0.67a§	0.75a	2.51b	2.38a	2.78	-
Residue	Baled	0.64a¶	0.81a	2.53a	2.37a	2.77a	-
	Not Baled	0.71a	0.68a	2.48a	2.38a	2.78a	-
Cover crop	None	0.65a	0.72a	2.57b	2.37a	2.77a	-
	Rye	0.70a	0.77a	2.44a	2.38a	2.79a	-

†Year X cover crop, year X residue, residue X cover crop and year X residue X cover crop interactions were not significant.

‡ Prior to week 10 in 2011, hail damage affected corn height so statistical analysis was not conducted.

§ Means within main effect year and within a WAE followed by the same letter are not significantly different (F-test, P=0.05).

¶ Means within a column and within a main effect followed by the same letter are not significantly different (LSD, P=0.05).

Table 3-7: Means of residue and cover crop treatment combinations for average plant height of corn 6 weeks after emergence (WAE) †.

		6 WAE	
Residue	Cover crop	2010	2011
		---------------------- m --------------------	
Baled	None	1.38b‡	1.73b
Baled	Rye	1.22ab	1.62b
Not Baled	None	1.32b	1.37a
Not Baled	Rye	1.15a	1.64b

†Year X cover crop, residue X cover crop and year X residue X cover crop interactions were significant.

‡Means within a column followed by the same letter are not significantly different (LSD, P=0.05).

Table 3-8: Treatment means within a year and within residue and cover crop main effects for corn grain yield †.

Main effect	Treatment	2010	2011
		--------------- kg ha^{-1}	--------------
Year		10,939b	8,699a
Residue	Baled	10,964a	8,760a
	Not Baled	10,914a	8,637a
Cover crop	None	11,053a	8,946a
	Rye	10,824a	8,450a

†Year X cover crop, year X residue, residue X cover crop and year X residue X cover crop interactions were not significant.

‡ Means within the main effect year are significantly different (F-test, P=0.05).

§ Means within a column and within a main effect followed by the same letter are not significantly different (LSD, P=0.05).

Table 3-9: Means of residue and cover crop treatment combinations for corn residue yield †.

Residue	Crop	2010	2011
		------------- kg ha^{-1}	--------------
Baled	None	10,313a‡	6,243a
Baled	Rye	9,808a	8,376ab
Not Baled	None	8,807a	12,338b
Not Baled	Rye	11,477a	7,145a

† Year X residue X cover crop interaction was significant.

‡ Means followed by the same letter within a column are not significantly different (LSD, P=0.05).

Table 3-10: Means of residue and cover crop treatment combinations for total yield and harvest index (HI) †.

		Total yield		HI	
Residue	Cover Crop	2010	2011	2010	2011
		--------- kg ha^{-1} ---------			
Baled	None	21,253a‡	14,888a	0.52a	0.59b
Baled	Rye	20,795a	17,251ab	0.53a	0.52ab
Not Baled	None	19,974a	21,587b	0.56a	0.44a
Not Baled	Rye	22,138a	15,170a	0.49a	0.56ab

† Year X residue X cover crop interaction was significant.

‡ Means within a column followed by the same letter are not significantly different (LSD, P=0.05).

Table 3-11: Treatment means within a year and within residue and cover crop main effects on hemicellulose, cellulose and protein composition of fall corn residue.

		Hemicellulose†		Cellulose‡		Protein†	
Main effect	Treatment	2010	2011	2010	2011	2010	2011
		------------------------------ g kg^{-1} ------------------------------					
Year		216a§	245b	343a	302a	40a	50a
Residue	Baled	211a¶	241a	311a	310a	35a	48a
	Not Baled	222a	250a	376b	294a	46a	52a
Cover crop	None	221a	247a	338a	306a	36a	50a
	Rye	211a	243a	349a	399a	44a	49a

†Year X cover crop, year X residue, residue X cover crop and year X residue X cover crop interactions were not significant.

‡ Year X residue interaction was significant.

§ Means within the main effect year and chemical type followed by the same letter are significantly different (F-test, P=0.05).

¶ Means within a column and within a main effect followed by the same letter are not significantly different (LSD, P=0.05).

Table 3-12: Means of residue and cover crop treatment combinations for N concentration of corn residue in the spring †.

Residue	Cover Crop	N concentration of spring residue 2010	N concentration of spring residue 2011
		------------------ g kg^{-1} ---------------	
Baled	None	1.1a	0.9a
Baled	Rye	1.0ab	0.9a
Not Baled	None	1.4b	0.9a
Not Baled	Rye	1.1ab	0.9a

† Year X residue interaction was significant.

‡ Means within a column followed by the same letter are not significantly different (LSD, P=0.05).

Table 3-13: Means within a year and residue treatment for rye biomass weight at termination, concentrations of N, P, and K within rye biomass at termination and weight of N, P and K within rye biomass at termination †.

Main effect	Treatment	Rye Biomass	N	P	K	N	P	K
		kg ha^{-1}	---------- g kg^{-1} ----------			--------- kg ha^{-1} --------		
Year	2010	288a	27.9b‡	4.6b	30.4b	7.6a‡	1.3a	8.6a
	2011	595b	15.8a	3.4a	18.4a	9.4a	2.0a	10.9a
Residue	Baled	534a	21.8a	4.0a	24.6a	10.0a	2.0a	11.6a
	Not Baled	349a	21.9a	4.0a	24.2a	7.0a	1.3a	7.9a

†Year X cover crop, year X residue, residue X cover crop and year X residue X cover crop interactions were not significant.

‡ Means within a column and within a main effect followed by same letter are not significantly different (F-test, P=0.05).

CHAPTER IV

EFFECT OF CORN RESIDUE REMOVAL AND USE OF A COVER CROP ON CORN EMERGENCE CLASS DEVELOPMENT

ABSTRACT

Variation in corn *(Zea mays* L.*)* emergence is a concern for producers, because lack of uniformity could affect crop productivity. If producers employ corn residue removal for ethanol production, subsequent corn emergence and plant development characteristics could be affected. Research is needed to determine how partial corn residue removal and use of a cover crop affect corn emergence and the potential of a corn crop with non-uniform emergence. Management recommendations can be formed from the results. Early, median and late emerging corn plants of each residue and cover crop treatment were tracked throughout the growing season to evaluate how emergence order affected 24 plant development characteristics. Corn development characteristics were collected for two years in a no-till, corn-soybean rotation study with 60% residue removal and use of cereal rye (*Secale cereal* L.) as a cover crop. Average length of emergence period in 2010 and 2011 was eight and four days. Significant differences occurred among emergence classes for 6 of the 24 measured plant characteristics including: days after planting to corn emergence (VE), days after planting to corn silking (R1), length of vegetative development, length of lifecycle, stalk diameter, and corn residue cellulose content. Residue treatment only affected the plant height of

emergence classes. Cover crop treatment only affected the length of lifecycle for emergence classes. The results of this study illustrate that emergence order within an eight and four day emergence period of 2010 and 2011 had little effect on corn plant productivity. The 60% corn residue removal and rye as a cover crop had little effect emergence characteristics and corn development of each emergence class.

INTRODUCTION

If emergence of corn within a field is not uniform, producers question the yield potential of the corn, especially plants that emerge toward the end of the emergence period. Soil temperature and weather conditions at time of planting can influence corn emergence (Havlin et al., 2005; Sharratt, 2002). Emergence order of corn plants could affect productivity. It is speculated that earlier emerging corn plants are more competitive for resources because they have a head start in growth. Corn plants that are among the last to emerge could be limited to necessary resources causing delayed growth or an inferior plant. Research is needed to compare the growth of corn plants that emerged at different days within the emergence period.

The management practices applied within a production system effect soil characteristics that, in turn, influence corn emergence. Corn residue removal for biofuels can alter the soil environment and this may affect emergence of subsequent corn crops. Limiting corn residue removal to a portion less than 100% is most practical for soil conservation and collection equipment capabilities (Glassner et al., 1998). A corn-soybean rotation is very common in the Midwest and would limit residue removal to alternating years. No-till keeps remaining residues on the soil surface for soil conservation. Understanding how corn emergence variation affects corn development will assist producers in evaluating the potential of a corn crop with non- uniform emergence to aid in management and replant decisions. The objectives of this study include: 1) determine how corn plants that emerge early, median and late within the emergence period compare in corn development and 2) determine if residue and cover crop treatments affect the development of plants that emerge early, median and late within an emergence period.

MATERIALS AND METHODS

Field experiments were conducted at the University of Missouri - Bradford Extension Center. The predominant soil resource at this location was a Mexico silt loam (montmorillonitic, mesic, aeric, Vertic Epiaqualfs). These soils are classified by the USDA-NRCS as Major Land Resource area 113 - central claypan till plains. The parent materials for this resource are primarily loess, over pedisediment, over glacial till.

