WINTER COVER CROPS IN CORN AND FORAGE SORGHUM ROTATIONS IN THE GREAT PLAINS

by

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B.S., North Carolina State University, 2005
M.S. Prairie View A&M University, 2008

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Agronomy
College of Agriculture

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Abstract

In Kansas, winter cover crops have a new interest with the development of summer crops for biofuel. When a crop is harvested for bioenergy, the residue is removed leaving the soil prone to erosion during the winter. It is possible that the use of winter cover crops may allow for more residue to remain in a field while keeping the soil from blowing. Therefore, the objective of this research was to determine the effect of two winter cover crops on the growth of two biofuel crops, corn (*Zea mays* L.) and forage sorghum [*Sorghum bicolor* (L.) Moench] in a corn-forage sorghum rotation. The two cover crops were a legume, Austrian winter pea (*Pisum sativum* var. *arvense* Poir.) and winter wheat (*Triticum aestivum* L.). Control plots were fallowed. The experiment was done for two years (2010 and 2011) at two locations: under rain-fed conditions in Manhattan in the northeastern part of Kansas, where the soil was a Belvue silt loam (coarse-silty, mixed superactive non-acid, mesic Typic Udifluvents) and under irrigated conditions in Tribune in the western part of Kansas, where the soil was a Richfield silt loam (fine, smectitic, mesic Aridic Argiustolls). Two levels of nitrogen were added to the soil: 0 and 101 kg ha^{-1} N. Grain and stover yields of the corn and forage sorghum were determined at harvest of the crops in the fall, and dry matter production of the cover crops was determined at their termination in the springs of 2011 and 2012. Additional nitrogen fertilizer increased grain and stover yields in both growing seasons at both locations, except for Manhattan in 2010. During the second winter of the study, Austrian winter pea did not emerge in Manhattan, probably due to a combination of cold temperatures and drought. Austrian winter pea survived both winters at Tribune. Corn yielded more grain than did the forage sorghum in Manhattan in 2011 and in Tribune in 2011. This suggests that, under both rain-fed and irrigated conditions in Kansas, corn would potentially be more productive for bioenergy production than forage sorghum. The results of the study also showed that winter wheat for both Manhattan, Kansas, and Tribune, Kansas, should be the cover crop chosen, because of its ability to grow well during the off-season of the bioenergy crops and to provide soil cover during winter.

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Approved by:

Mary Beth Kirkham
Major Professor

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Chapter 1 – Literature Review

Bioenergy Development

With options for sustainable energy in the future becoming scarce (Brown and Brown, 2012), alternative sources are now needed and required to help meet sustainable energy goals on a global scale. Agriculturally derived biomass is a potentially abundant feedstock capable of providing a renewable supply of energy as an alternative to petrochemical use (Heggenstaller et al., 2008). Challenges in producing this abundant biomass to help meet energy supply needs, while maintaining food production, and conserving natural resources and preserving environmental quality, should not be overlooked (Heggenstaller et al., 2008).

Recent increases in food prices in the last few years can be attributed to the increase in bioenergy production, which has reduced the availability of food supply at both the national and international levels (Ajanovic, 2010). In addition to this, several agricultural scientists, farmers, and conservationists are concerned about the potential impacts of total biomass harvesting on soil and water quality (Laird, 2008). When all aboveground biomass is removed sequentially or annually for bioenergy production, the soil surface is essentially left "bare" which can potentially lead to soil nutrient and structure losses by way of soil erosion and runoff (Laird, 2008). These soil nutrients then move into different waterways, contaminating them, rendering them useless to many households that highly depend upon these water systems. Therefore, one of the greatest obstacles confronting biomass production for bioenergy is the development of cropping systems that balance the need for increased productive capacity with the maintenance of other critical ecosystem functions, which would include nutrient cycling retention (Heggenstaller et al., 2008). One option that can address the need of reducing soil losses (nutrient and structural) and overall environmental degradation is the introduction of cover crops. Cover crops are commonly defined as crops including grasses, legumes, forbs, or other herbaceous plants established for seasonal cover and conservation purposes (USDA-NRCS, 2013). In bioenergy cropping systems, cover crops offer the benefits of providing additional biomass to protect soil from aboveground losses (erosion, runoff) and recycling nutrients that can be or are lost belowground by way of leaching (Boardman, 2009).

Cover Crop Selection

Lu et al. (2000) define a cover crop as a crop planted primarily to manage soil fertility, soil quality, water, weeds, pests, diseases, biodiversity, and wildlife. The Midwest Cover Crops Council (MCCC, 2013) defines cover crops as plants seeded into agricultural fields, either within or outside of the regular growing season, with the primary purpose of improving or maintaining ecosystem quality.

Cover crops are typically planted during all seasons of the year. However, the "common niches" as described by Clark (2007) normally are winter and summer fallows. These are winter and summer cover crops that are grown during a time of the year that a cash crop cannot or will not be grown (Gliessman, 2000). They are often planted after the harvest of the primary crop to cover the soil during the fallow season, but they can also be planted in alternating years with the primary crop or grown in association with the primary crop (Gliessman, 2000).

Cover crops are usually legumes, non-legumes, or a mixture of both. Legume plants in general are defined as a plant in the family Fabaceae, or the fruit or seed of such a plant, which is usually grown agriculturally. Or their food or grain seed is grown for livestock forage and silage or as a soil enhancing green manure (Tree Encyclopedia, 2013). For use in cover cropping, legumes are primarily used for this soil-enhancing ability. Non-legumes are similar to legumes, as they are grown for the same purpose as legumes, except they are not members of the plant family Fabaceae (Tree Encyclopedia, 2013), and are primarily used for scavenging plant nutrients leftover from previous crops in addition to producing large amounts of plant residues (Clark, 2007).

Cover crop species are classified normally as legumes and non-legumes (Clark, 2007), while non-legumes are further split into brassicas and broadleaves (MCCC, 2013) because of the vast amounts of cover crops in each of those categories. For each cover crop within each category, there are many varieties widely available with over 50 suppliers across the United States (Clark, 2007). It is important to realize that cover crop characteristics are highly dependent upon location and, because of the widespread interest in cover cropping, new cultivars and accessions are introduced each year (Ingels et al., 1998).

Cover Crop Effects on Soils

More than likely the main reason for farmers to implement cover crops is their overall effect on soil fertility. By scavenging and mining soil nutrients and contributing nitrogen, cover crops can cut fertilizer costs (Clark, 2007). Nitrogen is considered to be the most important nutrient for crop production, and the easiest of all other nutrients to be lost. Therefore, nitrogen effects would be the number one priority of a farmer when implementing cover crops. Sainju et al. (2006) explain that, due to the increase of fertilizer costs and potential environmental hazards, improved soil and crop management practices are needed to increase nitrogen cycling and storage so that the rate and cost of nitrogen fertilization and the potential for nitrogen leaching can be reduced. When a farmer implements a legume cover crop, there is a greater chance that some of nitrogen needs can be met. Legumes fix nitrogen gas from the air in nodules (found on legume plant roots) into ammonium nitrogen, a plant usable form of nitrogen (Clark, 2007). In addition to nitrogen effects, both legume and non-legume cover crops help bring other nutrients back into the upper soil profile from deep soil layers to be released into soil organic matter after cover crop termination (Clark, 2007).

Along with enhancing soil fertility, cover crops can enhance soil structure. Winter cover crops can improve soil structure by reducing soil bulk density, increase water infiltration properties, and change the distribution of soil aggregate-size classes (Mendes et al., 1999). Clark (2007) claims that cover crops help "glue" soil by way of polysaccharides, a by-product made of complex sugars created when soil microorganisms digest plant material. They also produce some compounds in addition to the active and stable fractions of organic matter. Increased aggregation and porosity can promote root growth by decreasing soil bulk density and resistance to root penetration (Baldwin and Creamer, 2009).

Another high-priority concern of farmers is soil erosion. The loss of topsoil can be detrimental economically and environmentally to farmers where the loss of topsoil includes the loss of nutrients and pesticides via water or wind erosion, which is expensive, and the eroded material can be placed in areas where it does harm to humans, plants, and animals. In general, soils in eastern Kansas are more susceptible to water erosion than western Kansas, while soils in western Kansas are more susceptible to wind erosion than soils in eastern Kansas (Whitney et al., 1999). Vegetation on the soil surface does a good job of reducing both types of erosion by reducing wind speed at the soil surface for wind erosion and by slowing the action of moving water, reducing its soil-carrying capacity and essentially creating an obstacle course of leaves, stems, and roots through which the water must maneuver on its way downhill (Clark, 2007).

Cover crops, like any other crop, need moisture in order to produce any type of biomass. However, knowing that the greater the biomass the greater the soil moisture used means that this could potentially be hazardous in rotations where a cash crop such as corn, which requires a high amount of water, is grown. Cover crops can also be helpful in conserving soil moisture. Clark (2007) claims that residue from killed covers increases water infiltration and reduces evaporation, resulting in less moisture stress during drought. The amount of moisture retained by dead cover crop residue depends on the timing of precipitation relative to cover crop termination. Growers should monitor early spring conditions to maximize biomass production without severely depleting soil moisture before cash crop planting (Baldwin and Creamer, 2009).

Climate Effects On Annual and Cover Crops

Some basic necessities of any plant are light, air, and water. Each of these necessities is highly favorable to plants and is provided through various aspects of general climatic conditions throughout the world. Light from the sun is the primary source of energy for ecosystems and the primary driver for the earth's weather (Gliessman, 2000). Plants catch this sunlight to go through their life processes, such as photosynthesis and respiration. Therefore, sunlight is highly favorable for both annual and cover crop production. Temperature is another important climatic aspect of annual and cover crop production. The effect of temperature on the growth and development of plants has certain limits of tolerance for high and low temperatures, determined by a crop's particular adaptation for temperature extremes (Gliessman, 2000). The winter cover crop in the cooler zones complements a summer cash crop, while the summer cover crop in the warmer zones complements a fall or winter cash crop (Snapp et al., 2005). Air is also provided through climatic aspects and is necessary to plant growth and development. It can be provided by wind, downward air currents, and precipitation and is important due to its ability to supply carbon dioxide in addition to oxygen for respiration of the plant, as well as for chemical and biological processes in the soil (Martin et al., 1976).

Water, being one of the more important necessities for plant growth, is primarily provided through precipitation in the form of rain or snow (Gliessman, 2000). Rainfall amounts and growth of vegetation have a direct relationship because, for most terrestrial ecosystems, water is the most important limiting factor for growth (Gliessman, 2000). As there are favorable climatic conditions for annual and cover crops, there are unfavorable climatic conditions as well. Among these conditions are drought, flooding, and temperature stress. Drought occurs when there is not enough moisture present to meet annual and cover crop requirements at a specific time. This ends in reduced yields or death (Chrispeels and Sadava, 1994). The most significant factors for heat-stress related yield loss in crops include shortening of developmental stages, reduced light interception over the shortened life cycle, and perturbation of the processes associated with carbon assimilation (Barnabas et al., 2008).

Just as drought can have a detrimental effect on annual and cover crops, too much water can have the same effect on the production of these crops. Frequent and heavy rainfall creates problems of waterlogging, root diseases, nutrient leaching, abundant weed growth, and complications for most farming operations (Gliessman, 2000). Waterlogged soils literally suffocate most plant and soil organisms by filling in air spaces in the soil, blocking the inflow of air (Chrispeels and Sadava, 1994). Temperature-stress usually causes the above-mentioned unfavorable conditions in addition to others. While drought in combination with high temperature is the most common form of stress, when temperatures are low, annual and cover crop production suffers as well. Sudden cold snaps injure plants because they do not have enough time to become acclimated to the cold weather (Chrispeels and Sadava, 1994). Natural disasters also occur as a result of temperature-stress, such as tornadoes, hurricanes, and hailstorms that do physical harm to crops and the soil that supports the crops (Chrispeels and Sadava, 1994). When temperatures drop below the minimum required for growth, a plant can become dormant (Gliessman, 2000).

Annual Crop and Cover Crop Rotations

Cover crops are usually produced during periods when annual cash crops are not grown. They are important as they provide additional diversification to different farm situations, which in turn, provides benefits for a cropping system. One way for farmers to do this is by increasing the number of plant species in the system by introducing different planting practices into their cropping system (Gliessman, 2000). When implementing cover crops in a cropping system, growers should follow these simple steps of planting cover crops: plant them on time, use an adequate planting method, and terminate cover crops on time (Clark, 2007). Planting cover crops early is a good management practice as it allows cover crops to establish a strong rooting system to catch and hold nutrients before dormancy and to establish more biomass for more groundcover. It also reduces a cover crop's chance of suffering a winter kill (Clark, 2007). Due to different required row widths, cover crops are planted with different equipment than annual crops. Annual crops such as corn and sorghum are usually seeded in 30-in (76-cm) rows (Duncan et al., 2007; Vanderlip et al., 1998), while cover crops are seeded in with a drill (Shroyer et al., 1996). Cover crops can be introduced into cropping systems, too, by broadcast seeding, aerial seeding, or frost-seeding, and they can be reseeded after experiencing a heavy winter-kill (Clark, 2007). The timing of the cover crop termination is important as it is related to moisture and nutrient release. Timing of cover crop termination affects soil temperature, soil moisture, nutrient cycling, tillage, and planting operations on the subsequent cash crop (Clark, 2007). Growers need to monitor early spring conditions to maximize biomass production without severely depleting soil moisture before planting (Baldwin and Creamer, 2009).

Cover Crop Advantages and Disadvantages

With just about every farming practice, there are disadvantages as well as advantages. For cover crops these advantages and disadvantages range from production and management all the way to the economic aspect. Although cover crops can help increase overall soil fertility and organic matter along with increasing soil productivity by decreasing bulk density, reducing soil crust formation, and enhancing biological activity in the rooting zone (Gliessman, 2000), they can present the risks of nitrogen and water loss in addition to increased pest populations (Godsey, 2010). For example, alfalfa, a nitrogen rich legume annual and cover crop, enhances soil nitrogen. However, because of its large roots that extend deeply through soil horizons, it can increase water percolation and nitrogen loss by this increased percolation when terminated (Snapp et al., 2005).

Another important advantage of cover crops is their ability to reduce pest pressures. Cover crops, such as rye, produce growth inhibitors that slow growth of plants surrounding them and this reduces the chance of competition in a phenomenon called allelopathy (Gliessman, 2000). Beneficial insects destroy crop-damaging insects when introduced to a cropping system by use of cover crops. Cover crops provide a potential habitat for beneficial insects year-round to protect cash crops before and during their growth and development (Clark, 2007). In terms of disease management, many synthetic materials are used to reduce pest pressures to plants. However, these materials have the tendency to damage outer layers of crops, weakening their defenses, and making them more prone to disease (Clark, 2007). Cover crops help with this issue by reducing the need to use synthetic chemicals that cause this damage (Clark, 2007).

In reference to the economic aspect of cover crop production, the subject that is of great concern to a grower is additional costs of production associated with using cover crops (Bergtold and Maddy, 2008). Usually included in the economics of cover crop production are seed costs, planting, and termination (Bergtold and Maddy, 2008). Cover crop seed costs vary considerably from year to year and from region to region. But, historically, legume cover crops cost about twice as much as non-legumes (Clark, 2007). Planting cover crops also comes with additional costs associated with equipment use and the energy required to operate planting equipment (Bergtold and Maddy, 2008). Costs for termination of cover crops are similar to those of planting cover crops in terms of energy used for operation of equipment. However, there is the option of chemical termination, which is usually included in production costs and also includes the use of non-selective herbicides at various rates of application (Clark, 2007).

The returns on cover crops usually are in the forms of herbicide savings, fertilizer savings, and sub-soiling savings, (Bergtold and Maddy, 2008). In terms of herbicide savings, cover crops have the ability to remove necessary resources needed by weeds (light, water, nutrients) in addition to producing growth inhibiting compounds (allelopathy) to slow weed growth (Gliessman, 2000). Fertilizer savings are similar to herbicide savings, because cover crops add, as well as recycle, plant nutrients to upper soil horizons for subsequent crop usage. Legume cover crops add nitrogen while recycling other nutrients, just as non-legumes recycle nitrogen and all other nutrients to reduce the total amount of fertilizer that a farmer may need for a cash crop (Baldwin and Creamer, 2009). Sub-soiling savings come as a result of cover crop roots that essentially restructure the soil. These roots also open pathways for water infiltration, while cover crop residues above the soil provide enough shade to reduce evaporation of soil moisture (Clark, 2007).

Opportunity costs in cover crop production arise when another cash crop could be planted in place of the cover crop. The opportunity cost of income forgone from cash crops may be the biggest cost of cover crops and the chief reason that they are rarely grown during fallow periods (Snapp et al., 2005). Bergtold et al. (2012) claim that given the ability to double or possibly triple a crop, cover crops used in a system can have significant opportunity costs. In the end, it is up to the grower to determine the benefits of implementing a cover crop. Is it equivalent or greater than the economic gains of using a cover crop in place of a cash crop? The answer would be based on what the grower wants to accomplish.

Research Question and Justification

Winter fallows are common throughout the Great Plains. They usually occur after the harvest of summer cash crops, such as corn, sorghum, and soybeans, and normally result in bare soil, particularly if both grain and stover are removed for biofuel production. This bare soil is prone to problems such as erosion, soil compaction, water runoff, and nitrogen leaching. Growers in the Great Plains are now seriously considering the use of cover crops over winter fallow periods to avoid these issues. Studies have been conducted in central (Janke et al., 2002), south central (Janke et al., 2002; Heer et al., 2011), and western Kansas (Holman, 2012) to determine if cover crops can be produced and be beneficial in different cropping systems.

One major flaw in winter cover crop production across the state of Kansas is the inadequacy of soil moisture availability, especially from the central into the western part of Kansas. Even in the eastern region of the state, where there is greater soil moisture, farmers would still consider the soil moisture as marginal due to the fact that they grow cash crops such as corn that uses the majority of the annually available moisture without the aid of irrigation. Another issue in relation to winter cover crop research is that winter cover crop research in rotations of sorghum have only been done normally on winter wheat-sorghum rotations (Arnet, 2010; Janke et al., 2002). This leaves a need to do research with winter cover crops in different rotations of other crops and sorghum.

The purpose of this study was to determine the overall effects of legume and non-legume winter cover crops in rotations of corn and forage sorghum in eastern, south central, and western Kansas. The study evaluated grain and stover yields of corn and forage sorghum, as well as the dry matter, carbon-to-nitrogen ratio, and nitrogen uptake of the winter cover crops. The objectives of this study were to:

i. To evaluate the dry matter, carbon-to-nitrogen ratio, and nitrogen uptake of two winter cover crops, Austrian winter pea and winter wheat, and their effect on the grain, stover, and total biomass yields of two bioenergy crops, corn and forage sorghum, in three different rotations designed to maximize total biomass production.

ii. To evaluate the dry matter, carbon-to-nitrogen ratio, and nitrogen uptake of three legume and three non-legume cover crops when implemented in putative corn and forage sorghum rotations.

Chapter 2 – Winter Cover Crops in Corn and Forage Sorghum Rotations in the Great Plains

Abstract

In Kansas, winter cover crops have a new interest with the development of summer crops for biofuel. When a crop is harvested for bioenergy, the residue is removed leaving the soil prone to erosion during the winter. It is possible that the use of winter cover crops may allow for more residue to remain in a field while keeping the soil from blowing. Therefore, the objective of this research was to determine the effect of two winter cover crops on the growth of two biofuel crops, corn (*Zea mays* L.) and forage sorghum [*Sorghum bicolor* (L.) Moench] in a corn-forage sorghum rotation. The two cover crops were a legume, Austrian winter pea (*Pisum sativum* var. *arvense* Poir.) and winter wheat (*Triticum aestivum* L.). Control plots were fallowed. The experiment was done for two years (2010 and 2011) at two locations: under rain-fed conditions in Manhattan in the northeastern part of Kansas, where the soil was a Belvue silt loam (coarse-silty, mixed superactive non-acid, mesic Typic Udifluvents) and under irrigated conditions in Tribune in the western part of Kansas, where the soil was a Richfield silt loam (fine, smectitic, mesic Aridic Argiustolls). Two levels of nitrogen were added to the soil: 0 and 101 kg ha^{-1} N. Grain and stover yields of the corn and forage sorghum were determined at harvest of the crops in the fall, and dry matter production of the cover crops was determined at their termination in the springs of 2011 and 2012. Additional nitrogen fertilizer increased grain and stover yields in both growing seasons at both locations, except for Manhattan in 2010. During the second winter of the study, Austrian winter pea did not emerge in Manhattan, probably due to a combination of cold temperatures and drought. Austrian winter pea survived both winters at Tribune. Corn yielded more grain than did the forage sorghum in Manhattan in 2011 and in Tribune in 2011. This suggests that, under both rain-fed and irrigated conditions in Kansas, corn would potentially be more productive for bioenergy production than forage sorghum. The results of the study also showed that winter wheat for both Manhattan, Kansas, and Tribune, Kansas, should be the cover crop chosen, because of its ability to grow well during the off-season of the bioenergy crops and to provide soil cover during winter.

Introduction

Cover crops have been used for centuries to protect the soil against erosion, provide nutrients to the primary crop, and to enhance soil quality (Blevins et al., 1994). Annual cover crops are established each year after harvest of a primary crop, and their growth is often terminated before they reach maturity (Unger, 2006), as a means of providing a cover for the soil (Martin et al., 1976).

Extensive work has been done on cover crops in the humid regions of the USA. In the Southeastern USA, cover crops are successfully used in corn (*Zea mays* L.), soybean [*Glycine max* (L.) Merr.], and cotton (*Gossypium hirsutum* L.) production (Blevins et al., 1994; Busscher et al., 2010). In a classic field experiment in Blacksburg, Virginia, Moschler et al. (1967) studied several winter crops after which corn was planted. The results showed that corn grain yields were enhanced by the presence of any of the cover crops: rye (*Secale cereale* L.), hairy vetch (*Vicia villosa* Roth), ryegrass (*Lolium perenne* L.), crimson clover (*Trifolium incarnatum* L.), and oat (*Avena sativa* L.). In the Tennessee Valley Region of North Alabama, the presence of a cover crop resulted in equal or greater yields of cotton (Raper et al., 2000). In the Southeast, use of winter, annual non-legume or legume cover crops is compatible with conservation tillage systems, which maintain surface residue that conserves water and reduces soil erosion. Therefore, cover crops are recommended as a good cropping management strategy in the Southeast (Blevins et al., 1994).

In the Mid-South region, keeping the soil covered was recognized by Bennett et al. (1919) as the only feasible way of adequately controlling soil erosion on steep slopes. Bennett and his colleagues observed that gully erosion was severe, even on much of the sloping land where contoured farming was used. In some cases, they thought terracing would help, but on many fields, conversion to grasses and clover (*Trifolium* spp.) or permanent pasture was the only solution. Many other experiments since then have shown the importance of soil coverage. In Arkansas, Bartholomew et al. (1939) found that soil loss in corn rotated with oats (*Avena sativa* L.) and clover was less than that in continuous corn. In addition to using cover crops to protect the soil from erosion, much research has been done in many Mid-South states on the use of cover crops to improve plant productivity, as reviewed by Locke et al. (2010). Data from these studies indicates great promise for the use of winter cover crops to provide additional soil cover, enhance crop yields, increase soil organic matter, improve soil physical properties, and, with legumes, supply fixed nitrogen to the following row crop. Because of their benefits, use of cover crops is now encouraged in the region (Zobeck, 2010).

In the Northeast, cover crops provide multiple benefits for soil quality enhancement, nutrient scavenging, erosion and runoff control, and pest suppression (van Es, 2010). Farmers and researchers are exploring opportunities to incorporate them into their cropping systems and have experimented with the use of cover crop mulches where winter grains and legumes are mulched within a no-tillage system. This provides excellent nutrient cycling, improved soil quality, good weed control, and virtual elimination of erosion concerns (van Es, 2010).