Experiment site management was discussed in Chapter 2. In summary, data were collected in 2010 and 2011, but site preparation for the experiment began in 2008. Experimental design was a randomized complete block with four replications. Treatment combinations were arranged in a split-split plot design. Whole plots (two residue treatments: Baled and Not Baled) and subplots (two winter cover crop treatments: Rye and None) were explained in chapter 2.The sub-sub treatments were three corn emergence classes, designated Early, Median and Late. To select plants for each emergence class, seedling emergence was monitored in 3.0 m sections of rows six and seven. Marked sections were observed daily to identify new seedling emergence (coleoptile visible). Color coded skewers for the dates of emergence were placed next to each newly emerged seedling. After VE was complete, VE dates for all seedlings were converted to number of days after planting. The three earliest, three median, and three latest emerging plants for each plot were selected for the Early, Median, and Late emergence classes and tagged.

All corn development characteristics were collected from the 9 tagged plants. Procedures used for data collection for phenology (VE, R1, R6), length of development phases (vegetative, reproductive, life cycle) and plant height were described in Chapter 3, except numbers in Chapter 4 represent emergence classes and not whole plots.

Rind puncture force at the internode below the primary ear was measured by using a modified Accuforce Cadet digital force gage, 22.7 kg capacity (Ametek, Largo, FL) (Sibale et al., 1992). The circumference at the center of the third internode above the soil line was measured then converted to diameter. The corn stalk was cut with sheers at the center of the third internode above the soil line and rind thickness was measured using a micrometer caliper.

Ear height was measured from the soil surface to the primary ear node. At maturity, ears from selected plants were hand harvested and dried at 45°C in an oven with forced ventilation for four days. Upon drier removal, grain was threshed from the cob; grain and cob were placed in separate paper bags. The remaining residue of each selected plant was cut 10.2 cm above the soil line, folded into a paper bag, and dried at 45°C in a forced ventilation oven for four days. Dry weights of each tissue (grain, cob and residue) were recorded for each tagged plant. Values of plants within each emergence class were averaged among tissue type.

Grain, cob and residue from the tagged plants within each emergence class were combined and ground for chemical analysis. Grain was ground using a Thomas Wiley Mill (Thomas Scientific, Swedesboro, NJ) to pass uniformly through a 1-mm screen. The oil within the grain prevented further grinding through a Udy Mill (Udy Corporation, Fort Collins, CO). Cobs were ground using a three step grinding process. Cobs were crushed through a 4-mm screen using a model C-H, Viking electric hammer mill (Horrick Manufacturing Co., Moorhead, MN), ground through a 1-mm screen using the Wiley Mill and through a 1-mm screen using a Udy Mill. Residue was also ground using a three step process. Residue was shredded using a 10 horse power, 1450 Intek series Troybilt chipper/shredder (Briggs & Stratton, Milwaukee, WI) to make the samples manageable. A residue subsample was ground through a 1-mm screen using a Wiley Mill and through a 1-mm screen using a Udy Mill.

Grain, cob and residue samples were analyzed using a 6500 Near-Infrared Reflectance Spectrometer (FOSS NIRSystems, Inc, Laurel, MD) to determine hemicellulose and cellulose concentrations. Operating software of the NIR was designed by Infrasoft International (Port Matilda, PA). All tissue samples were scanned with infrared radiation from 1100 to 2500 nm at 2-nm increments to develop reflectance values. Predicted concentrations of hemicellulose and cellulose were developed from relationships between reflectance and calibration data. Approximately 20% of grain, cob and residue samples were selected for wet chemistry calibration. Samples for calibration were processed by wet chemistry using the ANKOM Filter Bag method (ANKOM Technology, Macedon, NY, USA) and an ANKOM-200 Fiber Analyzer. Analysis of total nitrogen was conducted by a LECO nitrogen analyzer (LECO Corp., St. Joseph, MI) then multiplied by 6.25 to determine protein as determined by the Kjeldahl method (McClements, 2003).

Data from each of the three plants within an emergence group were averaged before data analyses. Data were analyzed using the SAS statistical software package (SAS Inst., 2001). Proc Mixed was used to perform the analysis of variance. Replication was considered random whereas all other sources of variation were considered fixed. Statistical significance was evaluated at $P \leq 0.05$. When treatment effects were significant, means were separated using least significant difference (LSD).

RESULTS AND DISCUSSION

Surface residues can affect soil temperature and, in turn, corn emergence (Ford and Hicks, 1992; Havlin et al., 2005; Sharratt, 2002), but neither residue nor cover crop treatment affected mean emergence of each separate emergence class. Planting took place as soon as field conditions allowed on 15 April 2010 and 4 May 2011. On the first day of emergence, average soil temperatures at a 6 cm depth were 14.0^{o}C in 2010 and 22.5^{o}C in 2011 (Table 2-5). The number of days between planting and mean emergence was greater in 2010 (17 days) than 2011 (7 days). The length of emergence period was also longer in 2010 (8 days) than 2011 (4 days). Therefore, mean emergence of the three emergence classes in 2010 were separated by more days than emergence classes of 2011. Mean emergence of Early, Median and Late emergence classes in 2010 were 13, 17 and 20 days after planting and in 2011 they were 6, 7 and 10 days after planting, respectively (Table 4-1). Yearly differences among emergence characteristics are speculated to result from soil temperatures associated with planting dates. Plants in the Early emergence class had a head start in development, which could provide a competitive advantage for vital resources (e.g. sunlight, water, nutrients). Two predictions were made for emergence class corn development. Emergence classes will consistently rank in order of emergence (Early, Median and Late) for the corn characteristic measured. Emergence classes of 2010 had greater emergence mean variation to cause more significant differences among corn development characteristics than 2011.

The number of days that separated the Early and Late emergence classes at VE (7 days in 2010 versus 4 days in 2011) was reduced by R1 (3 days in 2010 versus 1 day in 2011) (Table 4-1). Emergence classes did not differ for number of days after planting to reach R6 either year. As development progressed, emergence classes became more similar for number of days to reach each growth stage. Neither residue nor cover crop treatment affected the number of days for emergence classes to reach R1 or R6.

A year X emergence class interaction was significant for length of vegetative development (Table 4-2). In 2010, vegetative development for the Early class (66 days) was longer than the Median and Late (63 and 62 days) classes. In 2011, vegetative development for the Early class (60 days) was only longer than the Late class (58 days). The number of days that each class spent in vegetative development may have bearing on grain, cob and residue yield. Early, Median and Late classes in 2010 spent more time in vegetative development than the same classes in 2011 (9%, 7% and 6%

difference). Neither residue nor cover crop treatment had an effect on length of vegetative development for emergence classes.

A year X cover crop X emergence class interaction was significant for length of reproductive development (Table 4-2).The only year and cover crop combination for which emergence classes differed for length of reproductive development was 2010 X Rye. In that incidence, Early and Median classes exhibited longer reproductive development (both 57 days) than the Late class (49 days). Residue treatment did not affect the length of reproductive development for emergence classes.

A year X emergence class interaction was significant for length of lifecycle (Table 4-2). In 2010, the number of days in the lifecycle of Early (123 days), Median (119 days) and Late (115 days) emergence classes were all significantly different. The results show an earlier emergence leads to a longer lifecycle. No significant differences were found for lifecycle length of emergence classes in 2011. A cover crop X emergence class interaction was also significant for length of lifecycle. Emergence classes differed within both None and Rye cover crop treatments. Within None, the length of lifecycle for the Early class (119 days) was different only from the Late class (115 days). Within the Rye treatment, the length of lifecycle for the Early, Median and Late classes were all significantly different (122, 118 and 114 days, respectively). Rye caused a wider variation in lifecycle length among emergence classes (eight day difference) compared to None (four day difference). Residue treatments did not affect lifecycle length of emergence classes.

A residue X emergence class interaction was significant for plant height at R1 (Table 4-3). Within the Baled treatment, plants of the Early class was taller (2.62 m) than the Median class (2.50 m), but not the Late class (255 m). For the Not Baled treatment, plants of both the Median and Late classes (2.62 and 2.61 m, respectively) were taller than plants of the Early class (2.46 m). An assessment of plant height revealed that emergence order was not a feasible predictor of plant height. Cover crop treatment did not affect the plant height of emergence classes. Ear height at R6 was not affected by residue treatment, cover crop treatment or emergence class (Table 4-3).

The rind is the dense outside portion of the corn stalk accounting for 60% to 80% of the stalk strength (Zuber and Kangj (1978). The force needed to puncture corn stalk rind at the internode below the ear was not significantly different among corn plants within a residue treatment, cover crop treatment or emergence class (Table 4-4). Both Chesang-Chumo (1993) and Masole (1993) found a negative correlation between the force needed to puncture the rind of the corn stalk and corn stalk lodging. Based on rind puncture strength, all measured plants should have the same resistance to lodging.