In the Northwest, cropping systems that maximize year-round cover are encouraged. The region has low (dryland), intermediate, and high precipitation zones (Schillinger et al., 2010). Alternative crops such as winter canola (*Brassica napus* L.) can be planted soon after cereal-grain harvest in the intermediate and high precipitation zones. But in the low precipitation zone, cover crops are not used. The two-year winter wheat (*Triticum aestivum* L.) – summer fallow rotation is the dominant crop rotation and has remained so since 1890, because it is less risky and more profitable than other systems tested to date (Schillinger et al., 2010).

In the West and Southwest, the use of cover crops is not widely practiced. In many areas, especially California and Arizona, mild winters allow growing of cash crops year round. Cover crops have been used more extensively in perennial systems, such as orchards and vineyards. Planting of cover crops in vineyards has been practiced since the early 1990s. But overall the adoption of cover crops is less than 5% of agricultural land in the western United States (O'Geen et al., 2010).

In the Midwest, cover crops have been studied since the time of King (1901). He discusses their advantages and disadvantages and points out that cover crops dry the soil, resulting in the danger of the seeds of the primary crop not germinating when they are planted. Abundant and timely rains must be available to allow growth of cover crops and the subsequent primary crops. Currently, Midwest agriculture could be diversified by incorporating crops such as winter triticale (x *Triticosecale rimpaui* Wittm.) into corn and soybean rotations (Karlen et al, 2010). Grown for a cover crop, winter triticale could provide several advantages to Midwest cropping systems. Like rye, it can capture and use nitrogen left in the soil profile by previous crops, prevent soil erosion during periods of high rainfall, provide valuable forage or grain for swine or cattle and straw for either bedding or bioenergy production.

Relatively little research has been done with cover crops on the semi-arid Great Plains. Recent reviews of agricultural practices in the semi-arid Northern Great Plains (Tanaka et al, 2010) and in the Southern Great Plains (Stewart et al., 2010) do not mention cover crops. In fact, cover crops generally are not recommended for use under dryland conditions, as for example in the Southern Great Plains (Unger et al., 2010). This is because they use water and may result in limited soil water for the following crop. Cover crops generally are better suited for humid and sub-humid regions, where precipitation is more reliable, than to semi-arid regions, where precipitation is limited (Unger et al., 2010).

Nevertheless, cover crops are a practical means to control wind erosion after harvest (Schillinger et al., 2010), and wind erosion is a serious problem in Kansas and other semi-arid regions. In central and eastern Kansas in a wheat/row crop rotation, the 10 to 11 months between winter wheat harvest and planting of the next grain crop the following spring provides an opportunity to insert a cover crop (Roozeboom, 2013). Planting a cover crop immediately after wheat harvest can take advantage of the 20 to 30 cm of precipitation usually received in this part of the state from July through September. Also cover crops are being recommended for Kansas because they can increase crop intensity, which reduces evaporation from the soil due to greater amounts of residue (Roozeboom et al., 2012a, 2012b). This can increase water use efficiency (Arnet, 2010; Roozeboom et al., 2012c).

In Kansas, cover crops have a new, added interest with the development of crops for biofuel. However, when a crop is harvested for bio-energy, residue removal rates will need to be reduced to prevent soil erosion. It is possible that the use of winter cover crops may allow for more residue to be removed from a field while protecting the soil from blowing. In the humid regions of the Midwest of the USA, corn is grown for bio-energy production. However, in the semi-arid environments of the Great Plains where drought and temperature stress are common, grain and forage sorghums are likely to be better suited than corn. Sorghum's drought and temperature tolerance make it an ideal crop for bio-energy feedstock production the Central Great Plains. Corn is also planted throughout the region under both dryland and irrigated conditions. Although widely believed to provide contributions to the biofuel feedstock supplies, corn will not likely produce higher yields than forage sorghum in more arid environments. Biofuel research in Kansas supports the fact that forage sorghums have the ability to produce greater amounts of biomass and ethanol than corn (Propheter, 2009). Because the removal of crop residues from agricultural fields may affect the productivity and erodibility of soils, the use of winter cover crops could offset some of the impacts of residue removal on soil quality and erosion. They would allow for higher residue removal rates for the summer crop.

Because little information exists concerning the use of cover crops in Kansas, the objective of this research was to determine the effect of two winter cover crops on the growth of two biofuel crops, corn and forage sorghum [*Sorghum bicolor* (L.) Moench], in either a corn-forage sorghum rotation or in a continuous forage sorghum system. Both systems are designed to maximize forage sorghum as a bioenergy feedstock production.

Materials and Methods

Field studies were conducted from the summer of 2009 to the spring of 2012 in Manhattan, Kansas, and Tribune, Kansas. In Manhattan (39^{o} 8′ 39.61″ N; 96^{o} 37′ 44.12″ W), the study was conducted at the Ashland Bottoms Research Farm on a Belvue silt loam (coarse-silty, mixed, superactive non-acid, mesic Typic Udifuvents). In Tribune (38^{o} 31′ 45.52″ N; 101^{o} 39′ 34.36″ W), the study was conducted at the Southwest Research-Extension Center near Tribune, KS, on a Richfield silt loam (fine, smectitic, mesic Aridic Argiustolls). Two cover crops, winter wheat, and Austrian winter pea, along with a fallow treatment (no cover crop), were evaluated in a three-year rotation with corn and forage sorghum. Austrian winter pea was chosen because it has been suggested to be a good cover crop for use in Kansas (Heer et al., 2011). Corn and forage sorghum were in the rotations of continuous forage sorghum and rotated forage sorghum and corn.

Crops were grown without irrigation at Manhattan and under irrigation at Tribune. Table 2.1 gives the rainfall and temperature during the three years of the study in Manhattan and Tribune. Table 2.2 gives the irrigation amounts applied for the 2009, 2010, and 2011 growing seasons in Tribune. Irrigation at Tribune was carried out only during the growing seasons of both corn and forage sorghum. Cover crops were not irrigated after the corn and forage sorghum were harvested. However, the cover crops did use residual water left in the soil profile from the irrigations during the summer. Corn and forage sorghum were irrigated with the same amounts of water. The amount of water added for each irrigation was based on reference evapotranspiration. Reference evapotranspiration was determined using the Penman-Monteith equation. The values for reference evapotranspiration are archived on the Weather Data Library website maintained by Kansas State University Research and Extension. On the Website, reference evapotranspiration values are given for both alfalfa and grass, the two reference crops. However, irrigation at Tribune is usually based on the alfalfa reference.

Starting in the summer of 2010, half of the plots received no nitrogen fertilizer and half of the plots received nitrogen fertilizer as urea (46% N-0% P-0% K) at the rate of 101 kg ha^{-1} (90 lb ac^{-1}). Nitrogen treatments were applied in the spring of 2010 with the continuation of corn and forage sorghum rotations. Plots were arranged in a randomized complete block design, with a split-split plot treatment structure, and four replications. Each block was 54.86 m (180 feet) by 12.19 m (40 feet). Each block was divided into three main plots, which were the crop rotations. The first split was cover-crop treatment (winter wheat, Austrian winter pea, or fallow), and the second split was nitrogen treatment. The smallest plot (a combination of one nitrogen treatment and one cover-crop treatment) was 3.05 m x 12.19 m (10 feet by 40 feet). There were 18 such subplots in each block (3 rotations; 3 cover-crop treatments; 2 nitrogen rates). All treatments occurred each year, with rotation, cover crop, and nitrogen treatments randomized within each block. The distance between blocks was 3.05 m (10 feet).

In the summer of 2009, a "bulk" planting was established at both Manhattan and Tribune before treatments with cover crops and nitrogen began. All planting, harvesting, sampling, and cover crop termination dates are provided in Table 2.3. In Manhattan before the bulk planting, the soil had been fallow one year and, before that, it had been planted in wheat. In Tribune before the bulk planting, the soil was in irrigated corn until August 2008. There were 4 blocks in the bulk planting. In each block, the three rotations were established. One-third of the entire block was planted for each rotation. In Manhattan, the variety of corn seed was DeKalb DKC 63-42 planted at a seeding rate of 74,000 seeds $hectare^{-1}$. The forage sorghum variety used was Northrup King 300 (NK 300) planted at a rate of 148,000 seeds $hectare^{-1}$. Both corn and forage sorghum were planted in 76 cm (30-in) rows with a White 6100 planter (AGCO Corp., Duluth, GA), at a depth of 5 cm (2 in). In 2009, plots were initially fertilized with urea (46-0-0) at a rate of 70 kg N ha^{-1}. Phosphorus and potassium were applied at a high rate to ensure that they were not deficient at any point in the study. Phosphorus was applied as triple super phosphate (0-46-0) at 151 kg P_2O_5 ha^{-1}, and potassium was applied as potash (0-0-60) at 336 kg K_2O ha^{-1}. Similar planting procedures were conducted at Tribune, excluding additional phosphorus and potassium, and with the corn cultivar Pioneer 37K11 and with forage sorghum cultivar NK 300. At Tribune, corn was planted with a starter fertilizer treatment of ammonium polyphosphate solution (10-34-0) at 93.5 L ha^{-1}. Forage sorghum was planted with the same starter fertilizer treatment. Both corn and forage sorghum were replanted with corn as DKC 52-59 hybrid at 74,000 seeds $hectare^{-1}$, and forage sorghum as NK 300 at 148,000 seeds $hectare^{-1}$.

Rotated forage sorghum plots that had forage sorghum in the bulk planting of 2009 had corn in the planting of 2010, and then again had forage sorghum in the planting of 2011. Similarly, rotated corn plots had corn in the bulk planting of 2009 had sorghum in the planting of 2010, and then again had corn in the planting of 2011. The plots in continuous forage sorghum, had only forage sorghum in the plots. Rotated forage sorghum results represent the performance of forage sorghum that had been rotated with corn. Rotated corn results represent the performance of corn that had been rotated with forage sorghum. In both cases, the rotation treatment followed the crop rather than the field position from one year to the next.

Plots in Manhattan were harvested for corn and for forage sorghum, with no measurements taken in 2009 because plots were intended to set up the rotations. The same steps were repeated in Tribune with corn and forage sorghum plots. Plots were then split into cover crop treatments, which consisted of a legume (Austrian winter pea), a non-legume (winter wheat), and a fallow, which was used as a check treatment. In Manhattan, cover crops were planted following corn and forage sorghum harvest. Austrian winter pea was planted at a rate of 133,633 seeds $hectare^{-1}$, while winter wheat was planted at a rate of 1,856,435 seeds $hectare^{-1}$, both in 20 cm rows. In Tribune, cover crops were not planted in 2009 due to equipment and budget constraints. Cover crops in Manhattan were planted with no additional nitrogen treatments in order to test their ability to cycle nitrogen, produce nitrogen (legumes), and to affect soil properties over the time period of late fall, winter, and early spring.

In Manhattan, cover crops were sampled from an area 1 m^2 that was hand-harvested, using a machete, and sampled for total biomass. Plants were cut at ground surface. The samples were weighed at harvest to obtain wet weight, then dried at 65 ^{o}C for 120 hours, and weighed again to obtain dry weight to estimate dry matter. Percent carbon and percent nitrogen in the cover crops were obtained from samples submitted to the Kansas State University Soil Testing Laboratory. Nitrogen and carbon were determined using a combustion technique (Instruction Manual for Model No. CNS 2000 Leco Corp., St. Joseph MI). The carbon and nitrogen were used to determine carbon-to-nitrogen ratio. Cover crop plots to be planted in forage sorghum were sampled using the same methods and procedures as were used for plots planted in corn. That is, total biomass (fresh weight), dry matter, percent nitrogen, and percent carbon were determined. Each cover crop plot was split down to apply the randomly assigned 0 kg ha^{-1} nitrogen and 101 kg ha^{-1} nitrogen rates to plots to be planted in corn and forage sorghum. Nitrogen treatments were broadcast applied as urea prior to both corn and forage sorghum planting at both locations.

Hand harvesting for plots was Manhattan was done by using a machete to cut the plants. Samples were taken from a randomly selected 357 cm (15 feet) of the center two rows of each plot and were cut 15 cm (6 inches) above the soil surface. Plant height was taken only in 2011 on the days that corn and forage sorghum was harvested at both locations. A plant was cut 15 cm above ground. The plant was laid on the ground and height was measured from the cut end to the top of the tassel with the tassel extended. Samples were weighed to estimate total biomass production, which was grain plus stover. Grain harvest was achieved by separating entire ears from the plant, weighing them, and threshing them using an Almaco ECS sheller for corn ears and an Almaco LBD thresher (Almaco, Nevada, IA) for forage sorghum grain heads. After shelling, grain moisture was obtained with a Dickey John GAC 2000 moisture reader (Dickey-john Corp., Springfield, IL), to aid in calculating grain yield. The moisture content (MC) of the grain was adjusted to a standard moisture content. For corn and forage sorghum, the formula was (100-MC)/87 or 13%.

Stover samples were weighed at harvest, shredded, then dried for 240 hours at 65 ^{o}C, and weighed again to determine stover dry matter yield. Total biomass was determined by the addition of grain yield to stover yield. In 2010, corn and forage sorghum were not harvested for measurements at Tribune as a result of no cover crops being planted in 2009. So there are no data for Tribune in 2010. These procedures were repeated in 2011 in Manhattan (second year of data). Corn and forage sorghum samples for Tribune were taken in 2011 using the hand harvesting methods used in Manhattan in 2011.

In 2010, cover crops were planted using the same methods used in 2009. The 'Spector' variety of Austrian winter pea was planted at a rate of 133,633 seeds $hectare^{-1}$, and the 'Everest' variety of winter wheat was planted at a rate of 1,856,435 seeds $hectare^{-1}$. Harvests for cover crop samples in 2011 and 2012 were methodologically identical to cover crop harvest in 2010 in both locations. Cover crop samples were submitted to the Kansas State University Soil Testing

Laboratory and analyzed for percent nitrogen, and percent carbon. Potential amount of nitrogen taken up and made available by the cover crop was determined using the following equations from (Sarrantoino, 1994 and Clark, 2007):

Cover crop nitrogen uptake (kg ha^{-1}) = (Cover crop yield (kg ha^{-1})) x (Nitrogen percent (%))/(100)

At both locations, weed control was achieved by the use of herbicides, which were applied primarily to terminate cover crops and control annual weeds in corn and forage sorghum plots. In Manhattan, all weed control applications were made on the dates of cover crop sampling. In 2009, plots in Manhattan were treated with a preplant burn down treatment of glyphosate (isopropylamine salt of N-phosphonomethyl glycine 56) (1.54 kg a.e. ha^{-1}) and 2,4 D (2,4-dichlorophenoxy acetic acid) (0.87 kg a.i. ha^{-1}) and a preplant emergence treatment of glyphosate (isopropylamine salt of N-phosphonomethyl glycine 56) (1.06 kg a.e. ha^{-1}) and preemergence Lumax (0.84 kg a.e. ha^{-1}) (Lumax consists of S-metolachlor, atrazine, mesotrione, which are (RS)-2-Chloro-N-(2-ethyl-6-methyl-phenyl)-N-(1-methoxypropan-2-yl)acetamide, 2-chloro-4-ethylamino-6-isopropylamino-s-triazine and 2-[4-(Methylsulfonyl)-2-nitrobenzoyl]cyclohexane-1,3-dione, respectively) treatment to plots planted with corn. Preplant Bicep II Magnum (1.9 kg a.i. ha^{-1}) (Bicep II Magnum consists of S-metolachlor and atrazine) ((RS)-2-Chloro-N-(2-ethyl-6-methyl-phenyl)-N-(1-methoxypropan-2-yl) acetamide and 2-chloro-4-ethylamino-6-isopropylamino-s-triazine, respectively) was applied to plots planted with forage sorghum. Throughout the corn growing season, two treatments of glyphosate (isopropylamine salt of N-phosphonomethyl glycine 56) (1.54 kg a.e. ha^{-1}) were applied. In 2009 in Tribune, all plots were preplant treated with glyphosate (1.54 kg a.i. ha^{-1}) along with Lumax (0.84 kg a.e. ha^{-1}) and Gramoxone (1,1-dimethyl-4,4-bipyridinium) (1.68 kg a.i. ha^{-1}) for replanted corn and forage sorghum. In 2010 in Tribune, Weathermax (potassium salt of glyphosate, 1.54 kg a.i. ha^{-1}) + Verdict, which consists of (N'-[2-chloro-4-fluoro-5-(3-methyl-2,6-dioxo-4-(trifluoromethyl)-3,6-dihydro-1(2H)-pyrimidinil)benzoyl]-N-isopropyl-N-methylsulfamide + (S)-(2-chloro-N-[(1-methyl-2-methoxy)ethyl]-N-(2,4-dimethyl-thien-3-yl)-acetamide) (1.12 kg a.i. ha^{-1}) + Atrazine 4L (2-chloro-4 ethylamino-6-isopropylamino-s-triazine) (1.4 kg a.i. ha^{-1}) were applied as preemergence weed control treatments to corn plots. In 2010 in Tribune, forage sorghum plots in the corn to forage sorghum plots were treated with Weathermax (potassium salt of glyphosate) (0.84 kg a.e. ha^{-1}). In Tribune in 2010, all other forage sorghum treatments were treated with glyphosate (0.84 kg a.e. ha^{-1}) and atrazine (1.12 kg a.i. ha^{-1}). In 2011 in Tribune preemergence weed control of corn plots was achieved with glyphosate (isopropylamine salt of N-phosphonomethyl glycine 56) + Lumax (2-chloro-4-ethylamino-6-isopropylamino-s-triazine) + atrazine (2-chloro-4 ethylamino-6-isopropylamino-s-triazine) (0.84 kg a.e. ha^{-1} + 6.7 kg a.i. ha^{-1} + 0.56 kg a.i. ha^{-1}, respectively). In forage sorghum plots, a preemergence treatment of glyphosate + atrazine (0.84 kg a.e. ha^{-1} + 0.84 kg a.e. ha^{-1}, respectively) was applied. A post-emergence application of glyphosate (0.84 kg a.e. ha^{-1}) was made to corn plots with drop nozzles.

Significance of main effect differences and their interactions in each environment was determined using the PROC GLIMMIX procedure (SAS Institute, 2013) with crop in rotation, cover crop, and nitrogen rate as fixed effects; with replications as random effects. Mean separations were performed for the main effect treatment effects if the F-tests for treatment effects were significant at the ($\alpha = 0.05$) level.

Results and Discussion

Corn and forage sorghum plant height

Nitrogen rate was the only significant factor affecting plant height in Manhattan in 2011 (Table 2.4). This is primarily because nitrogen is the most limiting nutrient for both corn (Duncan et al., 2007) and sorghum (Vanderlip et al., 1998) growth. Plant height in Tribune in 2011 was significantly affected by the crop in rotation, nitrogen rate, and the crop in rotation x nitrogen rate interaction (Table 2.5). In general, plant height of rotated corn was greater than plant height of forage sorghum in either rotation and was greater with the 101 kg ha^{-1} nitrogen treatment. However, the difference was greater with the 0 kg ha^{-1} nitrogen treatment than at the 101 kg ha^{-1} nitrogen treatment.

Corn and forage sorghum grain yield

In all three environments, grain yields were significantly increased with a nitrogen application (Tables 2.6, 2.7, and 2.8). In Manhattan in 2011, grain yields of both crops were greater following the winter wheat cover crop (Table 2.7). Corn grain yield was greater than forage sorghum grain yield in either rotation. The crop in rotation, the nitrogen rate, and the crop in rotation x cover crop interaction affected grain yields in Tribune in 2011 (Table 2.8). In general, rotated corn produced more grain than either continuous forage sorghum or rotated forage sorghum. However, following Austrian winter pea, rotated forage sorghum yielded less than the continuous forage sorghum and rotated corn (Table 2.8). In Tribune in 2011 at the time of forage sorghum harvest, heavy winds led to severe lodging and shattering of forage sorghum plants, which would have reduced grain yields of forage sorghum in that location and year.

Corn and forage sorghum stover yield

For Manhattan in 2010, rotated forage sorghum and continuous forage sorghum had similar stover yield across all cover crop and nitrogen treatments (Table 2.9). Rotated corn yielded less than rotated forage sorghum and continuous forage sorghum, but the difference was most pronounced after Austrian winter pea with 101 kg ha^{-1} nitrogen application and after fallow with 0 kg ha^{-1}. In Manhattan in 2011 and Tribune in 2011, nitrogen application increased stover yield regardless of cover crop or crop in rotation. Rotated corn produced more stover, and yield was greater for rotated corn than for forage sorghum in either rotation in Manhattan in 2011, but the opposite was true in Tribune in 2011 (Tables 2.10 and 2.11).

Corn and forage sorghum total biomass yield

In all three environments, response of total biomass yields to the treatment factors (Table 2.12, 2.13, and 2.14) was similar to that of stover (Table 2.9, 2.10, and 2.11), indicating that stover drove total biomass yields.

Cover crop dry matter

In Manhattan and Tribune in 2011, cover crop dry matter was significantly less before rotated corn (Table 2.15 and 2.16) because the cover crop was terminated approximately a month earlier to facilitate corn planting (Table 2.3). In Manhattan in 2011, cover crops yielded two to three times more with rotated forage sorghum than with rotated corn (Table 2.15), but in Tribune, the differences were five to six fold (Table 2.16). In Manhattan in 2011, winter wheat produced more dry matter than Austrian winter pea particularly before forage sorghum planting (Table 2.15). This might be due to the fact that winter wheat is well adapted to Kansas, as pointed out by Paulsen et al. (1997). In Manhattan in 2012, Austrian winter pea did become established due to a late planting date and a dry seedbed (Table 2.17). Winter wheat produced less dry matter before rotated forage sorghum than before continuous forage sorghum and rotated corn. Similarly in Tribune in 2012, both cover crops produced less dry matter before the rotated forage sorghum than before the continuous forage sorghum and the rotated corn (Table 2.18). Winter wheat produced more dry matter than Austrian winter pea.

Cover crop carbon-to-nitrogen ration (C:N)

Treatment factors had no effects on cover crop C:N in Manhattan in 2011 (Table 2.19). In Tribune in 2011, C:N was greater for winter wheat ahead of continuous and rotated forage sorghum than winter wheat ahead of rotated corn and Austrian winter pea in all three rotations Table 2.20). In Manhattan and Tribune in 2012, treatment factors had no effects on cover crop C:N (Table 2.21 and 2.22).

Cover crop nitrogen uptake

In Manhattan and Tribune in 2011, nitrogen uptake was much less before rotated corn than before continuous and rotated forage sorghum (Tables 2.23 and 2.24), because cover crop were terminated a month earlier to facilitate corn planting (Table 2.3). In Manhattan in 2011, winter wheat took up more nitrogen (Table 2.23), and in Tribune in 2011, Austrian winter pea took up more nitrogen (Table 2.24). In Manhattan in 2012 nitrogen uptake was affected by crop in rotation (Table 2.25). Austrian winter pea did not become established due to a late planting date and a dry seedbed (Table 2.25). Nitrogen uptake of winter wheat was less before rotated forage sorghum. There were no effects significantly affecting cover crop nitrogen uptake in Tribune 2012 (Table 2.26).

Conclusions

Corn and forage sorghum grain and stover yields were affected more by nitrogen rate than any other treatment. Corn grain yields were generally greater than grain yields of forage sorghum in both locations. In 2011, wind storms in Tribune affected overall grain yields of forage sorghum. Total biomass yields for both corn and forage sorghum were mainly driven by stover yields in all environments. Cover crop dry matter and nitrogen uptake were affected by the crop in rotation, where greater dry matter and nitrogen uptake were achieved when cover crops were terminated at the time of forage sorghum planting. In each environment, winter wheat on average, produced greater dry matter and took up more nitrogen than Austrian winter pea. In Manhattan 2012, Austrian winter pea did not establish a stand as a result of late planting dates and a dry seedbed due to drought. The results of this study indicated that nitrogen application to corn and forage sorghum will have a great effect on total biomass (grain + stover) yields. Winter wheat produced the most dry matter because of its good adaptation to climatic conditions in Kansas.

Tables

Table 2.1. Total monthly precipitation and average monthly temperatures at Manhattan, KS, and Tribune, KS, during the study (2009, 2010, 2011, and 2012).