The rind thickness at the third internode above the soil was not significantly different among corn plants within a residue treatment, cover crop treatment or emergence class (Table 4-4). Masole (1993) and Zuber and Grogan (1961) found a negative correlation between corn stalk rind thickness at the third internode above the soil line and corn stalk lodging. Since no significant treatment differences were found for rind thickness, lodging potential should not vary among corn plants of each treatment.

A year X emergence class interaction was significant for stalk diameter (Table 4-4). In 2010, no significant differences occurred for the corn stalk diameter for Early, Median and Late classes (2.31, 2.46 and 2.32 cm, respectively). In 2011, stalk diameter for the Early class (2.50 cm) was greater than the stalk diameter of the Late class (2.19 cm), but not the Median classm (2.36 cm). Masole (1993) and Esechie (1985) found a strong negative correlation (-0.90 and -0.88) between corn stalk diameter at the third internode above the soil line and corn stalk lodging. Late emerging plants are more prone to lodging with a smaller stalk diameter. Neither residue nor cover crop treatment affected the corn stalk diameter of emergence classes.

Producers question how lack of uniform corn emergence will affect corn grain yield. An eight and four day emergence period occurred in 2010 and 2011 and grain yields for plants within the Early, Median and Late emergence classes were not significantly different (Table 4-5). Over a two year average, Early, Median and Late emergence classes had a grain yield of 205, 216 and 190 g plant^{-1}. Therefore, an emergence variation up to eight days, as seen in 2010, does not affect corn grain yield. Plants that emerged at the end of the eight day emergence period did not yield significantly less than plants that emerged on the first day. Neither residue nor cover crop treatment affected the grain weight per plant among emergence classes. Many studies have evaluated corn grain yield following corn residue removal in a variety of production systems and results vary from a 21% reduction in yield (Doran et al., 1984) to no significant differences (Barber, 1979; Moranchan et al., 1972). Length of time spent in reproductive development was anticipated to affect grain yield, but had little, if any bearing on grain yield for each emergence class.

Residue yield per plant was not significantly different among emergence classes (Table 4-5). Early, Median and Late emergence classes had a two year average residue weight of 119, 117, and 112 g plant^{-1}. The longer amount of time spent in vegetative development in 2010 from that of 2011 did not increase residue yield as predicted. A previous study concluded 100% residue removal reduced subsequent corn residue yield by 12% in continuous corn (Power et al., 1998); however, residue yield of emergence classes for my study was not affected by residue or cover crop treatment. The remaining 40% corn residue left after baling and corn-soybean rotation was able to limit the effects of 60% corn residue removal.

Cob yield per plant did not vary among emergence classes (Table 4-5). Early, Median and Late classes had a two year average cob weight of 35, 35 and 38 g plant^{-1}. Potential exists to collect solely corn cobs as a cellulosic ethanol feedstock. Previous research has suggested that corn cobs only compose 15% of corn residues, leaving 85% of residues to remain in the field (Hanway, August 2007). My research calculates that approximately 20% to 25% of corn residue derives from cob. A residue removal percentage of 25% is still small and may not present a need for a residue management strategy. Cob yield for corn plants within each emergence class was not affected by residue or cover crop treatment.

Total above ground corn plant yield (grain + residue) did not differ for emergence classes (Table 4-6). Early, Median and Late classes had an average total yield of 359, 352 and 327 g plant^{-1}. This result was expected since no significant differences were found between emergence classes for grain, cob or residue yield. The total corn plant yield of each emergence class was not affected by residue or cover crop treatment.

Harvest index (HI) presents a ratio of grain weight to total weight of above ground biomass. The results of this three year study show HI was not easily influenced by emergence class, residue treatment or cover crop treatment since significant differences were not found (Table 4-6). Early, Median and Late emergence classes had an average harvest index of 0.56, 0.57 and 0.53. Current genetics produce plants with an approximate HI of 0.50, but can vary from 0.40 to 0.60 (Pennington, 2013). Improvement in corn genetics and production practices are gradually increasing this standard. I had earlier predicted that length of time spent in vegetative and reproductive development would affect corn biomass distribution (grain, cob and residue yield per plant). The HI of 2010 was expected to be low from more time spent in vegetative development than reproductive development. HI of 2011 was expected to be average from approximately equal time spent in vegetative and reproductive development. The HI of emergence classes did not differ among years, therefore, time spent in vegetative and reproductive development did not influence corn biomass distribution.

Within a tissue type (grain, cob, and residue) limited variation occurred for chemical characteristics for emergence classes. Hemicellulose and protein content of grain were not significantly different among emergence class (Table 4-7). Neither residue nor cover crop treatment affected the hemicellulose or protein content found in grain for each emergence class. Cellulose content of residue was the only chemical of any tissue to be affected by emergence class (Table 4-8). The cellulose contents of the Early and Median class (309 and 304 g plant^{-1}) were greater than the Late class (292 g plant^{-1}). Hemicellulose and protein content of residue were not significantly different among emergence classes. Neither residue nor cover crop treatment affected hemicellulose or protein content found in residue for each emergence class. Hemicellulose, cellulose and protein content of cob were not significantly different among emergence classes (Table 4-9). Neither residue nor cover crop treatment affected hemicellulose, cellulose or protein content found in cob for each emergence class.

Tissue type presented different averages for chemical characteristics. Grain was roughly 90 g kg^{-1} for both hemicellulose and protein (Table 4-7). Residue was roughly 250, 310 and 50 g kg^{-1} of hemicellulose, cellulose and protein, respectively (Table 4-8). Cob was roughly 310, 360 and 40 g kg^{-1} of hemicellulose, cellulose and protein, respectively (Table 4-9).

SUMMARY AND CONCLUSIONS

Producers question how emergence variation affects corn development and yield. For this study, 2010 and 2011 had an eight and four day emergence period. The three earliest, median and latest emerging plants were averaged into three separate classes (Early, Median and Late) to evaluate plant development in response to emergence order. One emergence class did not consistently rank first for the 25 plant characteristics measured. Significant differences among emergence classes occurred for 6 out of the 25 measured plant characteristics, including: mean emergence, days from planting to R1, length of vegetative development, length of lifecycle, stalk diameter and residue cellulose content. Several conclusions were drawn from an assessment of emergence class results. If a corn emergence period lasts up to eight days, corn plant development will exhibit few differences. Plants that emerge at the end of the eight day period do not yield significantly less for grain, cob or residue, than plants that emerge on the first day of emergence. The greater variation for VE among emergence classes in

2010 than 2011 did not cause more developmental differences among emergence classes.

Residue treatment only had an effect on the plant height of emergence classes. Cover crop treatment only had an effect on length of lifecycle for emergence classes. A year X cover crop X emergence class interaction was significant for only length of reproductive development. Ultimately, partial corn residue removal and use of a cover crop has few effects on the development of plants between each emergence class.

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Table 4-1: Treatment means within a year and within an emergence class for the number of days from planting to vegetative emergence (VE), silking (R1) and maturity (R6).

	VE†		R1‡		R6‡	
Emergence class	2010	2011	2010	2011	2010	2011
	---------------------------- days after planting -------------------------					
Early	13a§	6a	79a	66a	137a	123a
Median	17b	7b	80a	66a	136a	124a
Late	20c	10c	82b	67b	134a	125a

† Year X emergence class was significant.

‡ Residue X emergence class, cover crop X emergence class, year X residue X emergence class, year X cover crop X emergence class, residue X cover crop X emergence class and year X residue X cover crop X emergence class interactions were not significant.

§ Means within a column followed by the same letter are not significantly different (LSD, P=0.05).

Table 4-2: Treatment means within a year and within an emergence class for length of vegetative development, reproductive development and lifecycle.

Main effect	Treatment	Emergence class	Vegetative†‡ 2010	Vegetative†‡ 2011	Reproductive§ 2010	Reproductive§ 2011	Lifecycle¶ 2010	Lifecycle¶ 2011
			days					
Cover crop	None	Early	65b#	60b	58a	55a	123b	115a
		Median	62a	59ab	57a	58a	119ab	117a
		Late	61a	58a	56a	56a	117a	114a
	Rye	Early	67b	60b	57b	60a	124c	120a
		Median	63a	59ab	55b	58a	118b	117a
		Late	62a	58a	49a	59a	111a	117a
Emergence class		Early	66b††	60b	57b	57a	123c	117a
		Median	63a	59ab	56b	58a	119b	117a
		Late	62a	58a	53a	58a	115a	116a

† Vegetative = corn silking (R1) – corn emergence (VE); reproductive = corn physiological maturity (R6) – R1; lifecycle = R6 – VE.

‡ Year X emergence class was significant.

§ Year X emergence class and year X cover crop X emergence class was significant.

¶ Year X emergence class and cover crop X emergence class was significant.