	Precipitation		Temperature		Precipitation		Temperature	
Month	Manhattan	Tribune	Manhattan	Tribune	Manhattan	Tribune	Manhattan	Tribune
	-------mm-------		---------°C---------		-------mm-------		---------°C---------	
	2009				2011			
Jan.	1.0	8	-2.3	0.6	18	8	-4.3	-1.7
Feb.	17	12	3.1	3.8	23	18	-1.9	-1.1
Mar.	76	24	6.3	5.8	30	13	6.1	5.4
Apr.	133	55	10.8	9.3	73	35	12.7	11.4
May	25	25	17.6	16.1	139	20	17.3	15.7
June	215	72	23.8	21.5	132	122	24.6	23.5
July	166	56	232.0	24.3	55	129	30.1	27.2
Aug.	114	68	22.7	23.0	71	86	26.9	25.9
Sept.	52	20	17.8	17.9	35	24	19.3	18.1
Oct.	102	63	9.1	7.6	68	64	14.6	12.5
Nov.	37	24	8.1	6.8	108	16	6.6	4.9
Dec.	51	13	-4.3	-3.2	87	36	1.4	-2.2
	2010				2012			
Jan.	10	12	-5.3	-0.7	1	1	1.7	1.6
Feb.	14	13	-2.5	-1.1	54	8	2.6	1.3
Mar.	71	53	5.5	5.6	69	22	14.1	10.2
Apr.	88	38	14.2	11.4	54	56	15.3	13.1
May	100	88	16.8	14.7	34	5	21.4	18.3
June	195	49	24.7	23.4	105	15	25.1	25.3
July	97	104	26.4	25.8	---	---	---	---
Aug.	103	96	26.5	24.7	---	---	---	---
Sept.	89	9	20.7	21.3	---	---	---	---
Oct.	29	8	14.9	13.6	---	---	---	---
Nov.	48	3	6.9	5.5	---	---	---	---
Dec.	2	7	-0.7	1.4	---	---	---	---

Table 2.2. Total irrigation used on corn and forage sorghum at Tribune, KS, during the study (2009, 2010, and 2011).

		Year			
2009		2010		2011	
Date	Irrigation (in.)	Date	Irrigation (in.)	Date	Irrigation (in.)
10-Jul	1.34	8-Jun	1.60	16-May	0.79
17-Jul	1.52	3-Jul	1.78	13-Jun	1.45
23-Jul	1.45	19-Jul	1.59	23-Jun	0.91
3-Aug	1.66	30-Jul	1.60	29-Jun	1.45
16-Aug	1.62	5-Aug	1.51	8-Jul	1.13
22-Aug	1.34	12-Aug	1.43	15-Jul	1.84
---	---	21-Aug	0.85	24-Jul	1.20
---	---	27-Aug	1.50	13-Aug	1.26
---	---	31-Aug	1.50	21-Aug	1.46
---	---	---	---	27-Aug	1.58
---	---	---	---	---	---
TOTALS	**8.93**	**TOTALS**	**13.36**	**TOTALS**	**13.07**

Table 2.3. Planting, sampling, and harvest dates of corn, forage sorghum, and the cover crops rotated within them each year in Manhattan and Tribune, KS.

				Manhattan			
				Year			
		2009		2010		2011	
Crop	Cover crop†	Planting date	Sampling/harvest date	Planting date	Sampling/harvest date	Planting date	Sampling/harvest date
Corn		6 May	2 October	2 May	3 October	3 May	6 October
	Austrian winter pea	4 October	25 April 2010	6 October	16 April	14 October	16 April 2012
	Winter wheat	4 October	25 April 2010	6 October	16 April	14 October	16 April 2012
Forage Sorghum		21 May	7 November	25 May	7 November	29 May	7 November
	Austrian winter pea	13 November	14 May 2010	16 November	23 May	13 November	16 May 2012
	Winter wheat	13 November	14 May 2010	16 November	23 May	13 November	16 May 2012
				Tribune			
Corn		22 June	6 November	30 April	---	10 May	9 October
	Austrian winter pea	---‡	---	18 October	16 April 2011	22 November	4 May 2012
	Winter wheat	---	---	18 October	16 April 2011	22 November	4 May 2012
Forage Sorghum		22 June	11 November	28 May	---	10 June	19 November
	Austrian winter pea	---	---	18 October	30 April 2011	22 November	3 June 2012
	Winter wheat	---	---	18 October	30 April 2011	22 November	3 June 2012

†Cover crops reflect those used in rotation with the before-mentioned crop within each column.
‡Within each set of planting dates and sampling harvest dates, (---) represents no occurrence of the particular event.

Table 2.4. Plant height (cm) means and analysis of variance for crop in rotation, cover crop, and nitrogen rate in Manhattan, Kansas, 2011.

	Cover crop							
	Austrian winter pea		Winter wheat		Fallow		Mean	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101	0	101
	---------- cm ----------							
	CIR x CC x NR†						CIR x NR	
Continuous forage sorghum	167	169	167	179	164	176	166	175
Rotated forage sorghum	172	179	167	171	180	192	173	181
Rotated corn	159	179	175	161	168	184	168	174
	CC x NR						NR	
Mean	166	176	170	170	171	184	168b‡	177a
	CIR x CC						CIR	
Continuous forage sorghum	168		173		170		170	
Rotated forage sorghum	176		169		186		177	
Rotated corn	169		168		176		171	
	CC							
Mean	171		170		177			

ANOVA			
Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR)	2	0.18	0.8410
Cover crop (CC)	2	0.67	0.5244
CIR x CC	4	0.35	0.8431
Nitrogen rate (NR)	1	11.97	0.0019
CIR x NR	2	0.05	0.9497
CC x NR	2	2.83	0.0772
CIR x CC x NR	4	2.71	0.0517

† CIR = Crop in rotation, CC = Cover crop, NR = Nitrogen rate.
‡Within each set of means, values followed by the same letter are not significantly different (α = 0.05).

Table 2.5. Plant height (cm) means and analysis of variance for crop in rotation, cover crop, and nitrogen rate in Tribune, Kansas, 2011.

	Cover crop							
	Austrian winter pea		Winter wheat		Fallow		Mean	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101	0	101
	---------- cm ----------							
	CIR x CC x NR†						CIR x NR	
Continuous forage sorghum	178	197	189	208	193	209	187c	205bc
Rotated forage sorghum	198	216	203	224	188	206	197bc	215ab
Rotated corn	240	230	233	227	227	228	233a	229ab
	CC x NR						NR	
Mean	205	215	209	220	203	214	206b	216a

	CIR x CC			CIR
Continuous forage sorghum	188	199	201	196b‡
Rotated forage sorghum	207	214	197	206b
Rotated corn	235	231	227	230a
	CC			
Mean	210	214	208	

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR)	2	11.02	0.0098
Cover crop (CC)	2	0.73	0.4941
CIR x CC	4	1.49	0.2473
Nitrogen rate (NR)	1	13.03	0.0013
CIR x NR	2	6.74	0.0044
CC x NR	2	0.06	0.9401
CIR x CC x NR	4	0.20	0.9383

† CIR = Crop in rotation, CC = Cover crop, NR = Nitrogen rate.
‡Within each set of means, values followed by the same letter are not significantly different ($\alpha = 0.05$).

Table 2.6. Grain yield (kg ha^{-1}) means and analysis of variance for crop in rotation, cover crop, and nitrogen rate in Manhattan, Kansas, 2010.

	Cover crop						Mean	
	Austrian winter pea		Winter wheat		Fallow			
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101	0	101
	-------------------------kg ha^{-1}-------------------------							
	CIR x CC x NR†						CIR x NR	
Continuous forage sorghum	5218	5900	5171	4946	4013	4871	4801	5239
Rotated forage sorghum	6208	6039	4993	6307	4631	5511	5277	5952
Rotated corn	4136	5160	4865	5749	4111	4757	4371	5222
	CC x NR						NR	
Mean	5187	5699	5009	5667	4251	5046	4816b‡	5471a

	CIR x CC			CIR
Continuous forage sorghum	5559	5058	4442	5020
Rotated forage sorghum	6123	5650	5071	5614
Rotated corn	4648	5307	4434	4796
	CC			
Mean	5443	5338	4649	

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR)	2	1.38	0.3206
Cover crop (CC)	2	1.88	0.1817
CIR x CC	4	0.40	0.8049
Nitrogen rate (NR)	1	15.19	0.0006
CIR x NR	2	0.51	0.6085
CC x NR	2	0.24	0.7915
CIR x CC x NR	4	1.76	0.1654

† CIR = Crop in rotation, CC = Cover crop, NR = Nitrogen rate.
‡Within each set of means, values followed by the same letter are not significantly different (α = 0.05).

Table 2.7. Grain yield (kg ha^{-1}) means and analysis of variance for crop in rotation, cover crop, and nitrogen rate in Manhattan, Kansas, 2011.

	Cover crop							
	Austrian winter pea		Winter wheat		Fallow		Mean	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101	0	101
	---------kg ha^{-1}---------							
	CIR x CC x NR†						CIR x NR	
Continuous forage sorghum	4846	5158	5588	5332	5081	5301	5172	5264
Rotated forage sorghum	5220	5544	5622	5950	4690	5601	5177	5698
Rotated corn	6636	8358	7327	8881	7248	7536	7071	8258
	CC x NR						NR	
Mean	5567	6353	6179	6721	5673	6146	5807b‡	6407a
	CIR x CC						CIR	
Continuous forage sorghum	5002		5460		5191		5218b	
Rotated forage sorghum	5382		5786		5145		5438b	
Rotated corn	7497		8104		7392		7664a	
	CC							
Mean	5960b		6450a		5909b			
	ANOVA							
Source of Variation	DF		F Value		Pr > F			
Crop in rotation (CIR)	2		8.72		0.0168			
Cover crop (CC)	2		5.80		0.0120			
CIR x CC	4		0.44		0.7789			
Nitrogen rate (NR)	1		7.91		0.0092			
CIR x NR	2		2.18		0.1335			
CC x NR	2		0.20		0.8167			
CIR x CC x NR	4		0.90		0.4757			

† CIR = Crop in rotation, CC = Cover crop, NR = Nitrogen rate.

‡Within each set of means, values followed by the same letter are not significantly different ($\alpha = 0.05$).

Table 2.8. Grain yield (kg ha^{-1}) means and analysis of variance for crop in rotation, cover crop, and nitrogen rate in Tribune, Kansas, 2011.

	Cover crop							
	Austrian winter pea		Winter wheat		Fallow		Mean	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101	0	101
	-----------------------kg ha^{-1}-----------------------							
	CIR x CC x NR†						CIR x NR	
Continuous forage sorghum	5538	6211	4999	5760	4711	5372	5082	5781
Rotated forage sorghum	4495	5207	4699	5682	5178	5993	4790	5627
Rotated corn	9265	9623	8450	10051	8697	9957	8804	9877
	CC x NR						NR	
Mean	6232	7014	6049	7164	6195	7108	6226b‡	7095a
	CIR x CC						CIR	
Continuous forage sorghum	5874b		5379bc		5041cd		5432b	
Rotated forage sorghum	4851d		5190bcd		5586bc		5209b	
Rotated corn	9444a		9251a		9327a		9341a	
	CC							
Mean	6723		6607		6651			

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR)	2	47.73	<0.0001
Cover crop (CC)	2	1.05	0.8171
CIR x CC	4	1.75	0.0432
Nitrogen rate (NR)	1	3.64	<0.0001
CIR x NR	2	0.37	0.3049
CC x NR	2	0.98	0.0910
CIR x CC x NR	4	0.76	0.2973

† CIR = Crop in rotation, CC = Cover crop, NR = Nitrogen rate.

‡Within each set of means, values followed by the same letter are not significantly different ($\alpha = 0.05$).

Table 2.9. Stover yield (kg ha^{-1}) means and analysis of variance for crop in rotation, cover crop, and nitrogen rate in Manhattan, Kansas, 2010.

	Cover crop							
	Austrian winter pea		Winter wheat		Fallow		Mean	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101	0	101
	----kg ha^{-1}----							
	CIR x CC x NR†						CIR x NR	
Continuous forage sorghum	13025ab‡	14509a	12061ab	12709ab	12631ab	13380ab	12572	13533
Rotated forage sorghum	13391ab	12666ab	12763ab	14495a	13118ab	14362a	13091	13841
Rotated corn	10906bc	9210c	12204ab	10809bc	9408c	12039ab	10839	10686
	CC x NR						NR	
Mean	12441	12129	12343	12671	11719	13260	12167	12687

	CIR x CC			CIR
Continuous forage sorghum	13767	12385	13005	13052a
Rotated forage sorghum	13029	13629	13740	13466a
Rotated corn	10058	11507	10723	10763b
	CC			
Mean	12285	12507	12490	

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR)	2	6.42	0.0323
Cover crop (CC)	2	0.11	0.8987
CIR x CC	4	1.29	0.3092
Nitrogen rate (NR)	1	3.03	0.0931
CIR x NR	2	1.31	0.2861
CC x NR	2	3.32	0.0515
CIR x CC x NR	4	3.17	0.0294

† CIR = Crop in rotation, CC = Cover crop, NR = Nitrogen rate.
‡Within each set of means, values followed by the same letter are not significantly different (α = 0.05).

Table 2.10. Stover yield (kg ha^{-1}) means and analysis of variance for crop in rotation, cover crop, and nitrogen rate in Manhattan, Kansas, 2011.

	Cover crop							
	Austrian winter pea		Winter wheat		Fallow		Mean	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101	0	101
	--------------------kg ha^{-1}--------------------							
	CIR x CC x NR†						CIR x NR	
Continuous forage sorghum	10544	14581	11085	13961	12817	14351	11482	14298
Rotated forage sorghum	10125	14531	10085	14520	10408	14821	10206	14624
Rotated corn	11767	17693	13669	17966	12380	15237	12605	16965
	CC x NR						NR	
Mean	10812	15602	11613	15482	11868	14803	11431b‡	15296a
	CIR x CC						CIR	
Continuous forage sorghum	12562		12523		13584		12890b	
Rotated forage sorghum	12328		12303		12614		12415b	
Rotated corn	14730		15818		13808		14785a	
	CC							
Mean	13207		13548		13336			
	ANOVA							
Source of Variation	DF		F Value		Pr > F			
Crop in rotation (CIR)	2		5.95		0.0376			
Cover crop (CC)	2		0.07		0.9347			
CIR x CC	4		0.49		0.7428			
Nitrogen rate (NR)	1		64.74		<0.0001			
CIR x NR	2		1.22		0.3118			
CC x NR	2		1.29		0.2927			
CIR x CC x NR	4		0.34		0.8512			

† CIR = Crop in rotation, CC = Cover crop, NR = Nitrogen rate.
‡Within each set of means, values followed by the same letter are not significantly different ($\alpha = 0.05$).

Table 2.11. Stover yield (kg ha^{-1}) means and analysis of variance for crop in rotation, cover crop, and nitrogen rate in Tribune, Kansas, 2011.

	Cover crop							
	Austrian winter pea		Winter wheat		Fallow		Mean	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101	0	101
	---kg ha^{-1}---							
	CIR x CC x NR†						CIR x NR	
Continuous forage sorghum	20758	24928	21744	22536	22002	21995	21502	23153
Rotated forage sorghum	17722	24738	19335	23544	24673	23770	20577	24017
Rotated corn	13721	15947	15657	18152	15069	15444	14815	16514
	CC x NR						NR	
Mean	17400	21871	18912	21411	20581	20403	18964b‡	21228a
	CIR x CC						CIR	
Continuous forage sorghum	22843		22140		21999		22327a	
Rotated forage sorghum	21230		21439		24222		22297a	
Rotated corn	14834		16904		15256		15665b	
	CC							
Mean	19635		20161		20492			

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR)	2	30.43	0.0007
Cover crop (CC)	2	0.46	0.6400
CIR x CC	4	1.50	0.2446
Nitrogen rate (NR)	1	8.14	0.0084
CIR x NR	2	0.56	0.5806
CC x NR	2	2.85	0.0760
CIR x CC x NR	4	0.53	0.7123

† CIR = Crop in rotation, CC = Cover crop, NR = Nitrogen rate.
‡Within each set of means, values followed by the same letter are not significantly different ($\alpha = 0.05$).

Table 2.12. Total biomass yield (kg ha^{-1}) means and analysis of variance for crop in rotation, cover crop, and nitrogen rate in Manhattan, Kansas, 2010.

	Cover crop							
	Austrian winter pea		Winter wheat		Fallow		Mean	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101	0	101
	----------kg ha^{-1}----------							
	CIR x CC x NR†						CIR x NR	
Cont. forage sorghum	17565abcd‡	19643ab	16559bcde	17013abcde	16122cdef	17618abcd	16748	18091
Rotated forage sorghum	18791abc	17919abc	17107abcde	19982a	17147abcd	19156abc	17682	19019
Rotated corn	14549def	13763ef	16490bcde	15874cdef	13029f	16229cde	14689	15286
	CC x NR						NR	
Mean	16969ab	17106a	16719ab	17623a	15432b	17668a	16373b	17466a
	CIR x CC						CIR	
Cont. forage sorghum	18604		16786		16870		17420	
Rotated forage sorghum	18355		18545		18152		18350	
Rotated corn	14153		16182		14629		14988	
	CC							
Mean	17037		17171		16550			

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR)	2	4.31	0.0692
Cover crop (CC)	2	0.50	0.6123
CIR x CC	4	1.49	0.2456
Nitrogen rate (NR)	1	11.94	0.0018
CIR x NR	2	0.61	0.5488
CC x NR	2	3.76	0.0363
CIR x CC x NR	4	3.47	0.0207

† CIR = Crop in rotation, CC = Cover crop, NR = Nitrogen rate.
‡Within each set of means, values followed by the same letter are not significantly different ($\alpha = 0.05$).

Table 2.13. Total biomass yield (kg ha^{-1}) means and analysis of variance for crop in rotation, cover crop, and nitrogen rate in Manhattan, Kansas, 2011.

	Cover crop							
	Austrian winter pea		Winter wheat		Fallow		Mean	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101	0	101
	-----kg ha^{-1} -----							
	CIR x CC x NR†						CIR x NR	
Continuous forage sorghum	14760	19069	15947	18599	17238	18963	15982	18877
Rotated forage sorghum	14666	19354	14976	19697	14448	19694	14710	19582
Rotated corn	17540	24964	20194	25843	18686	21793	18807	24200
	CC x NR						NR	
Mean	15655	21129	17039	21380	16804	20150	16499b‡	20886a

	CIR x CC			CIR
Continuous forage sorghum	16914	17273	18101	17429b
Rotated forage sorghum	17010	17336	17091	17146b
Rotated corn	21252	23019	20239	21503a
	CC			
Mean	18392	19209	18477	

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR)	2	11.79	0.0084
Cover crop (CC)	2	0.39	0.6832
CIR x CC	4	0.56	0.6940
Nitrogen rate (NR)	1	59.91	<0.0001
CIR x NR	2	1.81	0.1834
CC x NR	2	1.22	0.3119
CIR x CC x NR	4	0.55	0.6974

† CIR = Crop in rotation, CC = Cover crop, NR = Nitrogen rate.

‡Within each set of means, values followed by the same letter are not significantly different ($\alpha = 0.05$).

Table 2.14. Total biomass yield (kg ha^{-1}) means and analysis of variance for crop in rotation, cover crop, and nitrogen rate in Tribune, Kansas, 2011.

	Cover crop							
	Austrian winter pea		Winter wheat		Fallow		Mean	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101	0	101
	----------kg ha^{-1}----------							
	CIR x CC x NR†						CIR x NR	
Continuous forage sorghum	25576	33011	26093	27547	26100	26669	25923	28182
Rotated forage sorghum	21632	29268	23423	28487	29178	28984	24744	28913
Rotated corn	21781	24319	23008	26897	22635	24018	22475	25078
	CC x NR						NR	
Mean	22996	27973	24175	27644	25971	26577	24381b‡	27391a
	CIR x CC						CIR	
Continuous forage sorghum	27954		26820		26385		27053a	
Rotated forage sorghum	25450		25955		29081		26829a	
Rotated corn	23050		24952		23327		23776b	
	CC							
Mean	25484		25909		26264			
	ANOVA							
Source of Variation	DF		F Value		Pr > F			
Crop in rotation (CIR)	2		5.79		0.0397			
Cover crop (CC)	2		0.30		0.7410			
CIR x CC	4		1.73		0.1862			
Nitrogen rate (NR)	1		14.21		0.0009			
CIR x NR	2		0.55		0.5839			
CC x NR	2		2.56		0.0963			
CIR x CC x NR	4		0.65		0.6321			

† CIR = Crop in rotation, CC = Cover crop, NR = Nitrogen rate.
‡Within each set of means, values followed by the same letter are not significantly different ($\alpha = 0.05$).

Table 2.15. Cover crop dry matter (kg ha^{-1}) means and analysis of variance for crop in rotation, cover crop, and nitrogen rate in Manhattan, Kansas, 2011.

	Cover crop				Mean	
	Austrian winter pea		Winter wheat			
Crop in Rotation	0	101	0	101	0	101
	---kg ha^{-1}---					
	CIR x CC x NR†				CIR x NR	
Cont. forage sorghum	1380	1095	1955	2380	1668	1738
Rotated forage sorghum	1240	1163	3190	3343	2215	2253
Rotated corn	615	635	900	780	758	708
	CC x NR				NR	
	1078	964	2015	2068	1547	1566
	CIR x CC				CIR	
Cont. forage sorghum	1238bc		2168b		1703a‡	
Rotated forage sorghum	1201bc		3266a		2234a	
Rotated corn	625c		840c		733b	
	CC					
Mean	1021b		2091a			

	ANOVA		
	DF	F-Value	Pr > F
Crop in rotation (CIR)	2	10.34	0.0114
Cover crop (CC)	2	23.78	0.0009
CIR x CC	4	6.03	0.0218
Nitrogen rate (NR)	1	0.02	0.8992
CIR x NR	2	0.06	0.9442
CC x NR	2	0.80	0.3834
CIR x CC x NR	4	0.68	0.5194

† CIR = Crop in rotation, CC = Cover crop, NR = Nitrogen rate.

‡Within each set of means, values followed by the same letter are not significantly different ($\alpha = 0.05$).

Table 2.16. Cover crop dry matter (kg ha^{-1}) means and analysis of variance for crop in rotation, cover crop, and nitrogen rate in Tribune, Kansas, 2011.

	Cover crop					
	Austrian winter pea		Winter wheat		Mean	
Crop in Rotation	0	101	0	101	0	101
	-----kg ha^{-1}-----					
	CIR x CC x NR†				CIR x NR	
Cont. forage sorghum	2513	3065	3000	3008	2756	3036
Rotated forage sorghum	2658	2750	2935	3823	2796	3286
Rotated corn	555	580	547	585	545	583
	CC x NR				NR	
	1908	2132	2157	2472	2033	2302
	CIR x CC				CIR	
Cont. forage sorghum	2789		3004		2896a‡	
Rotated forage sorghum	2704		3379		3041a	
Rotated corn	568		560		564b	
	CC					
Mean	2020		2314			

ANOVA	DF	F-Value	Pr > F
Crop in rotation (CIR)	2	28.45	0.0009
Cover crop (CC)	2	0.96	0.3539
CIR x CC	4	0.45	0.6537
Nitrogen rate (NR)	1	1.42	0.2493
CIR x NR	2	0.33	0.7201
CC x NR	2	0.04	0.8416
CIR x CC x NR	4	0.74	0.4923

† CIR = Crop in rotation, CC = Cover crop, NR = Nitrogen rate.

‡Within each set of means, values followed by the same letter are not significantly different ($\alpha = 0.05$).

Table 2.17. Cover crop dry matter (kg ha^{-1}) means and analysis of variance for crop in rotation, and nitrogen rate in Manhattan, Kansas, 2012.

	Cover crop					
	Austrian winter pea		Winter wheat		Mean	
Crop in Rotation	0	101	0	101	0	101
	----------kg ha^{-1}----------					
	CIR x NR†				CIR	
Cont. forage sorghum	---‡	---	2178	1853	2015a§	
Rotated forage sorghum	---	---	1828	1735	1781a	
Rotated corn	---	---	1075	808	941b	
					NR	
Mean					1693	1465

	ANOVA		
	DF	F-Value	Pr > F
Crop in rotation (CIR)	2	12.64	0.0071
Nitrogen rate (NR)	1	3.95	0.0783
CIR x NR	2	0.37	0.7008

† CIR = Crop in rotation, NR = Nitrogen rate.
‡ Cover crop did not produce a stand in the specified growing year.
§ Within each set of means, values followed by the same letter are not significantly different ($\alpha = 0.05$).

Table 2.18. Cover crop dry matter (kg ha^{-1}) means and analysis of variance for crop in rotation, and nitrogen rate in Tribune, Kansas, 2012.

	Cover crop					
	Austrian winter pea		Winter wheat		Mean	
Crop in Rotation	0	101	0	101	0	101
	----------------kg ha^{-1}----------------					
	CIR x CC x NR†				CIR x NR	
Cont. forage sorghum	1508	1203	1315	1350	1411	1276
Rotated forage sorghum	1218	1165	1400	1438	1309	1301
Rotated corn	888	1045	1100	1110	994	1078
	CC x NR				NR	
	1204	1138	1272	1299	1238	1218
	CIR x CC				CIR	
Cont. forage sorghum	1355		1333		1344a‡	
Rotated forage sorghum	1191		1419		1305a	
Rotated corn	966		1105		1036b	
	CC					
Mean	1171b		1285a			

	ANOVA		
	DF	F-Value	Pr > F
Crop in rotation (CIR)	2	16.34	0.0037
Cover crop (CC)	2	5.71	0.0405
CIR x CC	4	2.33	0.1530
Nitrogen rate (NR)	1	0.17	0.6877
CIR x NR	2	1.75	0.2019
CC x NR	2	0.96	0.3390
CIR x CC x NR	4	2.15	0.1449

† CIR = Crop in rotation, CC = Cover crop, NR = Nitrogen rate.
‡Within each set of means, values followed by the same letter are not significantly different ($\alpha = 0.05$).

Table 2.19. Cover crop C:N means and analysis of variance for crop in rotation, and nitrogen rate in Manhattan, Kansas, 2011.

	Cover crop					
	Austrian winter pea		Winter wheat		Mean	
Crop in Rotation	0	101	0	101	0	101
	CIR x CC x NR†				CIR x NR	
Cont. forage sorghum	14:1	14:1	13:1	14:1	13:1	14:1
Rotated forage sorghum	14:1	14:1	12:1	12:1	13:1	13:1
Rotated corn	14:1	12:1	12:1	13:1	13:1	13:1
	CC x NR				NR	
	14:1	13:1	13:1	13:1	13:1	13:1
	CIR x CC				CIR	
Cont. forage sorghum	14:1		14:1		14:1	
Rotated forage sorghum	14:1		12:1		13:1	
Rotated corn	13:1		13:1		13:1	
	CC					
Mean	14:1		13:1			

	ANOVA		
	DF	F-Value	Pr > F
Crop in rotation (CIR)	2	0.89	0.4566
Cover crop (CC)	2	1.61	0.2359
CIR x CC	4	0.84	0.4617
Nitrogen rate (NR)	1	0.14	0.7139
CIR x NR	2	0.74	0.4917
CC x NR	2	0.98	0.3346
CIR x CC x NR	4	0.36	0.7015

† CIR = Crop in rotation, CC = Cover crop, NR = Nitrogen rate.

Table 2.20. Cover crop C:N means and analysis of variance for crop in rotation, and nitrogen rate in Tribune, Kansas, 2011.

	Cover crop					
	Austrian winter pea		Winter wheat		Mean	
Crop in Rotation	0	101	0	101	0	101
	CIR x CC x NR†				CIR x NR	
Cont. forage sorghum	11:1	10:1	27:1	20:1	19:1	15:1
Rotated forage sorghum	11:1	11:1	25:1	22:1	18:1	16:1
Rotated corn	13:1	15:1	14:1	12:1	13:1	13:1
	CC x NR				NR	
	12:1	12:1	18:1	22:1	17:1	15:1
	CIR x CC				CIR	
Cont. forage sorghum	10:1b‡		24:1a		17:1	
Rotated forage sorghum	11:1b		23:1a		17:1	
Rotated corn	14:1b		12:1b		13:1	
	CC					
Mean	12:1b		20:1a			

	ANOVA		
	DF	F-Value	Pr > F
Crop in rotation (CIR)	2	2.32	0.1788
Cover crop (CC)	2	21.88	0.0012
CIR x CC	4	7.23	0.0134
Nitrogen rate (NR)	1	2.37	0.1409
CIR x NR	2	1.48	0.2548
CC x NR	2	3.30	0.0858
CIR x CC x NR	4	0.30	0.7467

† CIR = Crop in rotation, CC = Cover crop, NR = Nitrogen rate.
‡Within each set of means, values followed by the same letter are not significantly different ($\alpha = 0.05$).

Table 2.21. Cover crop C:N means and analysis of variance for crop in rotation, and nitrogen rate in Manhattan, Kansas, 2012.

	Cover crop					
	Austrian winter pea		Winter wheat		Mean	
Crop in Rotation	0	101	0	101	0	101
	CIR x NR†				CIR	
Cont. forage sorghum	---‡	---	17:1	17:1	17:1	
Rotated forage sorghum	---	---	16:1	18:1	17:1	
Rotated corn	---	---	21:1	21:1	21:1	
					NR	
Mean					18:1	18:1

	ANOVA		
	DF	F-Value	Pr > F
Crop in rotation (CIR)	2	2.71	0.1453
Nitrogen rate (NR)	1	0.10	0.7568
CIR x NR	2	0.18	0.8353

† CIR = Crop in rotation, NR = Nitrogen rate.
‡ Cover crop did not produce a stand in the specified growing year.

Table 2.22. Cover crop C:N means and analysis of variance for crop in rotation, and nitrogen rate in Tribune, Kansas, 2012.

	Cover crop					
	Austrian winter pea		Winter wheat		Mean	
Crop in Rotation	0	101	0	101	0	101
	CIR x CC x NR†				CIR x NR	
Cont. forage sorghum	16:1	17:1	17:1	18:1	16:1	17:1
Rotated forage sorghum	16:1	18:1	17:1	17:1	16:1	18:1
Rotated corn	13:1	11:1	11:1	11:1	12:1	11:1
	CC x NR				NR	
	15:1	15:1	15:1	15:1	15:1	15:1
	CIR x CC				CIR	
Cont. forage sorghum	16:1		17:1		17:1	
Rotated forage sorghum	17:1		17:1		17:1	
Rotated corn	12:1		11:1		11:1	
	CC					
Mean	15:1		15:1			

	ANOVA		
	DF	F-Value	Pr > F
Crop in rotation (CIR)	2	2.52	0.1607
Cover crop (CC)	2	0.00	0.9485
CIR x CC	4	0.05	0.9479
Nitrogen rate (NR)	1	0.19	0.6720
CIR x NR	2	0.47	0.6325
CC x NR	2	0.13	0.7219
CIR x CC x NR	4	0.77	0.4761

† CIR = Crop in rotation, CC = Cover crop, NR = Nitrogen rate.

Table 2.23. Cover crop nitrogen uptake (kg ha^{-1}) means and analysis of variance for crop in rotation, and nitrogen rate in Manhattan, Kansas, 2011.

	Cover crop					
	Austrian winter pea		Winter wheat		Mean	
Crop in Rotation	0	101	0	101	0	101
	----------kg ha^{-1}----------					
	CIR x CC x NR†				CIR x NR	
Cont. forage sorghum	14	17	26	16	41	40
Rotated forage sorghum	28	28	72	93	50	61
Rotated corn	33	27	49	53	21	17
	CC x NR				NR	
	25	24	49	54	37	39
	CIR x CC				CIR	
Cont. forage sorghum	30		51		40ab‡	
Rotated forage sorghum	28		82		55a	
Rotated corn	16		22		19b	
	CC					
Mean	24b		52a			

ANOVA	DF	F-Value	Pr > F
Crop in rotation (CIR)	2	5.94	0.0378
Cover crop (CC)	2	11.45	0.0081
CIR x CC	4	3.10	0.0945
Nitrogen rate (NR)	1	0.14	0.7104
CIR x NR	2	0.88	0.4328
CC x NR	2	0.30	0.5897
CIR x CC x NR	4	0.19	0.3269

† CIR = Crop in rotation, CC = Cover crop, NR = Nitrogen rate.

‡Within each set of means, values followed by the same letter are not significantly different ($\alpha = 0.05$).

Table 2.24. Cover crop nitrogen uptake (kg ha^{-1}) means and analysis of variance for crop in rotation, and nitrogen rate in Tribune, Kansas, 2011.

	Cover crop					
	Austrian winter pea		Winter wheat		Mean	
Crop in Rotation	0	101	0	101	0	101
	--------kg ha^{-1}--------					
	CIR x CC x NR†				CIR x NR	
Cont. forage sorghum	18	18	16	19	62	84
Rotated forage sorghum	84	93	34	54	59	73
Rotated corn	82	114	42	54	17	19
	CC x NR				NR	
	61	75	31	43	46	59
	CIR x CC				CIR	
Cont. forage sorghum	98		48		73a‡	
Rotated forage sorghum	88		44		66a	
Rotated corn	18		18		18b	
	CC					
Mean	68a		37b			

	ANOVA		
	DF	F-Value	Pr > F
Crop in rotation (CIR)	2	12.73	0.0069
Cover crop (CC)	2	10.47	0.0102
CIR x CC	4	2.64	0.1253
Nitrogen rate (NR)	1	2.98	0.1015
CIR x NR	2	0.69	0.5136
CC x NR	2	0.01	0.9080
CIR x CC x NR	4	0.44	0.6532

† CIR = Crop in rotation, CC = Cover crop, NR = Nitrogen rate.
‡Within each set of means, values followed by the same letter are not significantly different ($\alpha = 0.05$).

Table 2.25. Cover crop nitrogen uptake (kg ha^{-1}) means and analysis of variance for crop in rotation, and nitrogen rate in Manhattan, Kansas, 2012.

	Cover crop					
	Austrian winter pea		Winter wheat		Mean	
Crop in Rotation	0	101	0	101	0	101
	kg ha^{-1}					
	CIR x NR†				CIR	
Cont. forage sorghum	---‡	---	49	43	46a§	
Rotated forage sorghum	---	---	43	38	41a	
Rotated corn	---	---	22	15	19b	
					NR	
Mean					38	32

	ANOVA		
	DF	F-Value	Pr > F
Crop in rotation (CIR)	2	8.53	0.0176
Nitrogen rate (NR)	1	4.18	0.0713
CIR x NR	2	0.01	0.9909

† CIR = Crop in rotation, NR = Nitrogen rate.
‡ Cover crop did not produce a stand in the specified growing year.
§ Within each set of means, values followed by the same letter are not significantly different ($\alpha = 0.05$).

Table 2.26. Cover crop nitrogen uptake (kg ha^{-1}) means and analysis of variance for crop in rotation, and nitrogen rate in Tribune, Kansas, 2012.

	Cover crop					
	Austrian winter pea		Winter wheat		Mean	
Crop in Rotation	0	101	0	101	0	101
	kg ha^{-1}					
	CIR x CC x NR†				CIR x NR	
Cont. forage sorghum	30	25	37	40	37	31
Rotated forage sorghum	40	28	35	34	33	33
Rotated corn	28	38	40	40	34	39
	CC x NR				NR	
	32	30	37	38	35	34
	CIR x CC				CIR	
Cont. forage sorghum	34		34		34	
Rotated forage sorghum	28		38		33	
Rotated corn	33		40		36	
	CC					
Mean	31		38			

ANOVA	DF	F-Value	Pr > F
Crop in rotation (CIR)	2	0.22	0.8101
Cover crop (CC)	2	2.00	0.1905
CIR x CC	4	0.47	0.6417
Nitrogen rate (NR)	1	0.11	0.7476
CIR x NR	2	2.69	0.0948
CC x NR	2	0.46	0.5071
CIR x CC x NR	4	2.76	0.0902

† CIR = Crop in rotation, CC = Cover crop, NR = Nitrogen rate.

Chapter 3 – Winter Cover Crop Alternatives for Winter Fallow Systems

Abstract

Because little information exists for cover crops in the Great Plains, this study compared legume and non-legume winter cover crops grown for three years (2010-2012) at two locations in Kansas: Manhattan in the northeastern part of the state and in Hutchinson, in the south central part of the state. Six cover crops were studied, three legumes, alfalfa (*Medicago sativa* L.), Austrian winter pea (*Pisum sativum var.* arvense *Poir.*), and red clover (*Trifolium pratense* L.), and three non-legumes, triticale (X *Triticosecale*; *Triticum* x *Secale*), winter oats (A*vena sativa* L.), and winter wheat (*Triticum aestivum* L.). The cover crops were planted at times corresponding to when they might be used in a corn (*Zea mays* L.) and forage sorghum [*Sorghum bicolor* (L.) Moench] rotation. However, they were not in rotation with these crops, but in putative rotations in which the cover crops were planted at times to match corn and forage sorghum harvest times and sampled at times to match corn and forage sorghum planting times in the following year. Dry matter and nitrogen and carbon content in the plants were determined. Cover crop carbon-to-nitrogen ratio (C:N) and nitrogen uptake were estimated. Putative crop rotation had the greatest effect on all cover crop factors (dry matter, C:N, nitrogen uptake). Triticale produced the greatest amount of dry matter and had the greatest nitrogen uptake. In 2011, alfalfa and red clover did not produce a stand as a result of late planting in both locations. In 2012, alfalfa, Austrian winter pea, and red clover did not produce a stand in either location. In addition, winter oats did not produce a stand in Manhattan of that year. The results of this study indicate that the putative crop rotation is a major determining factor in how productive a cover crop will be by controlling the length of the growing season of the cover crop. Triticale produced the greatest amount of dry matter and had the greatest nitrogen uptake because it is well adapted to Kansas climatic conditions, which may be a result of triticale being a crossbred of rye and wheat, which is also well adapted to Kansas.

Introduction

Cover crops traditionally have not been recommended for growth in semi-arid regions, because they use water that may result in limited soil water for the following crop (Unger et al., 2010). However, recent work suggests that cover crops might have a place in Kansas agriculture, especially in the eastern half of the state where rainfall is more plentiful. A gradient in precipitation exists across Kansas. It ranges from 38 to 51 cm per year in the western part of the state to 89 to 102 cm in the eastern part of the state. Mean annual precipitation in the middle part of the state ranges from 64 to 76 cm per year (Sophocleous, 1998). Even though cover crops do not produce a marketable product, they can potentially benefit rotations by increasing organic matter, maintaining surface residue (which reduces evaporation), reducing nitrate leaching, reducing soil erosion, suppressing weeds, and adding diversity to crop sequences (Roozeboom, 2013). Worldwide, cover crops are being used on small farms to maintain soil cover, increase organic matter, suppress weeds, and to add nitrogen (Florentín et al., 2011). If cover crops can be grown in Kansas, they, in particular, would provide protection against wind erosion, a big problem in the state.

In central and eastern Kansas in a wheat (*Triticum aestivum* L.) and row crop rotation, the 10 to 11 months between winter wheat harvest and planting of the next grain crop the following spring provide an opportunity to insert a cover crop (Roozeboom, 2013). Planting a cover crop immediately after wheat harvest can take advantage of the 20 to 30 cm of precipitation usually received in this part of the state from July through September. A number of cover crops have been evaluated in experiments in central and eastern Kansas. Winter non-legume cover crops have included canola (*Brassica napus* L.), barley (*Hordeum vulgare* L.), annual rye (*Secale cereale* L.), oats (*Avena sativa* L.), winter triticale (X *Triticosecale*; *Triticum* x *Secale*), and annual fescue [*Vulpia myuros* (L.) K.C. Gmel.]. Winter legumes studied have included winter pea (*Pisum* sp.) and yellow sweet clover (*Melilotus officinalis* Lam.). Yield of sorghum [*Sorghum bicolor* (L.) Moench] after these cover crops ranged from low (with winter triticale) to medium high (with canola and winter pea) (Roozeboom, 2013).

Cover crops also are being recommended for Kansas because they can increase crop intensity, which reduces evaporation from the soil. A basic principle of efficient crop water use is shifting as much of the total water use, or evapotranspiration, to crop transpiration and away from evaporation (Roozeboom et al., 2012c). Rotations that include only winter annuals or only summer annuals typically use water relatively inefficiently. Increasing crop diversity by rotating summer and winter annuals can effectively increase cropping intensity. Research with cover crops in Kansas has revealed that they can increase yield of the following crop. For example, the influence of two cover crops, late-maturing soybeans [*Glycine max* (L.) Merr.] and sunn hemp (*Crotalaria juncea* L.), in a wheat-sorghum rotation was investigated at Hesston, Kansas. Nitrogen was added to the soil at different rates ranging from 0 to 90 lb acre^{-1} (0 to 101 kg ha^{-1}). When averaged over nitrogen application rates, grain sorghum yielded 8.8 bushels per acre (560 kg ha^{-1}) and 14.9 bushels per acre (948 kg ha^{-1}) more when grown with late-maturing soybean and sunn hemp cover crops, respectively, compared with sorghum grown with no cover crop.

Crotalaria is a legume and grown in the southeastern states as a summer annual cover crop. The five species of crotalaria in the United States are *Crotalaria intermedia*, *C. mucronata*, *C. spectabilis*, *C. lanceolata*, and *C. juncea*. *Crotalaria juncea* is called sunn hemp in India where it is grown frequently as a fiber crop (Martin et al., 1976). Roozeboom et al. (2012c) showed that sunn hemp would be a beneficial cover crop planted before grain sorghum in Kansas.

Sorghum response to cover crops in a wheat-sorghum-soybean rotation at Manhattan, Kansas, was similar to that of the wheat-sorghum rotation at Hesston, Kansas (Roozeboom et al., 2012c). With less than 80 lb acre^{-1} (91 kg ha^{-1}) of fertilizer nitrogen, sorghum planted after cover crops with C:N ratios less than 25:1 (late-maturity soybeans, winter pea, and winter canola) yielded more than sorghum after no cover crop.

Experience in the Southeast of the USA has shown that non-legume cover crops, such as wheat, provide good surface cover during winter months and produce high levels of biomass that decomposes slowly due to its high C:N ratio (Blevins et al., 1994). Problems include depletion of soil water before the primary crop is planted and immobilization of nitrogen. Fortunately, in many cases the immobilization problem is overcome by the addition of nitrogen fertilizer. Cover crops, whether legumes or non-legumes, may be managed to avoid excessive depletion of soil moisture prior to planting the primary crop. This may require killing the cover crop at least one week before planting the primary crop. A legume cover crop provides biologically fixed nitrogen to the primary crop in addition to the benefits offered by non-legume cover crops (Blevins et al., 1994).

Annual cool-season grasses are used as cover crops in regions where moisture does not limit their use (Phillips et al., 1996). They reduce soil erosion, add organic matter to the soil, and retain soil moisture during the fall and winter. Usually legumes are preferred as cover crops because of their N_2-fixing ability, but annual cool-season grasses work well as a cover crop in concert with a warm-season crop. Cultivated oat is a cool-season grass, but it is not commonly used as forage (Stubbendieck and Jones, 1996). In Kansas, cool-season grasses include oat, winter wheat, and triticale.

In a review of cover crops, organizations with cover crop experience are given for the following regions: northeast, north central, southern, and western parts of the USA (Clark, 2007, p. 200-202). No contact is given for the Great Plains. More information is needed on cover crop growth in the Great Plains. Therefore, six cover crops were studied for two years (2011 and 2012) at two locations in Kansas: Manhattan in the northeastern part of the state and in Hutchinson in the central part of the state. The six cover crops were three legumes and three non-legumes. The legumes were alfalfa (*Medicago sativa* L.), Austrian winter pea (*Pisum sativum* var. *arvense* Poir.), and red clover (*Trifolium pratense* L.), and the non-legumes were triticale (X *Triticosecale*; *Triticum* x *Secale*), oat (*Avena sativa* L.), and winter wheat (*Triticum aestivum* L.). At harvest, dry matter was determined along with the carbon and nitrogen percentages in the leaves to calculate the C:N ratio and nitrogen uptake. The cover crops were not in a rotation with a primary crop, but were planted into soils that had been fallow for a year.

Materials and Methods

Field studies were conducted from 2009 to 2012 at Ashland Bottoms Research farm in Manhattan, KS (39°8′39.61″N, 96°37′44.12″W) and the South Central Experiment Field near Hutchinson, KS (37°96′22.63″N, 98°12′32.37″W). In Manhattan, the experiment was conducted on a Bismarckgrove Kimo complex. This is a complex of two different soils that cannot be distinguished. The Bismarckgrove series is classified as a fine-silty, mixed, superactive, mesic Fluventic Hapludolls. In the 0 – 18 cm depth, the series is a silt loam and in the 18 – 51 cm depth, the soil is a silty clay loam. The Kimo series is classified as a clayey over loamy, smectic, mesic Fluvaquentic Hapludolls. In the 0 – 18 cm depth, the series is a silty clay loam, and in the 18 – 38 cm depth, the soil is a silty clay. In Hutchinson, experiments were conducted on a Funmar-Tarver loam (fine-loamy, mixed, superactive, mesic Pachic Argiustolls). A randomized complete block design split-plot with four replications was used at both locations, which were all in no-till production. Areas that were in fertilizer-intensive no-till cropping systems in the past were selected to be able to determine nitrogen uptake. Six cover crops were grown in the study. Three were legumes: red clover, Austrian winter pea, and alfalfa. Three were non-legumes: winter wheat, triticale, and winter oats. The cover crops were planted at rates set forth by Kansas Rural Center Sustainable Agriculture Management Guide and Kansas State University Research and Extension production guides. The planting rates for each cover crop were as follows: red clover (7,560,000 seeds hectare^{-1}), Austrian winter pea (133,633 seeds hectare^{-1}), alfalfa (7,426,500 seeds hectare^{-1}), winter wheat (1,856,435 seeds hectare^{-1}), triticale (1,856,435 seeds hectare^{-1}), and winter oats (2,592,000 seeds hectare^{-1}). Cover crops were planted in 6 m x 12 m plots within each replication. These plots were then split into two 3 m x 12 m plots that were planted and sampled at respective corn and forage sorghum planting times. Even though the cover crops were not in rotation with corn (*Zea mays* L.) and forage sorghum [*Sorghum bicolor* (L.) Moench], they were planted and harvested putatively to mimic the harvest and planting dates of these two crops. For the plots in putative rotation with forage sorghum, results represent the performance of cover crops planted following the typical forage sorghum harvest date, and they were sampled at the typical forage sorghum planting time in each location. Putative corn results represent the performance cover crops planted following the typical harvest date of corn, and they were sampled at the typical corn planting time in each location. Table 3.1 gives the rainfall and temperature during the three years of the study in Hutchinson. For Manhattan, this information has been presented in Chapter 2 (Table 2.1).

As noted, cover crops were sampled in the spring at corn and forage sorghum planting times (Table 3.2 and 3.3). Cover crops were sampled from a 1 m^2 area from a random location within each plot to determine dry matter production. Dry matter content was determined by drying the plants at 65^{o}C for 120 hours. After sampling, plots were terminated with glyphosate (isopropylamine salt of N-phosphonomethyl glycine 56) (1.5 kg a.e. ha^{-1}) and 2,4-D (2,4-dichlorophenoxy acetic acid) (0.90 kg a.i. ha^{-1}). Cover crop samples were analyzed for nitrogen percent and carbon percent. Potential amount of nitrogen taken up by the cover crop was determined using the following equation from Sarrantonio (1994) and Clark (2007):

Cover crop nitrogen uptake (kg ha^{-1}) = (Cover crop yield (kg ha^{-1})) x (Nitrogen percent (%))/(100).

Significance of main effect differences and of their interactions was determined using the PROC GLIMMIX procedure (SAS Institute, 2013) with putative crop and cover crop as fixed effects and with replications as a random effect. Mean separations were performed for the treatment and interaction effects if the F-tests for treatment effects were significant at the $\alpha = 0.05$ level.