Means within a column and within the same treatment for a main effect cover crop treatment followed by the same letter are not significantly different (LSD, P=0.05).

†† Means within a column and within the main effect emergence class followed by the same letter are not significantly different (LSD, P=0.05).

Table 4-3: Treatment means within a year and within a main effect, treatment, and emergence class combination on plant height at silking (R1) and primary ear height at maturity (R6).

			R1 Plant height†		R6 Ear height‡	
Main effect	Treatment	Emergence class	2010	2011	2010	2011
			----------------------- m		------------------------	
Residue	Baled	Early	2.82a§	2.42b	1.01a	0.88a
		Median	2.73a	2.27a	0.99a	0.90a
		Late	2.77a	2.33ab	0.98a	0.86a
	Not Baled	Early	2.67a	2.29a	1.00a	0.82a
		Median	2.85b	2.40b	0.96a	0.91a
		Late	2.84b	2.37ab	1.00a	0.84a
Emergence class		Early	2.74a¶	2.35a	1.00a	0.85a
		Median	2.79a	2.33a	0.98a	0.91a
		Late	2.81a	2.35a	0.99a	0.85a

† Residue X emergence class was significant.

‡ Year X emergence class, residue X emergence class, cover crop X emergence class, year X residue X emergence class, year X cover crop X emergence class, residue X cover crop X emergence class and year X residue X cover crop X emergence class interactions were not significant.

§ Means within a column and within the same treatment for a main effect residue followed by the same letter are not significantly different (LSD, P=0.05).

¶ Means within a column and within the main effect emergence class followed by the same letter are not significantly different (LSD, P=0.05).

Table 4-4: Treatment means within a year and within an emergence class for corn stalk rind puncture force at the internode below the corn ear, corn stalk rind thickness of the third internode above the soil and stalk diameter of the third internode above the soil.

Emergence class	Rind puncture force†		Rind thickness†		Stalk diameter‡	
	2010	2011	2010	2011	2010	2011
	------- kg cm^{-2} -------		-------- mm ---------		---------- cm ----------	
Early	5.6a§	5.9a	1.69a	1.42a	2.31a	2.50b
Median	6.0a	6.0a	1.60a	1.47a	2.46a	2.36ab
Late	5.8a	5.8a	1.51a	1.30a	2.32a	2.19a

†Year X emergence class, residue X emergence class, cover crop X emergence class, year X residue X emergence class, year X cover crop X emergence class, residue X cover crop X emergence class and year X residue X cover crop X emergence class interactions were not significant.

‡ Year X emergence class was significant.

§ Means within a column followed by the same letter are not significantly different (LSD, P=0.05).

Table 4-5: Treatment means within a year and within an emergence class for corn grain, cob and residue yield per plant†.

Emergence class	Grain		Cob		Residue	
	2010	2011	2010	2011	2010	2011
	---------------------------------- g plant^{-1}	----------------------------------				
Early	182a‡	229a	27a	43a	128a	109a
Median	172a	260a	26a	44a	127a	107a
Late	150a	231a	24a	51a	119a	105a

†Year X emergence class, residue X emergence class, cover crop X emergence class, year X residue X emergence class, year X cover crop X emergence class, residue X cover crop X emergence class and year X residue X cover crop X emergence class interactions were not significant.

‡ Means within a column followed by the same letter are not significantly different (LSD, P=0.05).

Table 4-6: Treatment means within a year and within an emergence class for total yield and harvest index (HI) †.

	Total corn yield		HI	
Emergence class	2010	2011	2010	2011
	-------- g plant^{-1} --------			
Early	336a‡	381a	0.54a	0.59a
Median	324a	380a	0.53a	0.61a
Late	294a	361a	0.51a	0.56a

†Year X emergence class, residue X emergence class, cover crop X emergence class, year X residue X emergence class, year X cover crop X emergence class, residue X cover crop X emergence class and year X residue X cover crop X emergence class interactions were not significant.

‡ Means within a column followed by the same letter are not significantly different (LSD, P=0.05).

Table 4-7: Treatment means within a year and within an emergence class for hemicellulose and protein content of corn grain at R6†.

	Hemicellulose		Protein	
Emergence class	2010	2011	2010	2011
	----------------------- g kg^{-1} ----------------------			
Early	92a‡	85a	89a	92a
Median	93a	81a	89a	85a
Late	90a	87a	88a	92a

†Year X emergence class, residue X emergence class, cover crop X emergence class, year X residue X emergence class, year X cover crop X emergence class, residue X cover crop X emergence class and year X residue X cover crop X emergence class interactions were not significant.

‡ Means within a column followed by the same letter are not significantly different (LSD, P=0.05).

Table 4-8: Treatment means within a year and within an emergence class for corn residue hemicellulose, cellulose and protein content†.

	Hemicellulose		Cellulose		Protein	
Emergence class	2010	2011	2010	2011	2010	2011
	---------------- g kg^{-1} ----------------					
Early	247a‡	248a	321b	297b	43a	60a
Median	248a	250a	311ab	298b	42a	55a
Late	240a	248a	304a	280a	46a	55a

†Year X emergence class, residue X emergence class, cover crop X emergence class, year X residue X emergence class, year X cover crop X emergence class, residue X cover crop X emergence class and year X residue X cover crop X emergence class interactions were not significant.

‡ Means within a column followed by the same letter are not significantly different (LSD, P=0.05).

Table 4-9: Treatment means within a year and within an emergence class for hemicellulose, cellulose and protein content of corn cobs †.

	Hemicellulose		Cellulose		Protein	
Emergence class	2010	2011	2010	2011	2010	2011
	----------	----------	---------- g kg^{-1}	----------	----------	----------
Early	307a‡	311a	381a	338a	39a	41a
Median	309a	314a	381a	352a	39a	38a
Late	307a	299a	391a	336a	38a	40a

†Year X emergence class, residue X emergence class, cover crop X emergence class, year X residue X emergence class, year X cover crop X emergence class, residue X cover crop X emergence class and year X residue X cover crop X emergence class interactions were not significant.

‡ Means within a column followed by the same letter are not significantly different (LSD, P=0.05).

APPENDICES

Appendix A: Journal article information of references used in this study

Author	Study length	Location	Soil type	Rotation	Tillage practice	Residue remaining	Grain yield (Mg ha^{-1})	Residue yield (Mg ha^{-1})
Doran et al. (1984)	4 years	Eastern, NE	Crete-Butler silty clay loam	Corn, sorghum, soybean	No-till	0% = 0 Mg ha^{-1} 50% = 2.55 Mg ha^{-1} 100% = 5.2 Mg ha^{-1} 150% = 8.4 Mg ha^{-1}	*3.1 Mg ha^{-1} 3.4 Mg ha^{-1} 3.9 Mg ha^{-1} 3.9 Mg ha^{-1}	*0%= 4.6Mg ha 5.1 Mg ha^{-1} 5.2 Mg ha^{-1} 5.6 Mg ha^{-1}
Moebius-Clune et al. (2008)	32 years	Chazy, NY	Raynham silt loam	Continuous corn	Plow-till No-till	0 100%	PT & 0% = 7.9 PT & 100% = 8.5 NT & 0% = 8.5 NT & 100% = 8.4	Not provided
Blanco-Canqui et al. (2007)	2 years	Coshocton, OH South Charleston, OH and Hoytville, OH	Rayne silt loam, Celina silt loam, Hoytville clay loam	Continuous corn	No-till	0% = 0 Mg ha^{-1} 25% = 1.8 Mg ha^{-1} 50% = 3.8 Mg ha^{-1} 75% = 5.9 Mg ha^{-1} 100% = 8.0 Mg ha^{-1}	0% = 9.5 Mg ha^{-1} 25% = 10.1 Mg ha^{-1} 50% = 10.2 Mg ha^{-1} 75% = 10.8 Mg ha^{-1} 100% = 10.7 Mg ha^{-1}	0% = 6.8 Mg ha^{-1} 25% = 7.1 Mg ha^{-1} 50% = 7.6 Mg ha^{-1} 75% = 7.9 Mg ha^{-1} 100% = 8.0 Mg ha^{-1}
Blanco-Canqui et al. (2009)	4 years	Coshocton, OH South Charleston, OH and Hoytville, OH	Rayne silt loam, Celina silt loam, Hoytville clay loam	Continuous corn	No-till	0% = 0 Mg ha^{-1} 25% = 1.75 Mg ha^{-1} 50% = 3.7 Mg ha^{-1} 75% = 5.5 Mg ha^{-1} 100% = 7.7 Mg ha^{-1}	0% = 8.2 Mg ha^{-1} 25% = 8.5 Mg ha^{-1} 50% = 8.9 Mg ha^{-1} 75% = 9.3 Mg ha^{-1} 100% = 9.3 Mg ha^{-1}	0% = 6.7 Mg ha^{-1} 25% = 7.0 Mg ha^{-1} 50% = 7.4 Mg ha^{-1} 75% = 7.4 Mg ha^{-1} 100% = 7.7 Mg ha^{-1}
Barber (1979)	11 years	Lafayette, IN	Raub silt loam	Continuous corn	Plow-till	0% 100% 200%	0% = 9.0 100% = 9.2 200% = 9.0	Not provided
Burgess et al. (1996)	3 years	Ste. Anned e Bellevue, Quebec	Sandy loam	Continuous corn	No-till (NT) Reduced till (10 cm)(RT) Conventional till (20 cm)(CT)	0% 100%	NT-R = 7.8 RT-R = 8.1 CT-R = 7.7 NT+R = 6.3 RT+R = 7.4 CT+R = 7.8	NT-R = 7.1 RT-R = 7.3 CT-R = 7.2 NT+R = 6.3 RT+R = 6.7 CT+R = 7.7
Wilts et	29	Morris, MN	Clay loam	Continuous	Plow-till	0%	0% = Not measured	0% = 8.46