Results and Discussion

Cover crop dry matter

Putative crop and cover crop treatment factors had a significant effect on cover crop dry matter production in Manhattan and Hutchinson in 2010 (Table 3.4). Cover crops sampled at putative corn planting time produced less dry matter than cover crops sampled at putative forage sorghum planting time. This is probably because cover crops sampled at putative forage sorghum planting time were allowed additional time to grow after cover crops sampled and terminated at putative corn planting time. This agrees with Baldwin and Creamer (2009) that delaying cover crop kill from April to May increased cover crop yield by as much as 160%. In Manhattan in 2010, the putative crop by cover crop interaction was significant because the magnitude of the advantage for cover crops in the putative forage sorghum rotation depended on cover crop, with triticale having the greatest increase (Table 3.4). In 2010 at Hutchinson the small grain cover crops (triticale, winter oats, and winter wheat) and Austrian winter pea all produced nearly twice as much dry matter as alfalfa and red clover (Table 3.4).

In 2011, at both locations, alfalfa and red clover did not establish a stand as a result of late planting date (Table 3.5). Alfalfa, Austrian winter pea, red clover, and winter oats did not establish a stand in Manhattan in 2012 as a result of late planting and a dry seed bed (Table 3.6). Alfalfa, Austrian winter pea, and red clover did not establish a stand in Hutchinson in 2012 as a result of late planting and a dry seed bed (Table 3.6). Winter wheat produced the greatest dry matter in Hutchinson 2011 (Table 3.5). The triticale cover crop treatment produced more dry matter than winter wheat in Manhattan in 2012 (Table 3.6). In Hutchinson in 2012, triticale and winter oats produced more dry matter than winter wheat (Table 3.6).

Cover crop carbon-to-nitrogen ration (C:N)

In Manhattan in 2010, C:N was greater for winter wheat and triticale in the putative forage sorghum rotation (Table 3.7). For alfalfa, C:N was less in the putative forage sorghum rotation, but rotation had no effect on C:N for the other cover crops (Table 3.7). In Hutchinson in 2010, C:N was greater in the putative corn rotation. Winter oats had a greater C:N than all other cover crops at that location and year (Table 3.7).

Cover crop C:N was greater with cover crops that were sampled at putative forage sorghum planting time at Manhattan and Hutchinson in 2011 and 2012 (Tables 3.8 and 3.9). Cover crop C:N was greater for winter wheat and triticale than for Austrian winter pea in Manhattan in 2011. In Hutchinson in 2011 winter wheat and winter oats had greater C:N compared to Austrian winter pea (Table 3.8) In Hutchinson in 2012, winter wheat and triticale had lower C:N than winter oats (Table 3.9).

Cover crop nitrogen uptake

Cover crop nitrogen uptake was greater in the putative forage sorghum crop rotation in both locations in 2010 (Table 3.10). In Manhattan the increase in the putative forage sorghum rotation was greatest for triticale. Nitrogen uptake was greatest for triticale in Manhattan in 2010 and for Austrian winter pea, triticale, and winter wheat in Hutchinson in 2010 (Table 3.10). In 2011 neither putative crop rotation nor cover crop affected nitrogen uptake at either location (Table 3.11). In Manhattan in 2012 nitrogen uptake was greater in the putative corn rotation compared to the putative forage sorghum rotation because the putative corn rotation avoided more of the severe drought conditions that year (Table 3.12). In Hutchinson in 2012 winter oats took up more nitrogen than triticale, which took up more nitrogen than winter wheat. Cover crops sampled at putative forage sorghum planting time took up the most nitrogen. In both locations in 2010 and in Manhattan in 2012, triticale took up the most nitrogen.

Conclusions

Putative crop rotation had the greatest effect on all cover crop factors (dry matter, C:N, and nitrogen uptake). In 2011, alfalfa, and red clover did not produce a stand as a result of late planting at both locations. In 2012, alfalfa, Austrian winter pea, and red clover did not produce a stand at either location. In addition, winter oats did not produce a stand in Manhattan of that year. The results of this study indicate that the putative crop rotation is a major determining factor in how productive a cover crop will be by controlling the length of the growing season of the cover crop. In general, triticale produced the greatest amount of dry matter and had the greatest nitrogen uptake because it is well adapted to Kansas climatic conditions, which may be a result of triticale being a hybrid of rye and wheat, which are also both well adapted to Kansas.

Tables

Table 3.1. Total monthly precipitation and average monthly temperatures at Hutchinson, KS, during the study (2009, 2010, 2011, and 2012).

	2009		2010		2011		2012	
Month	Ppt.	Temp.	Ppt.	Temp.	Ppt.	Temp.	Ppt.	Temp.
	mm	^{o}C	mm	^{o}C	mm	^{o}C	mm	^{o}C
Jan.	1	-1.0	12	-2.8	5	-2.7	2	2.2
Feb.	6	4.5	26	-1.2	20	-0.8	72	2.8
Mar.	45	6.3	33	6.6	23	7.2	67	13.3
Apr.	151	11.1	47	14.6	10	13.6	33	16.0
May	99	17.3	138	17.4	48	18.8	51	21.8
June	116	24.6	213	26.6	58	27.3	87	25.6
July	52	24.7	166	27.6	5	32.1	15	30.2
Aug.	105	23.6	121	27.3	84	28.8	87	25.4
Sept.	172	18.7	33	22.7	18	19.4	31	21.1
Oct.	81	9.7	13	15.5	42	14.6	7	12.6
Nov.	15	9.3	95	6.6	74	6.7	5	7.6
Dec.	10	-2.8	2	0.2	65	1.6	3	1.1

Table 3.2. Planting, sampling, and harvest dates of the cover crops rotated within putative corn and forage sorghum planting times for Manhattan, KS.

		Year					
		2009		2010		2011	
Crop	Cover crop	Planting date	Sampling date	Planting date	Sampling date	Planting date	Sampling date
Corn	Alfalfa	4 October	25 April 2010	6 October	21 April 2011	14 October	23 April 2012
	Austrian winter pea	4 October	25 April 2010	6 October	21 April 2011	14 October	23 April 2012
	Red clover	4 October	25 April 2010	6 October	21 April 2011	14 October	23 April 2012
	Triticale	4 October	25 April 2010	6 October	21 April 2011	14 October	23 April 2012
	Winter oats	4 October	25 April 2010	6 October	21 April 2011	14 October	23 April 2012
	Winter wheat	4 October	25 April 2010	6 October	21 April 2011	14 October	23 April 2012
Forage Sorghum	Alfalfa	13 November	14 May 2010	16 November	12 May 2011	13 November	16 May 2012
	Austrian winter pea	13 November	14 May 2010	16 November	12 May 2011	13 November	16 May 2012
	Red Clover	13 November	14 May 2010	16 November	12 May 2011	13 November	16 May 2012
	Triticale	13 November	14 May 2010	16 November	12 May 2011	13 November	16 May 2012
	Winter Oats	13 November	14 May 2010	16 November	12 May 2011	13 November	16 May 2012
	Winter wheat	13 November	14 May 2010	16 November	12 May 2011	13 November	16 May 2012

Table 3.3. Planting, sampling, and harvest dates of the cover crops rotated within putative corn and forage sorghum planting times in Hutchinson, KS.

		Year					
		2009		2010		2011	
Crop	Cover crop	Planting date	Sampling date	Planting date	Sampling date	Planting date	Sampling date
Corn	Alfalfa	11 October	25 April 2010	9 October	21 April 2011	21 October	23 April 2012
	Austrian winter pea	11 October	25 April 2010	6 October	21 April 2011	14 October	23 April 2012
	Red clover	11 October	25 April 2010	6 October	21 April 2011	14 October	23 April 2012
	Triticale	11 October	25 April 2010	6 October	21 April 2011	14 October	23 April 2012
	Winter oats	11 October	25 April 2010	6 October	21 April 2011	14 October	23 April 2012
	Winter wheat	11 October	25 April 2010	6 October	21 April 2011	14 October	23 April 2012
Forage Sorghum	Alfalfa	21 November	23 May 2010	19 November	15 May 2011	20 November	18 May 2012
	Austrian winter pea	21 November	23 May 2010	19 November	15 May 2011	20 November	18 May 2012
	Red Clover	21 November	23 May 2010	19 November	15 May 2011	20 November	18 May 2012
	Triticale	21 November	23 May 2010	19 November	15 May 2011	20 November	18 May 2012
	Winter Oats	21 November	23 May 2010	19 November	15 May 2011	20 November	18 May 2012
	Winter wheat	21 November	23 May 2010	19 November	15 May 2011	20 November	18 May 2012

Table 3.4. Cover crop dry matter (kg ha^{-1}) and analysis of variance of six cover crops planted and sampled at putative corn and forage sorghum harvest and planting times in Manhattan and Hutchinson, Kansas, 2010.

Factor	Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat	Putative crop mean
	Cover crop						
	kg ha^{-1}						
Manhattan 2010	PC x CC†						PC
Putative corn	1763ef‡	865f	2074ef	1969ef	1813ef	2569de	1842b
Putative forage sorghum	7150c	3800d	8050bc	12488a	8800b	7138c	7904a
Cover crop means	4456b	2332c	5062b	7228a	5306b	4853b	
Hutchinson 2010	PC x CC						PC
Putative corn	1181	1443	858	1769	1611	1236	1499b
Putative forage sorghum	1421	2594	1375	2995	3106	2171	2542a
Cover crop means	1301b	2698a	1116b	2383a	2359a	2267a	

Source of Variation	DF	F Value	Pr > F
	ANOVA		
Manhattan 2010			
Putative crop (PC)	1	585.08	0.0002
Cover crop (CC)	5	26.32	<0.0001
PC x CC	5	17.61	<0.0001
Hutchinson 2010			
Putative crop (PC)	1	43.95	0.0070
Cover crop (CC)	5	11.71	<0.0001
PC x CC	5	2.04	0.1056

†PC = Putative crop rotation, CC = Cover crop.
‡Within each set of means, values followed by the same letter are not significantly different (α = 0.05).

Table 3.5. Cover crop dry matter (kg ha^{-1}) and analysis of variance of six cover crops planted and sampled at putative corn and forage sorghum harvest and planting times in Manhattan and Hutchinson, Kansas, 2011.

Factor	Cover crop: Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat	Putative crop mean
	----------	----------	----------	kg ha^{-1}	----------	----------	----------
Manhattan 2010			PC x CC†				PC
Putative corn	---‡	1561	---	654	836	2118	1292
Putative forage sorghum	---	1251	---	3303	2674	2519	2437
Cover crop means	---	1406	---	1978	2318	1755	
Hutchinson 2010			PC x CC				PC
Putative corn	---	696d§	---	935d	910d	1120d	915b
Putative forage sorghum	---	1074d	---	3124b	2364c	3888a	2612a
Cover crop means	---	855c	---	2029b	1637b	2504a	

Source of Variation	ANOVA: DF	F Value	Pr > F
Manhattan 2010			
Putative crop (PC)	1	6.74	0.0807
Cover crop (CC)	3	0.76	0.5334
PC x CC	3	2.32	0.1097
Hutchinson 2010			
Putative crop (PC)	1	125.52	0.0015
Cover crop (CC)	3	20.44	<0.0001
PC x CC	3	11.58	0.0002

†PC = Putative crop rotation, CC = Cover crop.

‡ Cover crop did not produce a stand in the specified growing year.

§ Within each set of means, values followed by the same letter are not significantly different ($\alpha = 0.05$).

Table 3.6. Cover crop dry matter (kg ha^{-1}) and analysis of variance of six cover crops planted and sampled at putative corn and forage sorghum harvest and planting times in Manhattan and Hutchinson, Kansas, 2012.

Factor	Cover crop: Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat	Putative crop mean
	kg ha^{-1}						
Manhattan 2010	PC x CC†						PC
Putative corn	---‡	---	---	1670	---	1119	1394
Putative forage sorghum	---	---	---	1471	---	892	1160
Cover crop means	---	---	---	1581a§	---	974b	
Hutchinson 2010	PC x CC						PC
Putative corn	---	---	---	1491	1475	829	1265b
Putative forage sorghum	---	---	---	2313	2470	1271	2018a
Cover crop means	---	---	---	1902a	1973a	1050b	

Source of Variation	DF	F Value	Pr > F
Manhattan 2010			
Putative crop (PC)	1	1.67	0.2872
Cover crop (CC)	1	11.18	0.0156
PC x CC	1	0.09	0.7696
Hutchinson 2010			
Putative crop (PC)	1	43.95	0.0102
Cover crop (CC)	2	11.71	0.0001
PC x CC	2	2.04	0.2470

†PC = Putative crop rotation, CC = Cover crop.

‡ Cover crop did not produce a stand in the specified growing year.

§ Within each set of means, values followed by the same letter are not significantly different ($\alpha = 0.05$).

Table 3.7. Cover crop carbon-to-nitrogen ratio (C:N) and analysis of variance of six cover crops planted and sampled at putative corn and forage sorghum harvest and planting times in Manhattan and Hutchinson, Kansas, 2010.

	Cover crop						
Factor	Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat	Putative crop mean
	--------------------	--------------------	--------------------	kg ha^{-1}	--------------------	--------------------	--------------------
Manhattan 2010	PC x CC†						PC
Putative corn	19:1cd‡	17:1de	18:1cde	18:1cd	24:1ab	20:1c	19:1
Putative forage sorghum	14:1f	17:1cde	16:1ef	23:1b	26:1a	22:1b	20:1
Cover crop means	16:1c	17:1c	17:1c	20:1b	25:1a	21:1b	
Hutchinson 2010	PC x CC						PC
Putative corn	19:1	20:1	19:1	18:1	25:1	18:1	20:1a
Putative forage sorghum	15:1	15:1	14:1	14:1	26:1	16:1	16:1b
Cover crop means	17:1b	17:1b	17:1b	16:1b	24:1a	17:1b	

Source of Variation	ANOVA		
Manhattan 2010	DF	F Value	Pr > F
Putative crop (PC)	1	0.39	0.5769
Cover crop (CC)	5	29.39	<0.0001
PC x CC	5	7.42	0.0001
Hutchinson 2010			
Putative crop (PC)	1	43.95	0.0056
Cover crop (CC)	5	11.71	<0.0001
PC x CC	5	2.04	0.5791

†PC = Putative crop rotation, CC = Cover crop.

‡Within each set of means, values followed by the same letter are not significantly different (α = 0.05).

Table 3.8. Cover crop carbon-to-nitrogen ratio (C:N) and analysis of variance of six cover crops planted and sampled at putative corn and forage sorghum harvest and planting times in Manhattan and Hutchinson, Kansas, 2011.

	Cover crop						
Factor	Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat	Putative crop mean
	----------------------	-------------kg ha^{-1}	----------------------				
Manhattan 2010	PC x CC†						PC
Putative corn	---‡	13:1c§	---	11:1c	13:1c	14:1c	13:1b
Putative forage sorghum	---	19:1bc	---	33:1a	23:1b	40:1a	29:1a
Cover crop means	---	16:1c	---	22:1ab	18:1bc	27:1a	
Hutchinson 2010	PC x CC						PC
Putative corn	---	12:1d	---	13:1d	18:1c	18:1c	15:1b
Putative forage sorghum	---	17:1c	---	31:1b	32:1b	36:1a	29:1a
Cover crop means	---	15:1c	---	22:1b	25:1a	27:1a	
Source of Variation	ANOVA						
Manhattan 2010	DF	F Value	Pr > F				
Putative crop (PC)	1	70.67	0.0035				
Cover crop (CC)	3	6.64	0.0033				
PC x CC	3	5.81	0.0058				
Hutchinson 2010							
Putative crop (PC)	1	278.32	0.0005				
Cover crop (CC)	3	42.25	<0.0001				
PC x CC	3	14.34	<0.0001				

†PC = Putative crop rotation, CC = Cover crop.
‡ Cover crop did not produce a stand in the specified growing year.
§ Within each set of means, values followed by the same letter are not significantly different (α = 0.05).

Table 3.9. Cover crop carbon-to-nitrogen ratio (C:N) and analysis of variance of six cover crops planted and sampled at putative corn and forage sorghum harvest and planting times in Manhattan and Hutchinson, Kansas, 2012.

	Cover crop						
Factor	Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat	Putative crop mean
	----------kg ha^{-1}----------						
Manhattan 2010	PC x CC†						PC
Putative corn	---‡	---	---	13:1	---	14:1	14:1b§
Putative forage sorghum	---	---	---	25:1	---	26:1	26:1a
Cover crop means	---	---	---	19:1	---	20:1	
Hutchinson 2010	PC x CC						PC
Putative corn	---	---	---	25:1	20:1	26:1	24:1b
Putative forage sorghum	---	---	---	39:1	26:1	44:1	36:1a
Cover crop means	---	---	---	16:1a	24:1b	17:1a	

Source of Variation	ANOVA		
Manhattan 2010	DF	F Value	Pr > F
Putative crop (PC)	1	117.18	0.0017
Cover crop (CC)	1	0.76	0.4164
PC x CC	1	0.10	0.7572
Hutchinson 2010			
Putative crop (PC)	1	38.45	0.0085
Cover crop (CC)	2	11.89	0.0014
PC x CC	2	2.61	0.1147

†PC = Putative crop rotation, CC = Cover crop.
‡ Cover crop did not produce a stand in the specified growing year.
§ Within each set of means, values followed by the same letter are not significantly different ($\alpha = 0.05$).

Table 3.10. Cover crop nitrogen uptake (kg ha^{-1}) and analysis of variance of six cover crops planted and sampled at putative corn and forage sorghum harvest and planting times in Manhattan and Hutchinson, Kansas, 2010.

Factor	Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat	Putative crop mean
	Cover crop						
	----kg ha^{-1}----						
Manhattan 2010	PC x CC†						PC
Putative corn	32f‡	15f	37f	35f	42f	27f	31b
Putative forage sorghum	182b	74e	162bc	229a	133cd	120d	150a
Cover crop means	107b	45d	99bc	132a	80c	82c	
Hutchinson 2010	PC x CC						PC
Putative corn	22	37	16	32	22	33	27b
Putative forage sorghum	37	85	33	75	56	69	59a
Cover crop means	29cd	61a	24d	54a	39bc	51ab	

Source of Variation	DF	F Value	Pr > F
	ANOVA		
Manhattan 2010			
Putative crop (PC)	1	356.18	0.0003
Cover crop (CC)	5	17.06	<0.0001
PC x CC	5	11.84	<0.0001
Hutchinson 2010			
Putative crop (PC)	1	56.62	0.0049
Cover crop (CC)	5	7.70	0.0001
PC x CC	5	1.74	0.1617

†PC = Putative crop rotation, CC = Cover crop.
‡Within each set of means, values followed by the same letter are not significantly different (α = 0.05).

Table 3.11. Cover crop nitrogen uptake (kg ha^{-1}) and analysis of variance of six cover crops planted and sampled at putative corn and forage sorghum harvest and planting times in Manhattan and Hutchinson, Kansas, 2011.

Factor	Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat	Putative crop mean
	Cover crop						
	kg ha^{-1}						
Manhattan 2010	PC x CC†						PC
Putative corn	---‡	40	---	22	18	35	29
Putative forage sorghum	---	27	---	27	26	19	24
Cover crop means	---	33	---	25	22	27	
Hutchinson 2010	PC x CC						PC
Putative corn	---	21	---	24	19	22	22
Putative forage sorghum	---	24	---	27	20	32	26
Cover crop means	---	23	---	25	19	27	

Source of Variation	ANOVA		
Manhattan 2010	DF	F Value	Pr > F
Putative crop (PC)	1	0.50	0.5322
Cover crop (CC)	3	0.69	0.5726
PC x CC	3	1.04	0.3968
Hutchinson 2010			
Putative crop (PC)	1	2.90	0.1874
Cover crop (CC)	3	2.21	0.1218
PC x CC	3	0.64	0.5998

†PC = Putative crop rotation, CC = Cover crop.

‡ Cover crop did not produce a stand in the specified growing year.

Table 3.12. Cover crop nitrogen uptake (kg ha^{-1}) and analysis of variance of six cover crops planted and sampled at putative corn and forage sorghum harvest and planting times in Manhattan and Hutchinson, Kansas, 2012.

	Cover crop						
Factor	Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat	Putative crop mean
	kg ha^{-1}						
Manhattan 2010	PC x CC†						PC
Putative corn	---‡	---	---	51	---	31	41a
Putative forage sorghum	---	---	---	23	---	12	18b
Cover crop means	---	---	---	37a§	---	21b	
Hutchinson 2010	PC x CC						PC
Putative corn	---	---	---	23	30	12	22
Putative forage sorghum	---	---	---	24	38	10	24
Cover crop means	---	---	---	24b	34a	11c	

Source of Variation	ANOVA		
Manhattan 2010	DF	F Value	Pr > F
Putative crop (PC)	1	29.91	0.0017
Cover crop (CC)	1	13.07	0.0112
PC x CC	1	1.04	0.3477
Hutchinson 2010			
Putative crop (PC)	1	0.55	0.5130
Cover crop (CC)	2	17.32	0.0003
PC x CC	2	0.83	0.4605

†PC = Putative crop rotation, CC = Cover crop.

‡ Cover crop did not produce a stand in the specified growing year.

§ Within each set of means, values followed by the same letter are not significantly different (α = 0.05).

Chapter 4 – General Comments and Future Research

The most common uses of cover crops in Kansas are for soil cover during a season where there is no crop grown to protect the soil. Implementing cover crops works best during a season where a cash crop is not grown. In a no-till crop rotation, cover crops add a soil cover in addition to maintaining harvested cash crop residues. They also possess the ability to cycle nutrients, especially nitrogen, which has the highest potential to be lost. In addition to these advantages, cover crops can out-compete weeds in the spring to limit their growth to a point where they would not interfere with the succeeding crop in the rotation (Clark, 2007). Growers also need to be aware of the potential disadvantages that come with adding cover crops into their rotations. With moisture being a limitation to Kansas farmers, adding cover crops may remove moisture, which may be needed by summer annual crops (Holman, 2012). Cover crops also present the disadvantage of potentially interfering with the production of an annual crop in that rotation (Bergtold and Maddy, 2008), such as Austrian winter pea which produces bountiful biomass that can quickly regrow from mechanical termination (mowing, disking) and chemical termination (Clark, 2007).

The results of this study indicate that non-legume cover crops are a good choice, when planted early. But, as Holman (2012) concluded, legume cover crops are not productive, especially Austrian winter pea, because they suffer from winterkill. Both legume and non-legume cover crops can produce vast biomass amounts, as their continued growth and regrowth begin in the spring of the year following their fall or winter planting.

In the 2011 and 2012 winter cover crop growing seasons, when droughty conditions occurred, non-legume cover crops were able to emerge and produce biomass better than legumes, which in both locations did not even produce a stand in 2012. Surprisingly, winter oats were able to produce a stand in the 2012 growing season, even though Shroyer et al. (1996) suggested not planting oats in winter throughout Kansas. The results of this dissertation suggest that oats can grow as a winter cover crop in droughty years. With every other cover crop measurement dependent on cover crop biomass production, it was apparent that the majority of measurements corresponded with winter cover crop biomass. As expected, the C:N ratios of non-legumes were higher than those of legumes, on average, while the same was observed with cover crop nitrogen uptake.

As with other research subjects and studies, future research is in order. For this study, however, future research should be in finding and testing more winter cover crops in corn and sorghum rotations in the Great Plains. Legumes and non-legumes should be tested to determine which winter cover crops would fit the needs of growers in this region. More research is needed on the timing of nitrogen release from non-legume cover crops. Current and future research on cover crop production considers various subjects. The success of finding ideal cover crops for this region is highly dependent on growers' choices and goals, and how well these fit into specific climatic and geographic factors of the region where cover crops are to be grown.