al. (2004)	years		and silt loam	corn		100% = Mg ha^{-1}	100% = 5.04	100% = 8.22
Karlen et al. (1984)	4 years	Not provided	Norfolk sandy loam	Continuous corn	Conservative tillage	10% 33% 100% For irrigated (+I) and nonirrigated (-I)	10%(+I) = 9.4 33%(+I) = 9.5 100%(+I) = 9.7 10%(-I) = 8.0 33%(-I) = 7.9 100%(-I) = 7.9	Not provided
Fortin and Pierce (1990)	2 years	East Lansing, MI	Conover loam	Continuous corn	No-till	0% = Mg ha^{-1} 100% = 5.25 Mg ha^{-1}	Not provided	Not provided
Swan	6 years	Lancaster, WI	Rozetta silt loam	Continuous		In row coverage Bare = 5% Normal = 48% Double = 86%	0% = 8.15 Mg ha^{-1} 100% = 8.59 Mg ha^{-1} 200% = 8.33 Mg ha^{-1}	Not provided
Wilhelm, Doran, and Power (1986)	4 years	Lincoln, NE	Crete-Butler silty clay loam	Continuous corn	No-till	0% = 0 Mg ha^{-1} 50% = 1.94 Mg ha^{-1} 100% = 4.55 Mg ha^{-1} 150% = 7.65 Mg ha^{-1}	0% = 1.66 Mg ha^{-1} 50% = 2.04 Mg ha^{-1} 100% = 2.23 Mg ha^{-1} 150% = 2.36 Mg ha^{-1}	0% = 2.98 Mg ha^{-1} 50% = 3.87 Mg ha^{-1} 100% = 4.55 Mg ha^{-1} 150% = 5.10 Mg ha^{-1}
Power	10 years	Lincoln, NE	Crete-Butler silty clay loam	Continuous corn	No-till	0% = 0 Mg ha^{-1} 50% = 2.75 Mg ha^{-1} 100% = 5.0 Mg ha^{-1} 150% = 8.1 Mg ha^{-1}	0% = 4.3 Mg ha^{-1} 50% = 4.6 Mg ha^{-1} 100% = 4.5 Mg ha^{-1} 150% = 4.9 Mg ha^{-1}	0% = 5.3 Mg ha^{-1} 50% = 5.5 Mg ha^{-1} 100% = 5.0 Mg ha^{-1} 150% = 5.4 Mg ha^{-1}

Appendix B: Interactions among treatments for soil characteristics.

Variable	Year	Res	Year* Res	Cover	Year* Cover	Res* Cover	Year* Res* Cover
Beginning bulk density		0.874		0.892		0.115	
Bulk density change		0.698		0.517		0.647	
Ending bulk density		0.373		0.384		0.554	
Ca 0 to 5 cm depth	0.048	0.280	0.804	0.779	0.905	0.548	0.718
Ca 5 to 20 cm depth	0.078	0.235	0.187	0.317	0.046	0.728	0.940
SOC 0 to 5 cm depth	0.082	0.190	0.820	0.758	0.331	0.646	0.124
SOC 5 to 20 cm depth	0.216	0.262	0.483	0.291	0.121	0.436	0.195
Crusting at VE	0.440	0.134	0.084	0.903	0.924	0.325	0.289
Crusting at R1	0.065	0.851	0.118	0.669	0.955	0.830	0.590
K 0 to 5 cm depth	0.001	**0.572**	0.528	0.737	0.475	0.230	0.449
K 5 to 20 cm depth	0.012	0.489	0.714	0.210	0.718	0.102	0.379
Mg 0 to 5 cm depth	0.369	0.041	0.607	0.874	0.788	0.277	0.722
Mg 5 to 20 cm depth	0.318	0.020	0.529	0.430	0.580	0.383	0.997
Soil water content at VE	0.003	0.649	0.995	0.886	0.623	0.658	0.156
Soil water content at R1	0.028	0.043	0.125	0.027	0.374	0.427	0.942
Ammonium	0.025	0.695	0.927	0.043	0.073	0.982	0.434
Nitrate	0.064	0.269	0.118	0.190	0.733	0.555	0.757
SOM 0 to 5 cm depth	0.214	0.765	0.157	0.159	0.663	0.223	0.990
SOM 5 to 20 cm depth	0.097	0.749	0.344	0.052	0.583	0.727	0.744
P 0 to 5 cm depth	0.007	0.176	0.651	0.455	0.593	0.855	0.310
P 5 to 20 cm depth	0.184	0.903	0.893	0.408	0.143	0.726	0.399
pH 0 to 5 cm depth	0.713	0.614	0.431	0.489	0.272	0.489	0.272
pH 5 to 20 cm depth	0.571	0.136	0.872	0.298	0.109	0.290	0.639
S 0 to 5 cm depth	0.044	0.354	0.547	0.142	0.521	0.154	0.144
S 5 to 20 cm depth	0.169	0.416	0.147	0.087	0.140	0.209	0.448
VE maximum temp.	0.000	0.330	0.936	0.111	0.015	0.445	0.242
VE minimum temp	0.000	0.909	0.943	0.002	0.008	0.319	0.168
VE average temp	0.000	0.534	0.678	0.001	0.001	0.595	0.123
R1 maximum temp	0.005	0.269	0.645	0.131	0.046	0.148	0.631
R1 minimum temp	0.004	0.337	0.789	0.629	0.290	0.775	0.215
R1 average temp	0.002	0.225	0.554	0.153	0.088	0.356	0.955

Appendix C: Interactions among treatments for whole plot corn development characteristics.

Variable	Year	Res	Year* Res	Cover	Year* Cover	Res* Cover	Year* Res* Cover
Coefficient of variance	0.035	0.982	0.652	0.560	0.131	0.216	0.774
Mean emergence	0.000	0.791	0.772	0.303	0.809	0.251	0.244
Length of emergence	0.015	0.694	0.937	0.539	0.200	0.659	0.791
Silking DAP	0.001	0.129	0.175	0.182	0.182	0.446	0.645
Senescence DAP	0.030	0.161	0.464	0.313	0.765	0.973	0.973
Vegetative length	0.003	0.266	0.360	0.104	0.165	0.378	0.378
Reproductive length	0.016	0.698	0.896	0.730	0.477	0.811	0.894
Lifecycle length	0.392	0.261	0.693	0.210	0.838	0.892	0.785
Coverage at 3 WAE	0.926	0.310	0.632	0.384	0.870	0.264	0.869
Coverage at 5 WAE	0.062	0.408	0.794	0.059	0.663	0.637	0.194
Coverage at 7 WAE	0.039	0.730	0.065	0.414	0.261	0.211	0.528
Coverage at 9 WAE		0.605		0.319		0.319	
Height at 10 WAE		0.865		0.760		0.880	
Height at 4 WAE	0.351	0.696	0.196	0.301	0.964	0.787	0.072
Height at 6 WAE	0.009	0.028	0.227	0.332	0.002	0.028	0.021
Height at 8 WAE	0.035	0.686	0.417	0.139	0.069	0.096	0.050
Stand density	0.018	0.503	0.077	0.030	0.007	0.699	0.816
Grain yield	0.010	0.829	0.928	0.364	0.734	0.216	0.570
Fall residue yield	0.235	0.281	0.311	0.798	0.153	0.249	0.010
Total yield	0.042	0.336	0.349	0.523	0.132	0.110	0.008
Harvest index	0.973	0.425	0.388	0.966	0.382	0.382	0.041
Fall residue hemicellulose	0.011	0.101	0.881	0.091	0.430	0.298	0.210
Fall residue cellulose	0.077	0.165	0.039	0.844	0.451	0.272	0.528
Fall residue protein	0.072	0.081	0.395	0.348	0.225	0.272	0.177
Spring residue N	0.011	0.038	0.030	0.452	0.201	0.382	0.280
Cover crop biomass	0.031	0.060	0.121				
Cover crop potassium	0.003	0.812	0.488				
Cover crop nitrogen	0.002	0.903	0.508				
Cover crop phosphorus	0.019	0.982	0.416				
Cover crop kg N ha^{-1}	0.309	0.092	0.125				
Cover crop kg P ha^{-1}	0.099	0.056	0.090				
Cover crop kg K ha^{-1}	0.304	.0807	0.155				

Appendix D: Interactions among emergence classes and other treatments for corn development characteristics.