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Appendix A – Chapter 2 Soils Data

This section of this appendix contains text and data in reference to soil samples taken in conjunction to the study mentioned in the second chapter, which were not included in the chapter text. Soil sampling was done at both Manhattan and Tribune in the fall and spring seasons of 2011 and 2012 at the time of corn and forage sorghum harvest and planting times, which were at the same times at which cover crops were terminated. Samples taken in the fall and spring seasons were used to estimate the change in nitrogen and carbon. The samples were taken to a depth of 30 cm and were analyzed at the Kansas State University Soil Testing Laboratory for percent nitrogen and percent carbon.

Soils Data Tables

Table A.1. Soil nitrogen percent and analysis of variance of soil samples collected at the planting times of corn and forage sorghum under rotations with two cover crops and a control of no cover crop with two levels of nitrogen in the spring of 2011 in Manhattan, Kansas.

	Cover crop					
	Austrian winter pea		Winter wheat		Fallow	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101
	------%					------
Corn	0.09ab†	0.09ab	0.09ab	0.09ab	0.09a	0.08abc
Forage Sorghum	0.06bc	0.06c	0.07abc	0.07abc	0.07abc	0.07abc

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR)‡	1	15.31	0.0002
Cover crop (CC)	2	0.32	0.7246
CIR x CC	2	0.32	0.7246
Nitrogen rate (NR)	1	0.40	0.5305
CIR x NR	1	0.21	0.6453
CC x NR	2	0.14	0.8667
CIR x CC x NR	2	0.09	0.9170

†Within each set of means, values followed by the same letter are not significantly different ($\alpha = 0.05$).
‡CIR = Crop in rotation, CC = Cover crop, NR = Nitrogen rate.

Table A.2. Soil nitrogen percent and analysis of variance of soil samples collected at the planting times of corn and forage sorghum under rotations with two cover crops and a control of no cover crop with two levels of nitrogen in the spring of 2011 in Tribune, Kansas.

	Cover crop					
	Austrian winter pea		Winter wheat		Fallow	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101
	--------------------	--------------------	---------%	---------	--------------------	--------------------
Corn	0.14ab†	0.14a	0.13abcd	0.13abcd	0.14abcd	0.14abc
Forage Sorghum	0.12d	0.13cd	0.13bcd	0.12d	0.13cd	0.13cd

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR)‡	1	20.34	<0.0001
Cover crop (CC)	2	0.85	0.4317
CIR x CC	2	1.57	0.2165
Nitrogen rate (NR)	1	0.01	0.9298
CIR x NR	1	0.38	0.5383
CC x NR	2	0.38	0.6834
CIR x CC x NR	2	0.10	0.9035

†Within each set of means, values followed by the same letter are not significantly different (α = 0.05).
‡CIR = Crop in rotation, CC = Cover crop, NR = Nitrogen rate.

Table A.3. Soil nitrogen percent and analysis of variance of soil samples collected at the planting times of corn and forage sorghum under rotations with two cover crops and a control of no cover crop with two levels of nitrogen in the spring of 2012 in Manhattan, Kansas.

	Cover crop					
	Austrian winter pea		Winter wheat		Fallow	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101
	---------------------------------------		-------------%	-----------------	-------------------------------------	
Corn	---†	---	0.09a‡	0.08a	0.09a	0.09a
Forage Sorghum	---	---	0.08a	0.08a	0.08a	0.09a

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR)§	1	0.31	0.5813
Cover crop (CC)	2	459.81	<0.0001
CIR x CC	2	0.65	0.5276
Nitrogen rate (NR)	1	0.01	0.9371
CIR x NR	1	0.16	0.6934
CC x NR	2	0.38	0.6835
CIR x CC x NR	2	0.08	0.9217

†Cover crop did not produce a stand in the specified growing year.
‡Within each set of means, values followed by the same letter are not significantly different (α = 0.05)
§CIR = Crop in rotation, CC = Cover crop, NR = Nitrogen rate.

Table A.4. Soil nitrogen percent and analysis of variance of soil samples collected at the planting times of corn and forage sorghum under rotations with two cover crops and a control of no cover crop with two levels of nitrogen in the spring of 2012 in Tribune, Kansas.

	Cover crop					
	Austrian winter pea		Winter wheat		Fallow	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101
	--------------------	--------------------	--------------------	%	--------------------	--------------------
Corn	0.14a†	0.17a	0.17a	0.14a	0.16a	0.15a
Forage Sorghum	0.18a	0.17a	0.15a	0.17a	0.16a	0.15a

ANOVA

Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR)‡	1	0.35	0.5553
Cover crop (CC)	2	0.41	0.6625
CIR x CC	2	0.49	0.6129
Nitrogen rate (NR)	1	0.04	0.8340
CIR x NR	1	0.03	0.8638
CC x NR	2	0.22	0.8022
CIR x CC x NR	2	1.35	0.2675

†Within each set of means, values followed by the same letter are not significantly different (α = 0.05).
‡CIR = Crop in rotation, CC = Cover crop, NR = Nitrogen rate.

Table A.5. Soil carbon percent and analysis of variance of soil samples collected at the planting times of corn and forage sorghum under rotations with two cover crops and a control of no cover crop with two levels of nitrogen in the spring of 2011 in Manhattan, Kansas.

	Cover crop					
	Austrian winter pea		Winter wheat		Fallow	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101
	----------------	----------------	----------------	%	----------------	----------------
Corn	0.66a†	0.62a	0.65a	0.60a	0.59a	0.62a
Forage Sorghum	0.74a	0.70a	0.83a	0.77a	0.82a	0.77a

ANOVA

Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR)‡	1	8.97	0.0041
Cover crop (CC)	2	0.16	0.8563
CIR x CC	2	0.52	0.5951
Nitrogen rate (NR)	1	0.52	0.4738
CIR x NR	1	0.09	0.7676
CC x NR	2	0.07	0.9336
CIR x CC x NR	2	0.06	0.9380

†Within each set of means, values followed by the same letter are not significantly different ($\alpha = 0.05$).
‡CIR = Crop in rotation, CC = Cover crop, NR = Nitrogen rate.

Table A.6. Soil carbon percent and analysis of variance of soil samples collected at the planting times of corn and forage sorghum under rotations with two cover crops and a control of no cover crop with two levels of nitrogen in the spring of 2011 in Tribune, Kansas.

	Cover crop					
	Austrian winter pea		Winter wheat		Fallow	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101
	-----------------------------		---------%---------		-----------------------------	
Corn	1.15cdef†	1.22abcdef	1.13ef	1.11f	1.14def	1.16bcdef
Forage Sorghum	1.26ab	1.24abc	1.29a	1.24abcd	1.23abcde	1.28a

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR)‡	1	24.35	<0.0001
Cover crop (CC)	2	0.53	0.5927
CIR x CC	2	0.99	0.3778
Nitrogen rate (NR)	1	0.09	0.7640
CIR x NR	1	0.45	0.5046
CC x NR	2	1.04	0.3591
CIR x CC x NR	2	0.47	0.6284

†Within each set of means, values followed by the same letter are not significantly different ($\alpha = 0.05$).
‡CIR = Crop in rotation, CC = Cover crop, NR = Nitrogen rate.

Table A.7. Soil carbon percent and analysis of variance of soil samples collected at the planting times of corn and forage sorghum under rotations with two cover crops and a control of no cover crop with two levels of nitrogen in the spring of 2012 in Manhattan, Kansas.

	Cover crop					
	Austrian winter pea		Winter wheat		Fallow	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101
	---------------------%	---------------------				
Corn	---†	---	0.67ab‡	0.70ab	0.71ab	0.72ab
Forage Sorghum	---	---	0.78a	0.75a	0.70ab	0.63b

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR) §	1	0.14	0.7105
Cover crop (CC)	2	252.75	<0.0001
CIR x CC	2	1.66	0.1995
Nitrogen rate (NR)	1	0.09	0.7632
CIR x NR	1	0.70	0.4057
CC x NR	2	0.11	0.8941
CIR x CC x NR	2	0.19	0.8260

†Cover crop did not produce a stand in the specified growing year.
‡Within each set of means, values followed by the same letter are not significantly different (α = 0.05)
§CIR = Crop in rotation, CC = Cover crop, NR = Nitrogen rate.

Table A.8. Soil carbon percent and analysis of variance of soil samples collected at the planting times of corn and forage sorghum under rotations with two cover crops and a control of no cover crop with two levels of nitrogen in the spring of 2012 in Tribune, Kansas.

	Cover crop					
	Austrian winter pea		Winter wheat		Fallow	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101
	---%---					
Corn	1.28a†	1.28a	1.23a	1.30a	1.24a	1.26a
Forage Sorghum	1.27a	1.25a	1.25a	1.30a	1.25a	1.28a

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR)‡	1	0.00	0.9451
Cover crop (CC)	2	0.15	0.8645
CIR x CC	2	0.15	0.8572
Nitrogen rate (NR)	1	0.81	0.3721
CIR x NR	1	0.01	0.9329
CC x NR	2	0.57	0.5708
CIR x CC x NR	2	0.07	0.9345

†Within each set of means, values followed by the same letter are not significantly different (α = 0.05).
‡CIR = Crop in rotation, CC = Cover crop, NR = Nitrogen rate.

Table A.9. Soil total nitrogen (kg ha^{-1}) and analysis of variance of soil samples collected at the planting times of corn and forage sorghum under rotations with two cover crops and a control of no cover crop with two levels of nitrogen in the spring of 2011 in Manhattan, Kansas.

	Cover crop					
	Austrian winter pea		Winter wheat		Fallow	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101
	---------- kg ha^{-1} ----------					
Corn	3668ab†	3772ab	3571ab	3746ab	3807a	3661ab
Forage Sorghum	2785bc	2440c	3109abc	2970abc	3133abc	2862abc

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR)‡	1	16.20	0.0002
Cover crop (CC)	2	0.39	0.6769
CIR x CC	2	0.52	0.5965
Nitrogen rate (NR)	1	0.26	0.6123
CIR x NR	1	0.53	0.4702
CC x NR	2	0.10	0.9011
CIR x CC x NR	2	0.05	0.9484

†Within each set of means, values followed by the same letter are not significantly different (α = 0.05).
‡CIR = Crop in rotation, CC = Cover crop, NR = Nitrogen rate.

Table A.10. Soil total nitrogen (kg ha^{-1}) and analysis of variance of soil samples collected at the planting times of corn and forage sorghum under rotations with two cover crops and a control of no cover crop with two levels of nitrogen in the spring of 2011 in Tribune, Kansas.

	Cover crop					
	Austrian winter pea		Winter wheat		Fallow	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101
	------------------------------------- kg ha^{-1} -----------------------------------					
Corn	6053a	6214a	5773abc	5757abc	5845abc	5910ab
Forage Sorghum	5433c	5470bc	5571bc	5400c	5468bc	5554bc

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR)‡	1	22.86	<0.0001
Cover crop (CC)	2	1.10	0.3396
CIR x CC	2	1.74	0.1840
Nitrogen rate (NR)	1	0.09	0.7713
CIR x NR	1	0.22	0.6427
CC x NR	2	0.43	0.6524
CIR x CC x NR	2	0.09	0.9170

†Within each set of means, values followed by the same letter are not significantly different (α = 0.05).
‡CIR = Crop in rotation, CC = Cover crop, NR = Nitrogen rate.

Table A.11. Soil total nitrogen (kg ha^{-1}) and analysis of variance of soil samples collected at the planting times of corn and forage sorghum under rotations with two cover crops and a control of no cover crop with two levels of nitrogen in the spring of 2012 in Manhattan, Kansas.

	Cover crop					
	Austrian winter pea		Winter wheat		Fallow	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101
	---------- kg ha^{-1} ----------					
Corn	---†	---	3649a‡	3596a	3726a	3954ab
Forage Sorghum	---	---	3617abc	3602abc	3551abc	3698abc

ANOVA

Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR)§	1	0.52	0.4750
Cover crop (CC)	2	534.83	<0.0001
CIR x CC	2	0.44	0.6489
Nitrogen rate (NR)	1	0.23	0.6311
CIR x NR	1	0.00	0.9462
CC x NR	2	0.42	0.6579
CIR x CC x NR	2	0.03	0.9728

†Cover crop did not produce a stand in the specified growing year.
‡Within each set of means, values followed by the same letter are not significantly different (α = 0.05)
§CIR = Crop in rotation, CC = Cover crop, NR = Nitrogen rate.

Table A.12. Soil total nitrogen (kg ha^{-1}) and analysis of variance of soil samples collected at the planting times of corn and forage sorghum under rotations with two cover crops and a control of no cover crop with two levels of nitrogen in the spring of 2012 in Tribune, Kansas.

	Cover crop					
	Austrian winter pea		Winter wheat		Fallow	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101
	---------- kg ha^{-1} ----------					
Corn	6194a†	7222a	7337a	6251a	7035a	6603a
Forage Sorghum	7985a	7244a	6428a	7488a	6740a	6312a

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR)‡	1	0.29	0.5897
Cover crop (CC)	2	0.35	0.7044
CIR x CC	2	0.44	0.5888
Nitrogen rate (NR)	1	0.23	0.8356
CIR x NR	1	0.00	0.8946
CC x NR	2	0.42	0.8799
CIR x CC x NR	2	0.03	0.2544

†Within each set of means, values followed by the same letter are not significantly different (α = 0.05).
‡CIR = Crop in rotation, CC = Cover crop, NR = Nitrogen rate.

Table A.13. Soil carbon-to-nitrogen ration (C:N) and analysis of variance of soil samples collected at the planting times of corn and forage sorghum under rotations with two cover crops and a control of no cover crop with two levels of nitrogen in the spring of 2011 in Manhattan, Kansas.

	Cover crop					
	Austrian winter pea		Winter wheat		Fallow	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101
	--------C:N ratio--------					
Corn	8:1 c†	7:1 cd	8:1 c	7:1 cd	6:1 d	7:1 cd
Forage Sorghum	11:1 ab	12:1 a	11:1 ab	11:1 b	12:1 ab	12:1 ab

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR)‡	1	300.50	<0.0001
Cover crop (CC)	2	1.31	0.2789
CIR x CC	2	0.99	0.3776
Nitrogen rate (NR)	1	0.00	1.0000
CIR x NR	1	1.68	0.2002
CC x NR	2	1.59	0.2119
CIR x CC x NR	2	2.64	0.0798

†Within each set of means, values followed by the same letter are not significantly different ($\alpha = 0.05$).
‡CIR = Crop in rotation, CC = Cover crop, NR = Nitrogen rate.

Table A.14. Soil carbon-to-nitrogen ration (C:N) and analysis of variance of soil samples collected at the planting times of corn and forage sorghum under rotations with two cover crops and a control of no cover crop with two levels of nitrogen in the spring of 2011 in Tribune, Kansas.

	Cover crop					
	Austrian winter pea		Winter wheat		Fallow	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101
	---C:N ratio---					
Corn	8:1 b†	9:1 b	9:1 b	9:1 b	9:1 b	9:1 b
Forage Sorghum	10:1 a	10:1a	10:1 a	10:1 a	10:1 a	10:1 a

ANOVA			
Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR)‡	1	127.51	<0.0001
Cover crop (CC)	2	0.15	0.8606
CIR x CC	2	0.41	0.6665
Nitrogen rate (NR)	1	0.19	0.6616
CIR x NR	1	0.02	0.8839
CC x NR	2	0.19	0.8246
CIR x CC x NR	2	0.80	0.4562

†Within each set of means, values followed by the same letter are not significantly different (α = 0.05).
‡CIR = Crop in rotation, CC = Cover crop, NR = Nitrogen rate.

Table A.15. Soil carbon-to-nitrogen ratio (C:N) and analysis of variance of soil samples collected at the planting times of corn and forage sorghum under rotations with two cover crops and a control of no cover crop with two levels of nitrogen in the spring of 2012 in Manhattan, Kansas.

	Cover crop					
	Austrian winter pea		Winter wheat		Fallow	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101
	--------C:N ratio--------					
Corn	---†	---	8:1 ab‡	9:1 ab	8:1 ab	8:1 ab
Forage Sorghum	---	---	10:1 a	9:1 ab	9:1 ab	7:1 b

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR)§	1	0.83	0.3654
Cover crop (CC)	2	186.96	<0.0001
CIR x CC	2	0.59	0.5598
Nitrogen rate (NR)	1	0.37	0.5453
CIR x NR	1	1.03	0.3148
CC x NR	2	0.37	0.6922
CIR x CC x NR	2	0.29	0.7509

†Cover crop did not produce a stand in the specified growing year.
‡Within each set of means, values followed by the same letter are not significantly different (α = 0.05).
§CIR = Crop in rotation, CC = cover crop, NR = Nitrogen rate.

Table A.16. Soil carbon-to-nitrogen ratio (C:N) and analysis of variance of soil samples collected at the planting times of corn and forage sorghum under rotations with two cover crops and a control of no cover crop with two levels of nitrogen in the spring of 2012 in Tribune, Kansas.

	Cover crop					
	Austrian winter pea		Winter wheat		Fallow	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101
	--------C:N ratio--------					
Corn	9:1 a†	8:1 a	8:1 a	9:1 a	8:1 a	9:1 a
Forage Sorghum	8:1 a	8:1 a	9:1 a	8:1 a	8:1 a	9:1 a

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR)‡	1	0.01	0.9350
Cover crop (CC)	2	0.16	0.8558
CIR x CC	2	0.28	0.7540
Nitrogen rate (NR)	1	0.67	0.4159
CIR x NR	1	0.03	0.8704
CC x NR	2	0.28	0.7540
CIR x CC x NR	2	0.67	0.5174

†Within each set of means, values followed by the same letter are not significantly different (α = 0.05).
§CIR = Crop in rotation, CC = cover crop, NR = Nitrogen rate.

Table A.17. Change in soil nitrogen percentage and analysis of variance of soil samples collected at the planting times of corn and forage sorghum under rotations with two cover crops and a control of no cover crop with two levels of nitrogen in the spring of 2011 in Manhattan, Kansas.

	Cover crop					
	Austrian winter pea		Winter wheat		Fallow	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101
	---%---					
Corn†	0.01ab‡	0.00b	0.01ab	0.02a	0.02ab	0.01ab
Forage Sorghum	-0.02cd	-0.03e	-0.02cde	0.02c	-0.02cd	-0.03de

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR)§	1	100.46	<0.0001
Cover crop (CC)	2	3.57	0.0346
CIR x CC	2	0.67	0.5160
Nitrogen rate (NR)	1	2.05	0.1576
CIR x NR	1	0.79	0.3791
CC x NR	2	2.68	0.0774
CIR x CC x NR	2	0.07	0.9284

†Means for each crop in rotation represents the change in soil nitrogen percentage between each respective cover crop's planting and termination times.

‡Within each set of means, values followed by the same letter are not significantly different (α = 0.05).

§CIR = Crop in rotation, CC = cover crop, NR = Nitrogen rate.

Table A.18. Change in soil nitrogen percentage and analysis of variance of soil samples collected at the planting times of corn and forage sorghum under rotations with two cover crops and a control of no cover crop with two levels of nitrogen in the spring of 2011 in Tribune, Kansas.

	Cover crop					
	Austrian winter pea		Winter wheat		Fallow	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101
	----------------------	----------------------	----------------------	%	----------------------	----------------------
Corn†	0.01a‡	0.01a	-0.01ab	-0.01ab	-0.01abc	-0.01a
Forage Sorghum	-0.02c	-0.02bc	-0.01bc	-0.01bc	-0.01a	-0.01a

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR)§	1	18.49	<0.0001
Cover crop (CC)	2	0.21	0.8138
CIR x CC	2	2.40	0.0998
Nitrogen rate (NR)	1	1.23	0.2718
CIR x NR	1	0.31	0.5812
CC x NR	2	0.87	0.4242
CIR x CC x NR	2	0.18	0.8375

†Means for each crop in rotation represents the change in soil nitrogen percentage between each respective cover crop's planting and termination times.

‡Within each set of means, values followed by the same letter are not significantly different (α = 0.05).

§CIR = Crop in rotation, CC = cover crop, NR = Nitrogen rate.

Table A.19. Change in soil nitrogen percentage and analysis of variance of soil samples collected at the planting times of corn and forage sorghum under rotations with two cover crops and a control of no cover crop with two levels of nitrogen in the spring of 2012 in Manhattan, Kansas.

	Cover crop					
	Austrian winter pea		Winter wheat		Fallow	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101
	------------------%	------------------				
Corn†	---‡	---	0.00a§	-0.01a	-0.01a	-0.01a
Forage Sorghum	---	---	-0.01a	-0.01a	-0.01a	-0.01a

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR)¶	1	0.01	0.9056
Cover crop (CC)	2	1.12	0.3333
CIR x CC	2	0.10	0.9057
Nitrogen rate (NR)	1	0.13	0.7222
CIR x NR	1	0.35	0.5539
CC x NR	2	0.55	0.5783
CIR x CC x NR	2	0.10	0.9057

†Means for each crop in rotation represents the change in soil nitrogen percentage between each respective cover crop's planting and termination times.

‡Cover crop did not produce a stand in the specified growing year.

§Within each set of means, values followed by the same letter are not significantly different ($\alpha = 0.05$).

¶CIR = Crop in rotation, CC = cover crop, NR = Nitrogen rate.

Table A.20. Change in soil nitrogen percentage and analysis of variance of soil samples collected at the planting times of corn and forage sorghum under rotations with two cover crops and a control of no cover crop with two levels of nitrogen in the spring of 2012 in Tribune, Kansas.

	Cover crop					
	Austrian winter pea		Winter wheat		Fallow	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101
	----------------------------	--------------------------	-----------	%-------------	--------------------------	--------------------------
Corn†	-0.07b‡	-0.03ab	-0.03ab	-0.05ab	-0.05ab	-0.05ab
Forage Sorghum	-0.03ab	-0.02a	-0.03ab	-0.03a	-0.02a	-0.04ab

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR)§	1	5.74	0.0199
Cover crop (CC)	2	0.16	0.8565
CIR x CC	2	0.03	0.9673
Nitrogen rate (NR)	1	0.10	0.7558
CIR x NR	1	0.27	0.6045
CC x NR	2	1.49	0.2337
CIR x CC x NR	2	0.86	0.4288

†Means for each crop in rotation represents the change in soil nitrogen percentage between each respective cover crop's planting and termination times.

‡Within each set of means, values followed by the same letter are not significantly different ($\alpha = 0.05$).

§CIR = Crop in rotation, CC = cover crop, NR = Nitrogen rate.

Table A.21. Change in soil carbon percentage and analysis of variance of soil samples collected at the planting times of corn and forage sorghum under rotations with two cover crops and a control of no cover crop with two levels of nitrogen in the spring of 2011 in Manhattan, Kansas.

	Cover crop					
	Austrian winter pea		Winter wheat		Fallow	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101
	---%---					
Corn†	0.01ab‡	-0.03ab	0.04ab	-0.02ab	-0.02ab	0.01ab
Forage Sorghum	-0.01ab	-0.03ab	0.06a	0.03ab	0.07a	-0.01ab

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR)§	1	0.94	0.3376
Cover crop (CC)	2	1.62	0.2066
CIR x CC	2	0.68	0.5089
Nitrogen rate (NR)	1	2.73	0.1038
CIR x NR	1	0.28	0.5979
CC x NR	2	0.06	0.9424
CIR x CC x NR	2	0.98	0.3818

†Means for each crop in rotation represents the change in soil carbon percentage between each respective cover crop's planting and termination times.

‡Within each set of means, values followed by the same letter are not significantly different (α = 0.05).

§CIR = Crop in rotation, CC = cover crop, NR = Nitrogen rate.

Table A.22. Change in soil carbon percentage and analysis of variance of soil samples collected at the planting times of corn and forage sorghum under rotations with two cover crops and a control of no cover crop with two levels of nitrogen in the spring of 2011 in Tribune, Kansas.

	Cover crop					
	Austrian winter pea		Winter wheat		Fallow	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101
	---	-----------------	--%	------------	-----------------	---
Corn†	-0.06cd‡	0.03abcd	-0.07cd	-0.08d	-0.08d	-0.05cd
Forage Sorghum	0.05abc	0.01bcd	0.09ab	0.05abc	0.02bcd	0.13a

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR)§	1	19.62	<0.0001
Cover crop (CC)	2	0.08	0.9226
CIR x CC	2	1.63	0.2049
Nitrogen rate (NR)	1	1.10	0.2990
CIR x NR	1	0.29	0.5906
CC x NR	2	1.27	0.2880
CIR x CC x NR	2	1.39	0.2570

†Means for each crop in rotation represents the change in soil carbon percentage between each respective cover crop's planting and termination times.