Variable	EClass	Year* EClass	Res* EClass	Year* Res* EClass	Cover* EClass	Year* Cover* EClass	Res* Cover* EClass	Year* Res* Cover* EClass
Cob yield	0.458	0.130	0.987	0.695	0.631	0.855	0.489	0.722
Ear height	0.490	0.080	0.672	0.528	0.859	0.320	0.813	0.588
Days after planting for VE	0.000	0.000	0.910	0.969	0.519	0.222	0.881	0.802
Grain yield	0.226	0.323	0.454	0.846	0.347	0.991	0.934	0.973
Harvest index	0.093	0.528	0.120	0.295	0.229	0.708	0.730	0.646
Lifecycle	0.000	0.001	0.575	0.157	0.040	0.108	0.469	0.260
Plant height	0.763	0.698	0.005	0.924	0.228	0.684	0.625	0.105
Days after planting for R1	0.000	0.206	0.693	0.252	0.693	0.206	0.492	0.492
Days after planting for R6	0.974	0.061	0.601	0.108	0.061	0.105	0.425	0.194
Reproductive development	0.053	0.017	0.554	0.238	0.081	0.028	0.325	0.398
Residue yield	0.460	0.821	0.166	0.344	0.261	0.693	0.757	0.710
Rind penetrometer	0.583	0.778	0.146	0.951	0.473	0.337	0.811	0.915
Rind thickness	0.060	0.304	0.417	0.996	0.534	0.679	0.444	0.913
Stalk diameter	0.041	0.049	0.715	0.435	0.708	0.839	0.956	0.950
Total corn yield	0.444	0.913	0.721	0.896	0.946	0.747	0.825	0.754
Vegetative development	0.000	0.044	0.831	0.340	0.433	0.459	0.596	0.826
Cob hemicellulose	0.155	0.298	0.316	0.621	0.416	0.805	0.930	0.583
Cob cellulose	0.713	0.393	0.302	0.186	0.683	0.739	0.061	0.977
Cob protein	0.682	0.616	0.160	0.380	0.663	0.916	0.197	0.629
Grain hemicellulose	0.619	0.124	0.809	0.774	0.762	0.808	0.491	0.851
Grain protein	0.213	0.122	0.859	0.896	0.980	0.163	0.862	0.436
Residue hemicellulose	0.097	0.236	0.494	0.999	0.763	0.426	0.978	0.722
Residue cellulose	0.001	0.395	0.428	0.429	0.285	0.915	0.409	0.172
Residue protein	0.520	0.288	0.460	0.734	0.979	0.821	0.887	0.714

Appendix E: Treatment means for soil organic matter content.

Residue	Cover Crop	0 to 5 cm depth 2010	0 to 5 cm depth 2011	5 to 20 cm depth 2010	5 to 20 cm depth 2011
		------------------------- g kg^{-1}	-------------------------	-------------------------	-------------------------
Baled	None	26.5	21.8	16.0	17.0
Baled	Rye	26.3	22.5	17.5	18.3
Not Baled	None	22.8	21.8	15.3	17.8
Not Baled	Rye	25.5	25.5	16.8	18.3
Means for main effect					
Year		25.3	22.9	16.4	17.8
Baled		26.4	22.1	16.8	17.6
Not Baled		24.1	23.6	16.0	18.0
	None	24.7	21.8	15.6	17.4
	Rye	25.9	24.0	17.1	18.3

Appendix F: Treatment means for soil organic carbon content.

Residue	Cover Crop	0 to 5 cm depth 2010	0 to 5 cm depth 2011	5 to 20 cm depth 2010	5 to 20 cm depth 2011
		------------------------- g kg^{-1}	-------------------------	-------------------------	-------------------------
Baled	None	16.1	12.9	9.8	10.1
Baled	Rye	15.3	12.9	9.9	10.1
Not Baled	None	14.0	12.9	8.5	10.1
Not Baled	Rye	15.5	11.6	10.0	9.8
Means for main effect					
Year		15.2	12.6	9.5	10.0
Baled		15.7	12.9	9.9	10.1
Not Baled		14.8	12.2	9.2	10.0
	None	15.0	12.9	9.1	10.1
	Rye	15.4	12.2	10.0	10.0

Appendix G: Treatment means for soil potassium concentration.

		0 to 5 cm depth		5 to 20 cm depth	
Residue	Cover Crop	2010	2011	2010	2011
		----------------------- mg kg^{-1}		------------------------	
Baled	None	179	87	65	43
Baled	Rye	170	79	51	33
Not Baled	None	168	91	59	41
Not Baled	Rye	181	88	65	38
Means for main effect					
Year		175	86	60	38
Baled		175	83	58	38
Not Baled		174	90	62	39
	None	173	89	62	42
	Rye	176	83	58	35

Appendix H: Treatment means for soil phosphorus concentration.

		0 to 5 cm depth		5 to 20 cm depth	
Residue	Cover Crop	2010	2011	2010	2011
		----------------------- mg kg^{-1}		------------------------	
Baled	None	60	34	14	11
Baled	Rye	58	29	13	8
Not Baled	None	55	25	12	12
Not Baled	Rye	47	29	15	7
Means for main effect					
Year		55	29	13	9
Baled		59	31	13	10
Not Baled		51	27	13	9
	None	58	30	13	11
	Rye	52	29	14	7

Appendix I: Treatment means for soil calcium concentration.

		0 to 5 cm depth		5 to 20 cm depth	
Residue	Cover Crop	2010	2011	2010	2011
		----------------------- mg kg^{-1}		------------------------	
Baled	None	1690	1471	1801	1511
Baled	Rye	1702	1409	1766	1679
Not Baled	None	1796	1477	2038	1511
Not Baled	Rye	1846	1563	1961	1653
Means for main effect					
Year		1759	1480	1891	1588
Baled		1696	1440	1783	1595
Not Baled		1821	1520	2000	1582
	None	1743	1474	1920	1511
	Rye	1774	1486	1863	1666

Appendix J: Treatment means for soil magnesium concentration.

		0 to 5 cm depth		5 to 20 cm depth	
Residue	Cover Crop	2010	2011	2010	2011
		----------------------- mg kg^{-1}		------------------------	
Baled	None	117	128	107	120
Baled	Rye	114	114	102	123
Not Baled	None	131	146	129	132
Not Baled	Rye	141	158	138	150
Means for main effect					
Year		126	136	119	131
Baled		116	121	104	121
Not Baled		136	152	134	141
	None	124	137	118	126
	Rye	128	136	120	136

Appendix K: Treatment means for soil sulfur concentration.

		0 to 5 cm depth		5 to 20 cm depth	
Residue	Cover Crop	2010	2011	2010	2011
		------------------------ mg kg^{-1} ------------------------			
Baled	None	10	6	6	4
Baled	Rye	11	5	6	4
Not Baled	None	16	7	5	6
Not Baled	Rye	10	6	5	4
Means for main effect					
Year		12	6	5	4
Baled		10	6	6	4
Not Baled		13	6	5	5
	None	13	7	6	5
	Rye	10	5	5	4

Appendix L: Treatment means for soil ammonium-N and nitrate-N.

		Ammonium-N		Nitrate-N	
Residue	Cover Crop	2010	2011	2010	2011
		------------------------ mg kg^{-1} ------------------------			
Baled	None	7	20	22	3
Baled	Rye	11	20	21	2
Not Baled	None	7	19	19	4
Not Baled	Rye	10	20	14	2
Means for main effect					
Year		9	20	19	3
Baled		9	20	21	2
Not Baled		8	20	17	3
	None	7	20	20	4
	Rye	10	20	18	2

Appendix M: Treatment means for soil pH.

		0 to 5 cm depth		5 to 20 cm depth	
Residue	Cover Crop	2010	2011	2010	2011
Baled	None	5.80	5.70	6.08	5.93
Baled	Rye	5.80	5.70	6.15	6.20
Not Baled	None	5.70	5.88	6.08	5.83
Not Baled	Rye	5.73	5.58	5.90	6.00
Means for main effect					
Year		5.76	5.71	6.05	5.99
Baled		5.80	5.70	6.11	6.06
Not Baled		5.71	5.73	5.99	5.91
	None	5.75	5.79	6.08	5.88
	Rye	5.76	5.64	6.03	6.10

Appendix N: Treatment means for soil bulk density.

Residue	Cover Crop	Beginning Bulk Density	Ending Bulk Density	Delta Change
		----------------------- g cm^{-3}	-----------------------	-----------------------
Baled	None	1.44	1.41	-0.04
Baled	Rye	1.47	1.44	-0.03
Not Baled	None	1.47	1.40	-0.07
Not Baled	Rye	1.43	1.40	-0.03
Means for main effect				
Baled		1.46	1.42	-0.03
Not Baled		1.45	1.40	-0.05
	None	1.45	1.40	-0.05
	Rye	1.45	1.42	-0.03

Appendix O: Treatment means for soil crust strength.

		VE		R1	
Residue	Cover Crop	2010	2011	2010	2011
		------------------------ kg cm^{-2}	------------------------		
Baled	None	2.00	1.68	2.66	2.10
Baled	Rye	2.20	1.69	2.58	2.13
Not Baled	None	1.85	1.70	2.41	2.36
Not Baled	Rye	1.66	1.73	2.40	2.22
Means for main effect					
Year		1.93	1.70	2.51	2.20
Baled		2.10	1.68	2.62	2.12
Not Baled		1.76	1.71	2.40	2.29
	None	1.93	1.69	2.53	2.23
	Rye	1.93	1.71	2.49	2.18

Appendix P: Treatment means for soil water content.

		VE		R1	
Residue	Cover Crop	2010	2011	2010	2011
		---------------------m^3	m^{-3}---------------------		
Baled	None	26.3	27.6	38.9	25.9
Baled	Rye	28.0	30.8	36.6	27.8
Not Baled	None	27.8	27.6	37.4	23.2
Not Baled	Rye	27.4	29.6	39.0	23.7
Means for main effect					
Year		27.4	38.0	28.9	25.2
Baled		27.1	37.7	29.2	26.7
Not Baled		27.6	38.2	28.6	23.4
	None	27.1	38.1	27.6	24.6
	Rye	27.7	37.8	30.2	25.8

Appendix Q: Means of residue and cover crop treatment combinations for soil temperature.

		VE			R1		
Residue	Cover Crop	Max	Min	Av	Max	Min	Av
		------------------------------- ^{o}C			---------------------------------		
Means for 2010							
Baled	None	20.3	8.1	13.5	26.2	23.4	24.5
Baled	Rye	21.8	9.3	14.6	25.8	23.3	24.3
Not Baled	None	20.2	8.4	13.6	25.6	23.3	24.2
Not Baled	Rye	21.4	9.0	14.5	25.7	23.3	24.3
Means for 2011							
Baled	None	27.4	19.6	22.7	29.4	24.2	26.5
Baled	Rye	26.5	19.6	22.5	29.9	24.4	26.8
Not Baled	None	26.5	19.5	22.3	28.2	24.2	26.0
Not Baled	Rye	26.8	19.7	22.6	29.5	24.2	26.5

Appendix R: Means of residue and cover crop treatment combinations for mean emergence, length of emergence period and coefficient of variability.

		Mean emergence		Length of emergence period		Coefficient of variability	
Residue	Cover crop	2010	2011	2010	2011	2010	2011
		-days after planting-		------- days -------		------ % -------	
Baled	None	17	7	7	5	3	5
Baled	Rye	17	7	9	4	3	4
Not Baled	None	17	7	7	4	2	4
Not Baled	Rye	16	7	8	4	4	4

Appendix S: Means of residue and cover crop treatment combinations for days after planting to reach VE, R1 and R6, length of vegetative development, length of reproductive development and length of lifecycle.

Residue	Cover Crop	VE	R1	R6	Vegeta-tive	Repro-ductive	Life cycle
		----- days after planting -----			--------- no. of days ---------		
Means for 2010							
Baled	None	16.4	82	129	65	47	112
Baled	Rye	15.4	85	130	70	45	115
Not Baled	None	17.0	86	133	69	47	116
Not Baled	Rye	17.2	88	134	71	47	117
Means for 2011							
Baled	None	7.4	66	122	59	56	115
Baled	Rye	7.2	67	125	59	58	118
Not Baled	None	7.4	67	124	59	57	116
Not Baled	Rye	7.2	67	126	60	60	119

Appendix T: Means for residue and cover crop treatment combinations of vegetative coverage at 3, 5, 7, and 9 weeks after emergence (WAE).

Residue	Cover crop	3 WAE		5 WAE		7 WAE		9 WAE	
		2010	2011	2010	2011	2010	2011	2010	2011
		------------------------------------- %	--------------------------------------						
Baled	None	15	15	44	50	67	71	98	-
Baled	Rye	15	16	32	51	63	77	94	-
Not Baled	None	15	15	37	54	62	81	97	-
Not Baled	Rye	12	10	31	42	55	77	97	-

Appendix U: Means for residue and cover crop treatment combinations of plant height at 4, 6, 8, and 10 weeks after emergence (WAE).

Residue	Cover crop	4 WAE		6 WAE		8 WAE		10 WAE	
		2010	2011	2010	2011	2010	2011	2010	2011
		---------------------------------- cm	----------------------------------						
Baled	None	57	138	258	277	83	173	243	-
Baled	Rye	70	122	247	278	79	165	231	-
Not Baled	None	72	132	255	277	60	137	231	-
Not Baled	Rye	69	115	241	280	76	164	246	-
Means for main effect									
Year		67	127	251	278	75	160	238	-
Baled		64	130	253	277	81	169	237	-
Not Baled		71	124	248	278	68	150	238	-
	None	65	135	257	277	72	155	237	-
	Rye	70	119	244	279	77	164	238	-

Appendix V: Means for residue and cover crop treatment combinations for stand density.

Residue	Cover crop	2010	2011
		--------- plants ha^{-1}	--------
Baled	None	61866	71321
Baled	Rye	67269	70781
Not Baled	None	64838	70241
Not Baled	Rye	69160	69430

Appendix W: Means for residue and cover crop treatment combinations for grain yield.

Residue	Cover Crop	2010	2011
		-------- kg ha^{-1}	---------
Baled	None	10940	8645
Baled	Rye	10988	8875
Not Baled	None	11167	9248
Not Baled	Rye	10660	8026

Appendix X: Treatment means for residue yield

Treatment	2010	2011
	--------- kg ha^{-1}	----------
Year	10101	8525
Baled	10060	7309
Not Baled	10142	9741
None	9560	9291
Rye	10642	7760

Appendix Y: Treatment means for total yield and harvest index (HI).

	Total weight		HI	
Treatment	2010	2011	2010	2011
	--------- kg ha^{-1}	----------		
Year	21040	17224	0.53	0.53
Baled	21024	16069	0.52	0.56
Not Baled	21056	18378	0.53	0.50
None	20613	18238	0.54	0.51
Rye	21467	16210	0.51	0.54

Appendix Z: Means for residue and cover crop treatment combinations for fall residue hemicellulose, cellulose and protein content.

		Hemicellulose		Cellulose		Protein	
Residue	Cover crop	2010	2011	2010	2011	2010	2011
		-------------------------------		g kg^{-1}		-------------------------------	
Baled	None	210	240	290	310	30	53
Baled	Rye	210	240	330	310	39	43
Not Baled	None	230	250	390	300	42	48
Not Baled	Rye	210	250	370	290	49	56

Appendix AA: Means for residue and cover crop treatment combinations for fall and spring protein content and overwinter N release.

Main effect	Treatment	Fall residue 2009	Spring residue 2010	N released overwinter	Fall residue 2010	Spring residue 2011	N released overwinter
		--------------------------------			g kg^{-1}	---------------------------------	
Year		3.0	1.3	540	6.4	0.9	860
Residue	Baled	4.2b‡	1.0a	730	5.6a	0.9a	830
	Not Baled	1.9a	1.5b	350	7.4b	0.9a	880
Cover crop	None	3.4a	1.3a	570	5.9a	0.9a	840
	Rye	2.7a	1.2a	510	7.0b	0.9a	870

Appendix BB: Means for residue, cover crop and emergence class combinations on number of days after planting to reach VE, R1 and R6.

Residue	Cover Crop	Emergence class	2010 VE	2010 R1	2010 R6	2011 VE	2011 R1	2011 R6
			-------------------		days after planting			-------------------
Baled	Rye	Early	14	78	136	6	66	121
Baled	Rye	Median	17	80	134	7	66	125
Baled	Rye	Late	20	81	138	10	67	122
Baled	None	Early	13	80	137	6	66	124
Baled	None	Median	17	79	135	7	66	126
Baled	None	Late	21	84	130	9	67	125
Not Baled	Rye	Early	15	79	137	6	66	120
Not Baled	Rye	Median	18	79	138	8	66	124
Not Baled	Rye	Late	20	81	136	10	68	126
Not Baled	None	Early	12	80	137	6	67	127
Not Baled	None	Median	17	80	136	7	67	122
Not Baled	None	Late	20	82	134	10	67	127

Appendix CC: Means for residue, cover crop and emergence class treatment combinations for length of vegetative development, reproductive development and lifecycle.