‡Within each set of means, values followed by the same letter are not significantly different (α = 0.05).

§CIR = Crop in rotation, CC = cover crop, NR = Nitrogen rate.

Table A.23. Change in soil carbon percentage and analysis of variance of soil samples collected at the planting times of corn and forage sorghum under rotations with two cover crops and a control of no cover crop with two levels of nitrogen in the spring of 2012 in Manhattan, Kansas.

	Cover crop					
	Austrian winter pea		Winter wheat		Fallow	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101
	-----%					-----
Corn†	---‡	---	-0.53c§	-0.48c	-0.38d	-0.56d
Forage Sorghum	---	---	0.17ab	0.19a	0.10abc	-0.01c

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR) ¶	1	117.11	<0.0001
Cover crop (CC)	2	12.19	<0.0001
CIR x CC	2	31.15	<0.0001
Nitrogen rate (NR)	1	0.98	0.3254
CIR x NR	1	0.04	0.8346
CC x NR	2	2.23	0.1167
CIR x CC x NR	2	0.15	0.8577

†Means for each crop in rotation represents the change in soil carbon percentage between each respective cover crop's planting and termination times.

‡Cover crop did not produce a stand in the specified growing year.

§Within each set of means, values followed by the same letter are not significantly different (α = 0.05).

¶CIR = Crop in rotation, CC = cover crop, NR = Nitrogen rate.

Table A.24. Change in soil carbon percentage and analysis of variance of soil samples collected at the planting times of corn and forage sorghum under rotations with two cover crops and a control of no cover crop with two levels of nitrogen in the spring of 2012 in Tribune, Kansas.

	Cover crop					
	Austrian winter pea		Winter wheat		Fallow	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101
	------%					------
Corn†	0.14a‡	0.08a	0.21a	0.09a	0.10a	0.12a
Forage Sorghum	0.10a	0.15a	0.12a	0.21a	0.14a	0.14a

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR)§	1	0.37	0.5451
Cover crop (CC)	2	0.42	0.6587
CIR x CC	2	0.02	0.9792
Nitrogen rate (NR)	1	0.02	0.8909
CIR x NR	1	1.90	0.1735
CC x NR	2	0.04	0.9630
CIR x CC x NR	2	1.01	0.3723

†Means for each crop in rotation represents the change in soil carbon percentage between each respective cover crop's planting and termination times.

‡Within each set of means, values followed by the same letter are not significantly different (α = 0.05).

§CIR = Crop in rotation, CC = cover crop, NR = Nitrogen rate.

Table A.25. Change in soil total nitrogen (kg ha^{-1}) and analysis of variance of soil samples collected at the planting times of corn and forage sorghum under rotations with two cover crops and a control of no cover crop with two levels of nitrogen in the spring of 2011 in Manhattan, Kansas.

	Cover crop					
	Austrian winter pea		Winter wheat		Fallow	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101
	---------- kg ha^{-1} ----------					
Corn†	141a‡	96a	485a	742a	586a	326a
Forage Sorghum	-744bc	1249c	-770bc	-697b	-654b	-1177bc

ANOVA

Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR)§	1	95.07	<0.0001
Cover crop (CC)	2	2.80	0.0690
CIR x CC	2	0.39	0.6794
Nitrogen rate (NR)	1	1.63	0.2072
CIR x NR	1	1.33	0.2532
CC x NR	2	1.67	0.1966
CIR x CC x NR	2	0.10	0.9064

†Means for each crop in rotation represents the change in soil total nitrogen between each respective cover crop's planting and termination times.

‡Within each set of means, values followed by the same letter are not significantly different (α = 0.05).

§CIR = Crop in rotation, CC = cover crop, NR = Nitrogen rate.

Table A.26. Change in soil total nitrogen (kg ha^{-1}) and analysis of variance of soil samples collected at the planting times of corn and forage sorghum under rotations with two cover crops and a control of no cover crop with two levels of nitrogen in the spring of 2011 in Tribune, Kansas.

	Cover crop					
	Austrian winter pea		Winter wheat		Fallow	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101
	---------- kg ha^{-1} ----------					
Corn†	172a‡	228a	-34ab	-386a	-388abcd	-172abcd
Forage Sorghum	767e	633cde	-434bcd	-599bcde	-688de	-244abcd

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR)§	1	18.45	<0.0001
Cover crop (CC)	2	0.37	0.6926
CIR x CC	2	2.98	0.0585
Nitrogen rate (NR)	1	0.80	0.3745
CIR x NR	1	0.06	0.8028
CC x NR	2	1.09	0.3442
CIR x CC x NR	2	0.18	0.8341

†Means for each crop in rotation represents the change in soil total nitrogen between each respective cover crop's planting and termination times.

‡Within each set of means, values followed by the same letter are not significantly different ($\alpha = 0.05$).

§CIR = Crop in rotation, CC = cover crop, NR = Nitrogen rate.

Table A.27. Change in soil total nitrogen (kg ha^{-1}) and analysis of variance of soil samples collected at the planting times of corn and forage sorghum under rotations with two cover crops and a control of no cover crop with two levels of nitrogen in the spring of 2012 in Manhattan, Kansas.

	Cover crop					
	Austrian winter pea		Winter wheat		Fallow	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101
	---------- kg ha^{-1} ----------					
Corn†	---‡	---	-122a§	-386a	-249a	-137a
Forage Sorghum	---	---	-325a	-348a	-185a	42a

Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR)¶	1	0.01	0.9330
Cover crop (CC)	2	1.19	0.3103
CIR x CC	2	0.14	0.8663
Nitrogen rate (NR)	1	0.00	0.9562
CIR x NR	1	0.15	0.7047
CC x NR	2	0.34	0.7160
CIR x CC x NR	2	0.05	0.9514

†Means for each crop in rotation represents the change in soil total nitrogen between each respective cover crop's planting and termination times.
‡Cover crop did not produce a stand in the specified growing year.
§Within each set of means, values followed by the same letter are not significantly different (α = 0.05).
¶CIR = Crop in rotation, CC = cover crop, NR = Nitrogen rate.

Table A.28. Change in soil total nitrogen (kg ha^{-1}) and analysis of variance of soil samples collected at the planting times of corn and forage sorghum under rotations with two cover crops and a control of no cover crop with two levels of nitrogen in the spring of 2012 in Tribune, Kansas.

	Cover crop					
	Austrian winter pea		Winter wheat		Fallow	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101
	kg ha^{-1}					
Corn†	-2727b‡	-1564ab	-1323ab	-2224ab	-2276ab	-1838ab
Forage Sorghum	-1382ab	-633cde	-1115ab	-1065ab	-976a	-1681ab

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR)§	1	5.17	0.0267
Cover crop (CC)	2	0.24	0.7898
CIR x CC	2	0.05	0.9473
Nitrogen rate (NR)	1	0.04	0.8454
CIR x NR	1	0.23	0.6331
CC x NR	2	1.07	0.3497
CIR x CC x NR	2	0.88	0.4198

†Means for each crop in rotation represents the change in soil total nitrogen between each respective cover crop's planting and termination times.

‡Within each set of means, values followed by the same letter are not significantly different ($\alpha = 0.05$).

§CIR = Crop in rotation, CC = cover crop, NR = Nitrogen rate.

Table A.29. Change in soil carbon-to-nitrogen ratio (percent carbon) and analysis of variance of soil samples collected at the planting times of corn and forage sorghum under rotations with two cover crops and a control of no cover crop with two levels of nitrogen in the spring of 2011 in Manhattan, Kansas.

	Cover crop					
	Austrian winter pea		Winter wheat		Fallow	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101
	---%					---
Corn†	-0.3c‡	-0.5c	-1.0c	-2.0c	-1.5c	-1.8c
Forage Sorghum	2.4b	4.3a	2.9ab	2.5b	3.1ab	3.5ab

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR)§	1	105.19	<0.0001
Cover crop (CC)	2	1.56	0.2186
CIR x CC	2	0.76	0.4719
Nitrogen rate (NR)	1	0.02	0.8812
CIR x NR	1	1.82	0.1821
CC x NR	2	1.08	0.3460
CIR x CC x NR	2	0.36	0.6989

†Means for each crop in rotation represents the change in soil carbon-to-nitrogen ratio between each respective cover crop's planting and termination times.

‡Within each set of means, values followed by the same letter are not significantly different ($\alpha = 0.05$).

§CIR = Crop in rotation, CC = cover crop, NR = Nitrogen rate.

Table A.30. Change in soil carbon-to-nitrogen ratio (percent carbon) and analysis of variance of soil samples collected at the planting times of corn and forage sorghum under rotations with two cover crops and a control of no cover crop with two levels of nitrogen in the spring of 2011 in Tribune, Kansas.

	Cover crop					
	Austrian winter pea		Winter wheat		Fallow	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101
	---	---	---	%	---	---
Corn†	-0.75c‡	-0.25c	-0.50c	-0.50c	0.25bc	0.0c
Forage Sorghum	1.4a	1.0ab	1.4a	1.3a	1.0ab	1.3a

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR)§	1	64.43	<0.0001
Cover crop (CC)	2	0.83	0.4401
CIR x CC	2	1.83	0.1702
Nitrogen rate (NR)	1	0.00	1.0000
CIR x NR	1	0.20	0.6573
CC x NR	2	0.04	0.9634
CIR x CC x NR	2	1.13	0.3298

†Means for each crop in rotation represents the change in soil carbon-to-nitrogen ratio between each respective cover crop's planting and termination times.

‡Within each set of means, values followed by the same letter are not significantly different (α = 0.05).

§CIR = Crop in rotation, CC = cover crop, NR = Nitrogen rate.

Table A.31. Change in soil carbon-to-nitrogen ratio (percent carbon) and analysis of variance of soil samples collected at the planting times of corn and forage sorghum under rotations with two cover crops and a control of no cover crop with two levels of nitrogen in the spring of 2012 in Manhattan, Kansas.

	Cover crop					
	Austrian winter pea		Winter wheat		Fallow	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101
	-------------------	-------------------	-------------------	%	-------------------	-------------------
Corn†	---‡	---	-6.0d§	-4.5cd	-3.5c	-5.8cd
Forage Sorghum	---	---	2.5a	2.9a	1.5ab	0.0b

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR)¶	1	116.73	<0.0001
Cover crop (CC)	2	7.67	0.0011
CIR x CC	2	32.43	<0.0001
Nitrogen rate (NR)	1	0.58	0.4499
CIR x NR	1	0.02	0.8796
CC x NR	2	4.05	0.0226
CIR x CC x NR	2	0.44	0.6462

†Means for each crop in rotation represents the change in soil carbon-to-nitrogen ratio between each respective cover crop's planting and termination times.

‡Cover crop did not produce a stand in the specified growing year.

§Within each set of means, values followed by the same letter are not significantly different (α = 0.05).

¶CIR = Crop in rotation, CC = cover crop, NR = Nitrogen rate.

Table A.32. Change in soil carbon-to-nitrogen ratio (percent carbon) and analysis of variance of soil samples collected at the planting times of corn and forage sorghum that were in rotations with two cover crops and a control of no cover crop with two levels of nitrogen in the spring of 2011 in Tribune, Kansas.

	Cover crop					
	Austrian winter pea		Winter wheat		Fallow	
	----kg N ha^{-1}----		----kg N ha^{-1}----		----kg N ha^{-1}----	
Crop in Rotation	0	101	0	101	0	101
	-------------------	-------------------	-------------------	%	-------------------	-------------------
Corn†	3.5a‡	2.0a	2.8a	3.0a	2.5a	2.8a
Forage Sorghum	1.7a	1.7a	2.0a	2.1a	2.0a	2.6a

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Crop in rotation (CIR)§	1	3.27	0.0760
Cover crop (CC)	2	0.20	0.8159
CIR x CC	2	0.33	0.7238
Nitrogen rate (NR)	1	0.01	0.9204
CIR x NR	1	0.49	0.4850
CC x NR	2	0.76	0.4730
CIR x CC x NR	2	0.34	0.7166

†Means for each crop in rotation represents the change in soil carbon-to-nitrogen ratio between each respective cover crop's planting and termination times.

‡Within each set of means, values followed by the same letter are not significantly different ($\alpha = 0.05$).

§CIR = Crop in rotation, CC = cover crop, NR = Nitrogen rate.

Appendix B – Chapter 3 Soils Data

This section of the appendix contains text and data in reference to soil samples taken in conjunction to the study mentioned in the third chapter, which were not included in the chapter text. Soil sampling was done at both Manhattan and Hutchinson in the fall and spring seasons of 2011 and 2012 at the time of corn and forage sorghum harvest and planting time, which was at the same time at which cover crops were terminated. Samples taken in the fall and spring seasons were used to estimate the change in nitrogen and carbon. Samples taken in the spring season were used only to estimate nitrogen and carbon at corn and forage sorghum planting times.

Soils Data Tables

Table B.1. Means and analysis of variance of soil nitrogen percentages in soil samples collected from plots where six cover crops were sampled at putative corn and forage sorghum planting times in the spring of 2011 in Manhattan, Kansas.

	Cover crop					
Factor	Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat
	--% --------------------------------------					
Putative corn	---†	0.10b‡	---	0.09bc	0.09bc	0.09bc
Putative forage sorghum	0.13a	0.13a	0.12a	0.12a	0.13a	0.13a

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Putative crop (PC)§	1	328.19	<0.0001
Cover crop (CC)	5	1.36	0.2488
PC x CC	5	0.26	0.9322

†Cover crop did not produce a stand in the specified growing year.
‡Within each set of means, values followed by the same letter are not significantly different (α = 0.05).
§ PC = Putative crop rotation, CC = Cover crop.

Table B.2. Means and analysis of variance of soil nitrogen percentages in soil samples collected from plots where six cover crops were sampled at putative corn and forage sorghum planting times in the spring of 2011 in Hutchinson, Kansas.

	Cover crop					
Factor	Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat
	--	----------	----------	% ----------	----------	----------
Putative corn	---†	0.13a‡	---	0.13a	0.13a	0.13a
Putative forage sorghum	0.11b	0.11b	0.11b	0.11b	0.11b	0.11b

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Putative crop (PC)§	1	189.49	<0.0001
Cover crop (CC)	5	0.28	0.9211
PC x CC	5	0.25	0.9385

†Cover crop did not produce a stand in the specified growing year.
‡Within each set of means, values followed by the same letter are not significantly different (α = 0.05).
§PC = Putative crop rotation, CC = Cover crop.

Table B.3. Means and analysis of variance of soil nitrogen percentages in soil samples collected from plots where six cover crops were sampled at putative corn and forage sorghum planting times in the spring of 2012 in Manhattan, Kansas.

	Cover crop					
Factor	Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat
	---% --------------------------------------					
Putative corn	---†	---	---	0.09a‡	---	0.09a
Putative forage sorghum	---	---	---	0.03b	---	0.03b

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Putative crop (PC)§	1	108.32	<0.0001
Cover crop (CC)	5	164.84	<0.0001
PC x CC	5	43.87	<0.0001

†Cover crop did not produce a stand in the specified growing year.

‡Within each set of means, values followed by the same letter are not significantly different (α = 0.05).

§PC = Putative crop rotation, CC = Cover crop.

Table B.4. Means and analysis of variance of soil nitrogen percentages in soil samples collected from plots where six cover crops were sampled at putative corn and forage sorghum planting times in the spring of 2012 in Hutchinson, Kansas.

	Cover crop					
Factor	Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat
	----------------------	----------------------	----------------%	----------------------	----------------------	----------------------
Putative corn	---†	---	---	0.05b‡	0.04b	0.04b
Putative forage sorghum	---	---	---	0.09a	0.09a	0.10a

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Putative crop (PC)§	1	87.97	<0.0001
Cover crop (CC)	5	124.20	<0.0001
PC x CC	5	18.50	<0.0001

†Cover crop did not produce a stand in the specified growing year.
‡Within each set of means, values followed by the same letter are not significantly different (α = 0.05).
§PC = Putative crop rotation, CC = Cover crop.

Table B.5. Means and analysis of variance of soil carbon percentages in soil samples collected from plots where six cover crops were sampled at putative corn and forage sorghum planting times in the spring of 2011 in Manhattan, Kansas.

	Cover crop					
Factor	Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat
	---	---	%	---		
Putative corn	---†	0.57b‡	---	0.45c	0.44c	0.46c
Putative forage sorghum	1.22a	1.29a	1.29a	1.24a	1.23a	1.25a

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Putative crop (PC)§	1	1506.35	<0.0001
Cover crop (CC)	5	2.11	0.0723
PC x CC	5	0.63	0.6797

†Cover crop did not produce a stand in the specified growing year.
‡Within each set of means, values followed by the same letter are not significantly different (α = 0.05).
§PC = Putative crop rotation, CC = Cover crop.

Table B.6. Means and analysis of variance of soil carbon percentages in soil samples collected from plots where six cover crops were sampled at putative corn and forage sorghum planting times in the spring of 2011 in Hutchinson, Kansas.

	Cover crop					
Factor	Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat
	---	-------------------------	-----------%	-------------------------	-----------	-----------
Putative corn	---†	1.11cd‡	---	1.12bcd	1.15abc	1.10cd
Putative forage sorghum	1.22a	1.22a	1.19ab	1.22a	1.20ab	1.21a

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Putative crop (PC)§	1	34.91	<0.0001
Cover crop (CC)	5	0.75	0.5892
PC x CC	5	0.56	0.7325

†Cover crop did not produce a stand in the specified growing year.
‡Within each set of means, values followed by the same letter are not significantly different (α = 0.05).
§PC = Putative crop rotation, CC = Cover crop.

Table B.7. Means and analysis of variance of soil carbon percentages in soil samples collected from plots where six cover crops were sampled at putative corn and forage sorghum planting times in the spring of 2012 in Manhattan, Kansas.

	Cover crop					
Factor	Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat
	--% --------------------------------------					
Putative corn	---†	---	---	0.99a‡	---	0.88b
Putative forage sorghum	---	---	---	0.48c	---	0.51c

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Putative crop (PC)§	1	160.24	<0.0001
Cover crop (CC)	5	670.20	<0.0001
PC x CC	5	66.09	<0.0001

†Cover crop did not produce a stand in the specified growing year.
‡Within each set of means, values followed by the same letter are not significantly different ($\alpha = 0.05$).
§PC = Putative crop rotation, CC = Cover crop.

Table B.8. Means and analysis of variance of soil carbon percentages in soil samples collected from plots where six cover crops were sampled at putative corn and forage sorghum planting times in the spring of 2012 in Hutchinson, Kansas.

	Cover crop					
Factor	Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat
	--% --------------------------------------					
Putative corn	---†	---	---	0.84a‡	0.80ab	0.83a
Putative forage sorghum	---	---	---	0.71cd	0.75bc	0.66d

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Putative crop (PC)§	1	22.47	<0.0001
Cover crop (CC)	5	814.03	<0.0001
PC x CC	5	6.67	<0.0001

†Cover crop did not produce a stand in the specified growing year.
‡Within each set of means, values followed by the same letter are not significantly different (α = 0.05).
§PC = Putative crop rotation, CC = Cover crop.

Table B.9. Means and analysis of variance of soil total nitrogen (kg ha^{-1}) in soil samples collected from plots where six cover crops were sampled at putative corn and forage sorghum planting times in the spring of 2011 in Manhattan, Kansas.

	Cover crop					
Factor	Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat
	------kg ha^{-1}------					
Putative corn	---†	4645b‡	---	4248bc	4240bc	4277bc
Putative forage sorghum	6005a	6173a	5987a	6028a	6038a	6069a

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Putative crop (PC)§	1	401.52	<0.0001
Cover crop (CC)	5	1.22	0.3074
PC x CC	5	0.31	0.9031

†Cover crop did not produce a stand in the specified growing year.
‡Within each set of means, values followed by the same letter are not significantly different (α = 0.05).
§PC = Putative crop rotation, CC = Cover crop.

Table B.10. Means and analysis of variance of soil total nitrogen (kg ha^{-1}) in soil samples collected from plots where six cover crops were sampled at putative corn and forage sorghum planting times in the spring of 2011 in Hutchinson, Kansas.

	Cover crop					
Factor	Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat
	--kg ha^{-1} --------------------------------------					
Putative corn	---†	5797a‡	---	5754a	6014a	6015a
Putative forage sorghum	4717b	4707b	4704b	4942b	4791b	4852b

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Putative crop (PC)§	1	253.05	<0.0001
Cover crop (CC)	5	0.86	0.5117
PC x CC	5	0.72	0.6080

†Cover crop did not produce a stand in the specified growing year.
‡Within each set of means, values followed by the same letter are not significantly different (α = 0.05).
§PC = Putative crop rotation, CC = Cover crop.

Table B.11. Means and analysis of variance of soil total nitrogen (kg ha^{-1}) in soil samples collected from plots where six cover crops were sampled at putative corn and forage sorghum planting times in the spring of 2012 in Manhattan, Kansas.

	Cover crop					
Factor	Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat
	----------kg ha^{-1}----------					
Putative corn	---†	---	---	4410a‡	---	4282a
Putative forage sorghum	---	---	---	1209b	---	1558b

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Putative crop (PC) §	1	118.99	<0.0001
Cover crop (CC)	5	178.14	<0.0001
PC x CC	5	48.06	<0.0001

†Cover crop did not produce a stand in the specified growing year.

‡Within each set of means, values followed by the same letter are not significantly different ($\alpha = 0.05$).

§PC = Putative crop rotation, CC = Cover crop.

Table B.12. Means and analysis of variance of soil total nitrogen (kg ha^{-1}) in soil samples collected from plots where six cover crops were sampled at putative corn and forage sorghum planting times in the spring of 2012 in Hutchinson, Kansas.

	Cover crop					
Factor	Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat
	--kg ha^{-1} --------------------------------------					
Putative corn	---†	---	---	2077b‡	1924b	1778b
Putative forage sorghum	---	---	---	4074a	3985a	4525a

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Putative crop (PC)§	1	88.00	<0.0001
Cover crop (CC)	5	127.51	<0.0001
PC x CC	5	18.41	<0.0001

†Cover crop did not produce a stand in the specified growing year.
‡Within each set of means, values followed by the same letter are not significantly different (α = 0.05).
§PC = Putative crop rotation, CC = Cover crop.

Table B.13. Means and analysis of variance of soil carbon-to-nitrogen ratio (C:N) in soil samples collected from plots where six cover crops were sampled at putative corn and forage sorghum planting times in the spring of 2011 in Manhattan, Kansas.

	Cover crop					
Factor	Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat
	--------------------------------------C:N ratio-----------------------------------					
Putative corn	---†	6:1 b‡	---	5:1 c	5:1 c	5:1 c
Putative forage sorghum	10:1 a	10:1 a	10:1 a	10:1 a	10:1 a	10:1a

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Putative crop (PC)§	1	1280.34	<0.0001
Cover crop (CC)	5	2.22	0.0605
PC x CC	5	0.89	0.4910

†Cover crop did not produce a stand in the specified growing year.
‡Within each set of means, values followed by the same letter are not significantly different (α = 0.05).
§PC = Putative crop rotation, CC = Cover crop.

Table B.14. Means and analysis of variance of soil carbon-to-nitrogen ratio (C:N) in soil samples collected from plots where six cover crops were sampled at putative corn and forage sorghum planting times in the spring of 2011 in Hutchinson, Kansas.

	Cover crop					
Factor	Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat
	--------------------------------------C:N ratio-----------------------------------					
Putative corn	---†	9:1 b‡	---	9:1 b	9:1 b	8:1 b
Putative forage sorghum	12:1 a	12:1 a	11:1 a	11:1 a	11:1 a	11:1a

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Putative crop (PC)§	1	518.20	<0.0001
Cover crop (CC)	5	0.99	0.4280
PC x CC	5	0.89	0.3188

†Cover crop did not produce a stand in the specified growing year.
‡Within each set of means, values followed by the same letter are not significantly different (α = 0.05).
§PC = Putative crop rotation, CC = Cover crop.