			Vegetative		Reproductive		Lifecycle	
Residue	Cover Crop	Emergence class	2010	2011	2010	2011	2010	2011
			---------------------------- no. of days ----------------------------					
Baled	Rye	Early	67	60	57	59	124	119
Baled	Rye	Median	62	59	55	60	117	119
Baled	Rye	Late	63	58	47	59	110	117
Baled	None	Early	65	60	58	55	123	115
Baled	None	Median	63	59	56	59	119	118
Baled	None	Late	62	57	57	55	119	112
Not Baled	Rye	Early	68	61	57	61	125	122
Not Baled	Rye	Median	64	60	56	56	120	116
Not Baled	Rye	Late	62	58	51	60	113	118
Not Baled	None	Early	65	60	58	55	123	115
Not Baled	None	Median	62	58	59	58	121	116
Not Baled	None	Late	60	58	56	58	116	116
Baled	-	Early	66	60	57	57	123	117
Baled	-	Median	62	59	55	59	117	118
Baled	-	Late	62	57	52	57	114	114
Not Baled	-	Early	66	60	57	58	123	118
Not Baled	-	Median	63	59	57	57	120	116
Not Baled	-	Late	61	58	54	59	115	117

Appendix DD: Means of residue, cover crop and emergence class treatment combinations for plant height and ear height.

		2010			2011		
Residue	Cover	Early	Median	Late	Early	Median	Late
		---------------------------- m ----------------------------					
Means on plant height							
Baled	None	2.88	2.65	2.77	2.37	2.17	2.35
Baled	Rye	2.77	2.80	2.77	2.48	2.36	2.32
Not Baled	None	2.62	2.86	2.84	2.34	2.29	2.30
Not Baled	Rye	2.72	2.83	2.85	2.23	2.52	2.45
-	None	2.75	2.76	2.80	2.35	2.23	2.32
-	Rye	2.74	2.82	2.81	2.35	2.44	2.34
Means on ear height							
Baled	None	1.07	1.04	0.99	0.92	0.93	0.93
Baled	Rye	0.95	0.95	0.98	0.83	0.88	0.78
Not Baled	None	1.04	0.99	1.04	0.82	0.93	0.87
Not Baled	Rye	0.96	0.93	0.96	0.82	0.90	0.81
-	None	1.05	1.01	1.01	0.87	0.93	0.90
-	Rye	0.95	0.94	0.97	0.82	0.89	0.80

Appendix EE: Means for residue, cover crop and emergence class treatment combinations for chlorophyll content of ear leaf at R1.

		2010			2011		
Residue	Cover	Early	Median	Late	Early	Median	Late
		---------------------- Relative greenness ------------------					
Baled	None	57	57	56	56	56	56
Baled	Rye	57	56	54	55	57	58
Not Baled	None	57	58	56	57	56	52
Not Baled	Rye	58	57	56	54	56	54
Means for main effect							
Year		57	57	56	56	56	55
Baled		57	57	55	56	56	57
Not Baled		57	57	56	56	56	53
None		57	57	56	57	56	54
Rye		57	57	55	55	57	56

Appendix FF: Means for residue, cover crop and emergence class treatment combinations for rind puncture force at the internode below the primary ear, rind thickness at third internode above the soil and stalk diameter at third internode above the soil.

			Rind puncture force		Rind thickness		Stalk diameter	
Main effect	Treatment	Emergence class	2010	2011	2010	2011	2010	2011
			----- kg cm^2 ----		----- mm -----		------- cm -------	
Residue	Baled	Early	5.3	5.5	1.73	1.44	2.28	2.37
		Median	6.2	6.1	1.58	1.44	2.43	2.35
		Late	5.6	5.3	1.47	1.32	2.25	2.20
	Not Baled	Early	5.9	6.3	1.66	1.39	2.34	2.63
		Median	5.9	6.0	1.61	1.50	2.50	2.38
		Late	6.1	6.2	1.55	1.41	2.39	2.17
Cover crop	None	Early	5.5	5.5	1.76	1.39	2.38	2.49
		Median	6.0	5.8	1.68	1.51	2.48	2.36
		Late	5.2	5.6	1.58	1.30	2.33	2.11
	Rye	Early	5.7	6.3	1.62	1.44	2.24	2.51
		Median	6.1	6.2	1.51	1.43	2.45	2.36
		Late	6.5	6.0	1.44	1.42	2.30	2.26

Appendix GG: Residue, cover crop and emergence class treatment combinations for grain, cob and residue yield.

Main effect	Treatment	Emergence class	Grain		Cob		Residue	
			2010	2011	2010	2011	2010	2011
			-------------------------- g plant^{-1} --------------------------					
Residue	Baled	Early	183	219	27	41	128	115
		Median	175	260	25	41	126	98
		Late	143	204	23	51	113	100
	Not Baled	Early	181	239	27	46	128	103
		Median	169	260	26	46	128	117
		Late	157	258	26	51	126	111
Cover crop	None	Early	195	230	28	43	133	106
		Median	163	241	25	39	129	108
		Late	150	223	25	38	118	94
	Rye	Early	168	228	26	48	123	112
		Median	181	279	26	51	125	107
		Late	150	239	26	54	121	117

Appendix HH: Means for residue, cover crop and emergence class treatment combinations for total yield and harvest index (HI).

Main effect	Treatment	Emergence class	Total yield		HI	
			2010	2011	2010	2011
			------- g plant^{-1} -------			
Residue	Baled	Early	337	375	0.54	0.57
		Median	326	399	0.54	0.64
		Late	278	355	0.51	0.52
	Not Baled	Early	336	388	0.54	0.61
		Median	323	361	0.52	0.59
		Late	309	366	0.51	0.60
Cover crop	None	Early	356	376	0.55	0.60
		Median	317	386	0.51	0.60
		Late	291	364	0.51	0.59
	Rye	Early	317	386	0.53	0.58
		Median	332	375	0.55	0.63
		Late	296	357	0.51	0.53
Emergence class		Early	336	381	0.54	0.59
		Median	324	380	0.53	0.61
		Late	294	361	0.51	0.56

Appendix II: Means for residue, cover crop and emergence class treatment combinations for hemicellulose, cellulose and protein content of fall residue.

	2010			2011		
Treatment	Early	Median	Late	Early	Median	Late
	------------------------------------ g kg^{-1} ------------------------------------					
Means for Hemicellulose						
Year	250	250	240	250	250	250
Baled	250	250	240	250	250	250
Not Baled	250	250	240	240	250	250
None	240	250	240	250	250	250
Rye	250	250	240	250	250	250
Means for Cellulose						
Year	320	310	300	300	300	280
Baled	320	310	310	300	300	290
Not Baled	330	310	300	290	300	280
None	320	320	310	300	310	290
Rye	320	310	300	290	290	270
Means for Protein						
Year	43	42	46	60	55	55
Baled	43	40	48	55	51	54
Not Baled	42	45	44	64	58	57
None	44	45	47	59	53	55
Rye	41	40	46	60	56	55

Appendix JJ: Means for residue, cover crop and emergence class treatment combinations for hemicellulose, cellulose and protein content of cob.

Treatment	2010			2011		
	Early	Median	Late	Early	Median	Late
	------------------------------------- g kg^{-1} -------------------------------------					
Means for Hemicellulose						
Year	310	310	310	310	310	300
Baled	310	310	310	320	320	300
Not Baled	300	310	300	300	320	300
None	310	310	310	310	320	310
Rye	310	310	310	310	310	290
Means for Cellulose						
Year	380	380	390	340	350	340
Baled	380	390	390	360	350	330
Not Baled	380	370	390	320	350	340
None	370	370	390	330	350	330
Rye	390	390	390	340	350	340
Means for Protein						
Year	39	39	38	41	38	40
Baled	37	38	36	36	38	41
Not Baled	42	41	39	47	37	40
None	42	41	38	43	39	41
Rye	37	37	37	39	37	40

Appendix KK: Means for residue, cover crop and emergence class treatment combinations for hemicellulose and protein content of grain.

Treatment	2010			2011		
	Early	Median	Late	Early	Median	Late
	---------------------------------- g kg^{-1} ----------------------------------					
Means for Hemicellulose						
Year	90	90	90	80	80	90
Baled	90	90	90	80	80	90
Not Baled	90	90	90	80	80	90
None	90	90	90	80	80	90
Rye	90	90	90	90	80	90
Means for Protein						
Year	89	89	88	92	85	92
Baled	89	89	89	89	85	91
Not Baled	89	89	87	94	86	94
None	88	88	91	92	86	90
Rye	90	90	86	91	84	95

VITA

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