Table B.15. Means and analysis of variance of soil carbon-to-nitrogen ratio (C:N) in soil samples collected from plots where six cover crops were sampled at putative corn and forage sorghum planting times in the spring of 2012 in Manhattan, Kansas.

	Cover crop					
Factor	Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat
	---------------------------------------C:N ratio-----------------------------------					
Putative corn	---†	---	---	11:1 a‡	---	10:1 a
Putative forage sorghum	---	---	---	11:1 a	---	8:1 b

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Putative crop (PC)§	1	1280.34	<0.0001
Cover crop (CC)	5	2.22	0.0605
PC x CC	5	0.89	0.4910

†Cover crop did not produce a stand in the specified growing year.

‡Within each set of means, values followed by the same letter are not significantly different (α = 0.05).

§PC = Putative crop rotation, CC = Cover crop.

Table B.16. Means and analysis of variance of soil carbon-to-nitrogen ratio (C:N) in soil samples collected from plots where six cover crops were sampled at putative corn and forage sorghum planting times in the spring of 2012 in Hutchinson, Kansas.

	Cover crop					
Factor	Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat
	---------------------C:N ratio---------------------					
Putative corn	---†	---	---	18:1 b‡	19:1 b	21:1 a
Putative forage sorghum	---	---	---	8:1 cd	9:1 c	7:1 d

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Putative crop (PC)§	1	303.89	<0.0001
Cover crop (CC)	5	355.88	<0.0001
PC x CC	5	64.32	<0.0001

†Cover crop did not produce a stand in the specified growing year.
‡Within each set of means, values followed by the same letter are not significantly different ($\alpha = 0.05$).
§PC = Putative crop rotation, CC = Cover crop.

Table B.17. Means and analysis of variance the change in soil nitrogen percentage in soil samples collected from plots where six cover crops were sampled at putative corn and forage sorghum planting times in the spring of 2011 in Manhattan, Kansas.

	Cover crop					
Factor	Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat
	--------------------	--------------------	--------------------	%	--------------------	--------------------
Putative corn†	---‡	0.02abc§	---	0.01bc	0.01bc	0.04abc
Putative forage sorghum	0.01c	0.07ab	0.07abc	0.05abc	0.04abc	0.08a

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Putative crop (PC)¶	1	5.58	0.0205
Cover crop (CC)	5	1.41	0.2306
PC x CC	5	0.40	0.8469

†Means for each factor represents the change in soil nitrogen percentage between each respective cover crop's planting and termination times.
‡Cover crop did not produce a stand in the specified growing year.
§Within each set of means, values followed by the same letter are not significantly different ($\alpha = 0.05$).
¶PC = Putative crop rotation, CC = Cover crop.

Table B.18. Means and analysis of variance of the change in soil nitrogen percentage in soil samples collected from plots where six cover crops were sampled at putative corn and forage sorghum planting times in the spring of Hutchinson, Kansas 2011.

	Cover crop					
Factor	Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat
	--------------------	--------------------	--------------------	%	--------------------	--------------------
Putative corn†	---‡	0.01ab§	---	0.00abc	0.01ab	0.01a
Putative forage sorghum	-0.02d	-0.01bcd	0.00abc	-0.01cd	-0.02d	-0.01bcd

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Putative crop (PC)¶	1	24.54	<0.0001
Cover crop (CC)	5	2.01	0.0859
PC x CC	5	1.08	0.3769

†Means for each factor represents the change in soil nitrogen percentage between each respective cover crop's planting and termination times.
‡Cover crop did not produce a stand in the specified growing year.
§Within each set of means, values followed by the same letter are not significantly different (α = 0.05).
¶PC = Putative crop rotation, CC = Cover crop.

Table B.19. Means and analysis of variance of the change in soil nitrogen percentage in soil samples collected from plots where six cover crops were sampled at putative corn and forage sorghum planting times in the spring of 2012 in Manhattan, Kansas.

	Cover crop					
Factor	Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat
	--%--					
Putative corn†	---‡	---	---	0.02a§	---	0.02a
Putative forage sorghum	---	---	---	-0.02c	---	-0.01bc

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Putative crop (PC)¶	1	14.99	0.0002
Cover crop (CC)	5	0.28	0.9253
PC x CC	5	6.04	<0.0001

†Means for each factor represents the change in soil nitrogen percentage between each respective cover crop's planting and termination times.
‡Cover crop did not produce a stand in the specified growing year.
§Within each set of means, values followed by the same letter are not significantly different (α = 0.05).
¶PC = Putative crop rotation, CC = Cover crop.

Table B.20. Means and analysis of variance of the change in soil nitrogen percentage in soil samples collected from plots where six cover crops were sampled at putative corn and forage sorghum planting times in the spring of 2012 in Hutchinson, Kansas.

	Cover crop					
Factor	Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat
	%					
Putative corn†	---‡	---	---	0.00b§	-0.05c	-0.07c
Putative forage sorghum	---	---	---	0.00b	0.00b	0.02a

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Putative crop (PC)¶	1	71.49	<0.0001
Cover crop (CC)	5	8.73	<0.0001
PC x CC	5	16.47	<0.0001

†Means for each factor represents the change in soil nitrogen percentage between each respective cover crop's planting and termination times.
‡Cover crop did not produce a stand in the specified growing year.
§Within each set of means, values followed by the same letter are not significantly different (α = 0.05).
¶PC = Putative crop rotation, CC = Cover crop.

Table B.21. Means and analysis of variance of the change in soil carbon percentage in soil samples collected from plots where six cover crops were sampled at putative corn and forage sorghum planting times in the spring of 2011 in Manhattan, Kansas.

	Cover crop					
Factor	Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat
	----------------------	----------------------	----------------------	%	----------------------	----------------------
Putative corn†	---‡	0.07d§	---	-0.21e	0.00de	0.04d
Putative forage sorghum	0.64bc	0.79abc	0.91a	0.59c	0.79abc	0.83ab

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Putative crop (PC)¶	1	264.04	<0.0001
Cover crop (CC)	5	3.88	0.0033
PC x CC	5	0.09	0.9935

†Means for each factor represents the change in soil carbon percentage between each respective cover crop's planting and termination times.
‡Cover crop did not produce a stand in the specified growing year.
§Within each set of means, values followed by the same letter are not significantly different (α = 0.05).
¶PC = Putative crop rotation, CC = Cover crop.

Table B.22. Means and analysis of variance of the change in soil carbon percentage in soil samples collected from plots where six cover crops were sampled at putative corn and forage sorghum planting times in the spring of 2011 in Hutchinson, Kansas.

	Cover crop					
Factor	Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat
	%					
Putative corn†	---‡	-0.06b§	---	-0.09b	-0.07b	-0.01b
Putative forage sorghum	0.16a	0.19a	0.22a	0.17a	0.11a	0.20a

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Putative crop (PC)¶	1	119.56	<0.0001
Cover crop (CC)	5	1.55	0.1846
PC x CC	5	0.34	0.8846

†Means for each factor represents the change in soil carbon percentage between each respective cover crop's planting and termination times.
‡Cover crop did not produce a stand in the specified growing year.
§Within each set of means, values followed by the same letter are not significantly different (α = 0.05).
¶PC = Putative crop rotation, CC = Cover crop.

Table B.23. Means and analysis of variance of the change in soil carbon percentage in soil samples collected from plots where six cover crops were sampled at putative corn and forage sorghum planting times in the spring of 2012 in Manhattan, Kansas.

	Cover crop					
Factor	Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat
	----------	----------	----------	%	----------	----------
Putative corn†	---‡	---	---	0.24ab§	---	0.17b
Putative forage sorghum	---	---	---	0.28a	---	0.27a

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Putative crop (PC)¶	1	2.94	0.0903
Cover crop (CC)	5	51.77	<0.0001
PC x CC	5	1.39	0.2359

†Means for each factor represents the change in soil carbon percentage between each respective cover crop's planting and termination times.
‡Cover crop did not produce a stand in the specified growing year.
§Within each set of means, values followed by the same letter are not significantly different (α = 0.05).
¶PC = Putative crop rotation, CC = Cover crop.

Table B.24. Means and analysis of variance of the change in soil carbon percentage in soil samples collected from plots where six cover crops were sampled at putative corn and forage sorghum planting times in the spring of 2012 in Hutchinson, Kansas.

	Cover crop					
Factor	Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat
	----------	----------	----------	%	----------	----------
Putative corn†	---‡	---	---	0.35a§	0.35a	0.41a
Putative forage sorghum	---	---	---	-0.01b	-0.08b	-0.04b

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Putative crop (PC)¶	1	116.03	<0.0001
Cover crop (CC)	5	14.89	<0.0001
PC x CC	5	24.15	<0.0001

†Means for each factor represents the change in soil carbon percentage between each respective cover crop's planting and termination times.
‡Cover crop did not produce a stand in the specified growing year.
§Within each set of means, values followed by the same letter are not significantly different (α = 0.05).
¶PC = Putative crop rotation, CC = Cover crop.

Table B.25. Means and analysis of variance of the change in soil total nitrogen (kg ha^{-1}) in soil samples collected from plots where six cover crops were sampled at putative corn and forage sorghum planting times in the spring of 2011 in Manhattan, Kansas.

	Cover crop					
Factor	Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat
	--kg ha^{-1}	--------------------------------------				
Putative corn†	---‡	1056abc§	---	704bc	620bc	1853abc
Putative forage sorghum	457c	3173ab	3348ab	2428abc	1778abc	3549a

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Putative crop (PC)¶	1	5.67	0.0197
Cover crop (CC)	5	1.41	0.2282
PC x CC	5	0.44	0.8206

†Means for each factor represents the change in soil total nitrogen between each respective cover crop's planting and termination times.
‡Cover crop did not produce a stand in the specified growing year.
§Within each set of means, values followed by the same letter are not significantly different (α = 0.05).
¶PC = Putative crop rotation, CC = Cover crop.

Table B.26. Means and analysis of variance of the change in soil total nitrogen (kg ha^{-1}) in soil samples collected from plots where six cover crops were sampled at putative corn and forage sorghum planting times in the spring of 2011 in Hutchinson, Kansas.

	Cover crop					
Factor	Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat
	----------kg ha^{-1}----------					
Putative corn†	---‡	183ab§	---	-46abc	173abc	417a
Putative forage sorghum	-666d	-399cd	153abc	-331bcd	-815d	-310bcd

ANOVA

Source of Variation	DF	F Value	Pr > F
Putative crop (PC)¶	1	21.82	<0.0001
Cover crop (CC)	5	2.05	0.0806
PC x CC	5	1.24	0.2972

†Means for each factor represents the change in soil total nitrogen between each respective cover crop's planting and termination times.
‡Cover crop did not produce a stand in the specified growing year.
§Within each set of means, values followed by the same letter are not significantly different (α = 0.05).
¶PC = Putative crop rotation, CC = Cover crop.

Table B.27. Means and analysis of variance of the change in soil total nitrogen (kg ha^{-1}) in soil samples collected from plots where six cover crops were sampled at putative corn and forage sorghum planting times in the spring of 2012 in Manhattan, Kansas.

	Cover crop					
Factor	Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat
	---kg ha^{-1}					-------------------------------------
Putative corn†	---‡	---	---	1080a§	---	928a
Putative forage sorghum	---	---	---	-733c	---	-584bc

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Putative crop (PC)¶	1	16.57	0.0001
Cover crop (CC)	5	0.29	0.9191
PC x CC	5	6.71	<0.0001

†Means for each factor represents the change in soil total nitrogen between each respective cover crop's planting and termination times.
‡Cover crop did not produce a stand in the specified growing year.
§Within each set of means, values followed by the same letter are not significantly different (α = 0.05).
¶PC = Putative crop rotation, CC = Cover crop.

Table B.28. Means and analysis of variance of the change in soil total nitrogen (kg ha^{-1}) in soil samples collected from plots where six cover crops were sampled at putative corn and forage sorghum planting times in the spring of 2012 in Hutchinson, Kansas.

	Cover crop					
Factor	Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat
	--	---------------	kg ha^{-1}	---------------	---------------	--
Putative corn†	---‡	---	---	-2501c§	-2388c	-2940c
Putative forage sorghum	---	---	---	56b	-99b	1032a

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Putative crop (PC)¶	1	72.69	<0.0001
Cover crop (CC)	5	9.18	<0.0001
PC x CC	5	16.74	<0.0001

†Means for each factor represents the change in soil total nitrogen between each respective cover crop's planting and termination times.
‡Cover crop did not produce a stand in the specified growing year.
§Within each set of means, values followed by the same letter are not significantly different (α = 0.05).
¶PC = Putative crop rotation, CC = Cover crop.

Table B.29. Means and analysis of variance of the change in soil carbon-to-nitrogen ratio (percent carbon) in soil samples collected from plots where six cover crops were sampled at putative corn and forage sorghum planting times in the spring of 2011 in Manhattan, Kansas.

	Cover crop					
Factor	Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat
	-----------------------	-----------------------	-----------------------	%	-----------------------	-----------------------
Putative corn†	---‡	-1.59ab§	---	-4.34b	-1.53ab	-5.05b
Putative forage sorghum	-0.71ab	0.69ab	1.13ab	-1.2ab	2.02a	-1.75ab

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Putative crop (PC)¶	1	8.21	0.0053
Cover crop (CC)	5	0.90	0.4878
PC x CC	5	0.18	0.9691

†Means for each factor represents the change in soil carbon-to-nitrogen ratio between each respective cover crop's planting and termination times.
‡Cover crop did not produce a stand in the specified growing year.
§Within each set of means, values followed by the same letter are not significantly different (α = 0.05).
¶PC = Putative crop rotation, CC = Cover crop.

Table B.30. Means and analysis of variance of the change in soil carbon-to-nitrogen ratio (percent carbon) in soil samples collected from plots where six cover crops were sampled at putative corn and forage sorghum planting times in the spring of 2011 in Hutchinson, Kansas.

	Cover crop					
Factor	Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat
	----------------------	----------------------	---------------------- %	----------------------	----------------------	----------------------
Putative corn†	---‡	-0.7c§	---	-0.7c	-0.8c	-0.6c
Putative forage sorghum	2.7a	2.3ab	1.4b	1.98ab	2.5ab	2.0ab

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Putative crop (PC)¶	1	136.96	0.0053
Cover crop (CC)	5	0.38	0.8585
PC x CC	5	0.83	0.5347

†Means for each factor represents the change in soil carbon-to-nitrogen ratio between each respective cover crop's planting and termination times.

‡Cover crop did not produce a stand in the specified growing year.

§Within each set of means, values followed by the same letter are not significantly different (α = 0.05).

¶PC = Putative crop rotation, CC = Cover crop.

Table B.31. Means and analysis of variance of the change in soil carbon-to-nitrogen ratio (percent carbon) in soil samples collected from plots where six cover crops were sampled at putative corn and forage sorghum planting times in the spring of 2012 in Manhattan, Kansas.

	Cover crop					
Factor	Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat
	---%---					
Putative corn†	---‡	---	---	-0.1bc§	---	-0.8c
Putative forage sorghum	---	---	---	5.4a	---	2.2b

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Putative crop (PC)¶	1	5.97	0.0167
Cover crop (CC)	5	2.32	0.0509
PC x CC	5	2.72	0.0253

†Means for each factor represents the change in soil carbon-to-nitrogen ratio between each respective cover crop's planting and termination times.

‡Cover crop did not produce a stand in the specified growing year.

§Within each set of means, values followed by the same letter are not significantly different ($\alpha = 0.05$).

¶PC = Putative crop rotation, CC = Cover crop.

Table B.32. Means and analysis of variance of the change in soil carbon-to-nitrogen ratio (percent carbon) in soil samples collected from plots where six cover crops were sampled at putative corn and forage sorghum planting times in the spring of 2012 in Hutchinson, Kansas.

	Cover crop					
Factor	Alfalfa	Austrian winter pea	Red clover	Triticale	Winter oats	Winter wheat
	----------	----------	----------	%	----------	----------
Putative corn†	---‡	---	---	13.3b§	13.9b	16.9a
Putative forage sorghum	---	---	---	-0.9cd	-0.4cd	-1.9d

	ANOVA		
Source of Variation	DF	F Value	Pr > F
Putative crop (PC)¶	1	414.73	<0.0001
Cover crop (CC)	5	63.51	<0.0001
PC x CC	5	87.88	<0.0001

†Means for each factor represents the change in soil carbon-to-nitrogen ratio between each respective cover crop's planting and termination times.
‡Cover crop did not produce a stand in the specified growing year.
§Within each set of means, values followed by the same letter are not significantly different ($\alpha = 0.05$).
¶PC = Putative crop rotation, CC = Cover crop.

Appendix C

Water use efficiency of six cover crops

Cover crops are crops grown to protect soil from erosion and loss of nutrients by leaching. It is desirable to have cover crops that not only hold the soil in place but also are efficient in using water. Water use efficiency is defined as the biomass produced divided by the water consumed to produce that biomass (Kirkham, 2011, p. 225). Little information exists concerning the water use efficiency of different cover crops. One way to determine water use efficiency is to analyze the carbon isotope ratio of leaves. The number, called the $\delta^{13}C$, represents the difference between the ratio of ^{13}C-^{12}C found in a given sample and the ratio that exists in a standard. The ratio is expressed as a per mil ($^{o}/_{oo}$) deviation from the standard. In plants with the C_3 photosynthetic system, an inverse relationship exists between the carbon isotope ratio and water use efficiency (Kirkham, 2011, p. 110-113). That is, plants with the least negative value of $\delta^{13}C$ have the highest water use efficiency.

Because no one had determined the water use efficiency of cover crops in Kansas by measuring the carbon isotope ratio, six cover crops were grown and their ratios were determined. The crops, all with C_3 photosynthesis, were planted in the falls of 2009 and 2010 at three locations in Kansas: Manhattan in the northeastern part of the state; Hutchinson in the south central part of the state; and Tribune, in the western part of the state. The six crops were three grain crops and three legumes, as follows: winter wheat (*Triticum aestivum* L.), triticale (X *Triticosecale*; *Triticum* x *Secale*), oat (*Avena sativa* L.), Austrian winter pea (*Pisum sativum* var. *arvense* Poir.), red clover (*Trifolium pratense* L.), and alfalfa (*Medicago sativa* L.). Only pea and wheat were grown at Tribune. In the springs of 2010 and 2011, an area 1 m^2 from each plot was harvested. The leaves were ground, and a sample was taken and placed in 120 cm^3 plastic container and submitted to the Stable Isotope Mass Spectrometry Laboratory in the Division of Biology at Kansas State University. The laboratory determined the $\delta^{13}C$ of the different crops as well as the carbon concentration in the leaves. Tables C.1 and C.2 show the results. In table C.1, the legumes (alfalfa, clover, and pea) are grouped together in the second, third, and fourth columns from the left, and the non-legumes (oat, triticale, and wheat) are grouped together in the first, second, and third columns from the right.

Differences between the legumes and non-legumes were not obvious in Hutchinson in either year or in Manhattan in 2010. However, in Manhattan in 2011, when there was a robust sample size for each crop (n=8), the three non-legumes (oat, triticale, and wheat) had the least negative $\delta^{13}C$ values. Wheat had the least negative $\delta^{13}C$ of all cover crops, and its value differed from the next value (triticale) by almost 2 $^{o}/_{oo}$. The three legumes (alfalfa, clover, and pea) had the most negative $\delta^{13}C$ values, and alfalfa had the most negative one. Alfalfa differed from wheat by 4.04 $^{o}/_{oo}$. In Hutchinson in 2011, wheat also had the least negative $\delta^{13}C$ value, and alfalfa had the most negative one. Wheat differed from alfalfa by 2.17 $^{o}/_{oo}$. The differences between the legumes and non-legumes were especially evident in Tribune under the irrigated conditions. Only pea and wheat were the cover crops at Tribune. In 2010, the sample size was too small to make any conclusions. However, when the sample size increased to 15, the difference between the legume and the non-legume became significant. Wheat differed from pea by 1.28 $^{o}/_{oo}$.

For an unknown reason, the carbon concentration of the leaves of the legumes was higher than that of the leaves of the non-legumes. In 2011 in Tribune, wheat (30.95% C) and pea (40.88% C) differed by almost 10% in their carbon concentration.

Using carbon isotope discrimination is an easy way to screen for water use efficiency. Only the leaves need to be sampled. The method negates the laborious measurements of soil water content with neutron probes that are necessary to determine water use during a season. And dry weight determinations of total yield at harvest are not needed.

Because wheat had the least negative $\delta^{13}C$ value, the results indicated that wheat should be planted to increase the water use efficiency of cover crops in Kansas.

Table C.1. Carbon isotope ratio and carbon concentration in biomass at harvest in 2010 and 2011 of six cover crops grown in the winters of 2009-2010 and 2010-2011 in Kansas at three locations: Manhattan, Hutchinson, and Tribune. Carbon concentration was determined only in 2011. Plants grown in Manhattan and Hutchinson were grown dryland. Plants grown at Tribune grew in plots that had been irrigated. Mean and standard deviation are shown. Number of samples (n) for each mean is given below each value for carbon isotope ratio. The same samples were used to get percent carbon.

Location & year of sampling	Alfalfa	Red Clover	Pea	Winter Oats	Triticale	Winter Wheat
	------$\delta^{13}C$, ‰------					
Hutchinson						
2010	-27.30 ±0.12 n=6	-27.55 ±0.34 n=6	-27.88 ±1.06 n=8	-28.57 ±0.63 n=2	-27.75 ±0.01 n=6	-27.64 ±1.07 n=3
2011	-28.62 ±0.27 n=8	-26.94 ±0.47 n=8	-26.22 ±0.11 n=8	-27.95 ±0.49 n=8	-26.40 ±0.67 n=8	-26.45 ±0.17 n=8
Manhattan						
2010	-29.19 ±0.06 n=4	-29.57 ±0.12 n=10	-29.00 ±0.26 n=8	-29.36 ±0.04 n=6	-29.08 ±0.26 n=6	-29.89 ±0.11 n=2
2011	-31.35 ±0.66 n=8	-30.48 ±0.15 n=8	-29.52 ±0.84 n=8	-29.07 ±0.15 n=8	-29.02 ±0.05 n=7	-27.31 ±0.31 n=8
Tribune						
2010	…[†]	…	-27.23 ±0.74 n=5	…	…	-27.11 ±0.31 n=4
2011	…	…	-27.66 ±0.02 n=15	…	…	-26.38 ±0.25 n=15
	------C, %------					
Hutchinson						
2011	43.19±0.14	42.98±0.14	40.96±0.56	39.39±2.29	39.84±1.83	37.38±1.46
Manhattan						
2011	39.46±0.89	37.59±1.54	39.70±1.82	31.92±2.65	30.71±9.66	34.41±1.86
Tribune						
2011	…	…	40.88±0.40	…	…	30.95±2.77

[†]Not determined

Table C.2. Carbon isotope ratio in leaves of two cover crops, Austrian winter pea and winter wheat, grown with and without added nitrogen in Tribune, Kansas, and harvested in 2011. In the forage sorghum-corn rotation, the cover crops were planted after corn. In the forage sorghum-forage sorghum rotation, the cover crops were planted after forage sorghum. Each value is an individual measurement.

	Replication			
Treatment	1	2	3	4
	-------------------- $\delta^{13}C$, $^{o}/_{oo}$ --------------------			
Forage sorghum-corn rotation				
Winter pea, 0 lb/A N	-27.51	-26.89	-27.37	-28.88
Winter pea, 90 lb/A N	-28.11	-28.47	-27.94	-27.36
Winter wheat, 0 lb/A N	-25.84	-26.78	-27.01	-26.70
Winter wheat 90 lb/A N	-26.40	-25.28	-26.61	-26.87
Forage sorghum-forage sorghum rotation				
Winter pea, 0 lb/A N	-27.06	-28.23	-28.22	-27.06
Winter pea, 90 lb/A N	-27.94	-28.53	-27.01	-25.75
Winter wheat, 0 lb/A N	-25.93	-24.81	-26.62	-25.18
Winter wheat, 90 lb/A N	-25.18	-26.40	-25.82	-26.66