REGIONAL ASSESSMENT OF SHORT-TERM IMPACTS OF CORN STOVER REMOVAL FOR BIOENERGY ON SOIL QUALITY AND CROP PRODUCTION

by

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B.S., Northern Illinois University, 2009

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Agronomy
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2011

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Abstract

The U.S. agricultural sector is in a prime position to provide crop residues such as corn (*Zea mays* L.) stover as feedstock for large-scale bioenergy production. While producing renewable energy from biomass resources is a worthy initiative, excessive removal of corn stover from agricultural fields has the potential to increase soil erosion, degrade soil properties, and reduce corn yields. A need exists to objectively assess stover removal impacts on agriculture and the environment on regional scales. This project assessed the effects of removing various rates of corn stover on runoff and erosion and changes in soil physical properties and corn yields on a regional scale across three soils at Colby, Hugoton, and Ottawa in Kansas, USA. The soils were Ulysses silt loam (Fine-silty, mixed, superactive, mesic Aridic Haplustolls) at Colby, Hugoton loam (Fine-silty, mixed, superactive, mesic Aridic Argiustolls) at Hugoton, and Woodson silt loam (Fine, smectitic, thermic Abruptic Argiaquolls) at Ottawa, all with slopes ≤ 1%. Five stover treatments were studied that consisted of removing 0, 25, 50, 75, and 100% of stover after harvest from no-till and strip-till continuous corn plots. Simulated rainfall was applied in spring 2010 at rates representing 5 yr return intervals at each site and included a dry and wet run. Runoff increased with an increase in stover removal at Colby and Hugoton, but not at Ottawa. At Colby, stover removal rates as low as 25% caused runoff to occur 16 min sooner and increased sediment loss. At this site, runoff and sediment-carbon (C) loss increased as removal rates exceeded 25%. At Hugoton, complete stover removal increased loss by total N by 0.34, total P loss by 0.07, PO_4-P by 0.003 and NO_3-N by 0.007 kg ha^{-1}. At Ottawa, PO_4-P loss decreased by 0.001 kg ha^{-1} with 25% removal and by 0.003 kg ha^{-1} with 50% removal. Mean weight diameter (MWD) of wet aggregates decreased with an increase in stover removal on all soils. At Ottawa, stover removal at 75% reduced soil C in the top 5 cm by 1.57 Mg ha^{-1}. Soil volumetric water content decreased with stover removal at Colby and Ottawa, but was variable at Hugoton. Soil temperature tended to increase with stover removal during summer months and decrease during winter months. Soil temperature also fluctuated much more widely with stover removal, resulting in more freeze-thaw events compared to no stover removal. No effect of stover removal on soil water retention was observed on any of the soils. In 2009, removal rates ≥50% resulted in greater grain yield at Colby, while removal rates ≥75% resulted in greater grain yields at Ottawa in 2009 and 2010. Results from the first two years of stover management suggest that stover removal at rates above 25% for bioenergy production increased water erosion, degraded soil structural properties, and altered soil water and temperature regimes. Higher rates of removal (≥75%) can also reduce soil C concentration in the short-term in rainfed regions. However, grain yields may be enhanced by stover removal from irrigated soils and from rainfed soils with adequate moisture. Overall, the increase in water erosion and alteration in soil properties in the short-term suggest that stover removal can detrimentally affect water quality and soil productivity in Kansas. Further long-term monitoring is warranted to conclusively discern stover removal implications.

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Acknowledgements

I would like to express thanks and appreciation to the following individuals:

Drs. DeAnn Presley and Humberto Blanco for serving as my co-major professors and guiding me through my graduate work

Dr. Charles Rice for serving on my advisory committee and teaching me about the fascinating world of soil microbes

The Kansas Corn Commission for financially supporting this project

Dr. Nathan Nelson for guidance in analyzing runoff samples

Dr. Gerard Kluitenberg for extensive assistance with soil water retention

Marvin Farmer and Dr. Brian Olson at the KSU Northwest Research Farm, Keith Janssen and Jim Kimble at the KSU East-Central Research Farm, and private producers in Hugoton, KS for maintaining and providing the study locations

Graduate students Nick Ihde, Ashley Harms, Tony Whitehair for assistance with fieldwork

Mike Eckroat at the research center in Hays, KS for help with rainfall simulations

Dr. Gary Pierzynksi for use of his rainfall simulator

Chapter 1 - Outline and Objectives

Large-scale harvesting of crop residues as feedstock for bioenergy production may soon occur in the United States. Therefore, this project aims to add to the scientific knowledge base the regional impacts of crop residue removal on agriculture and the environment. Specifically, this project focuses on the impacts of corn stover removal on soil erosion by water, soil physical properties, and crop production at three contrasting sites in Kansas. Soil physical properties were monitored between spring 2009 and spring 2011 and a one-time rainfall simulation study was conducted in spring 2010 to assess the impacts of stover removal on runoff and erosion across three ongoing stover removal experiments. This regional project examines the short-term ($\leq$ 2 yr) effects of different rates of corn stover removal for bioenergy production on:

1. Losses of sediment, C, and nutrients in runoff as indicators of soil degradation and non-point source pollutants affecting water quality.
2. Soil physical properties including aggregate stability, water retention characteristics, soil water content, soil temperature, and soil total C.
3. Corn grain and stover yield as indicators of crop sustainability.

An overall abstract discussing both studies will be presented early in the manuscript. Additionally, each study chapter will contain a separate, more detailed abstract. A review of the literature regarding the effects of crop residue removal on soil erosion and soil physical properties will be presented in Chapter 2. Each literature review will introduce the topic, discuss the processes involved and resulting implications, and will identify research needs. Chapter 3 will consist of the first study entitled “Effects of Corn Stover Removal on Soil Erosion by Water”. Chapter 4 will present the second study entitled “Effects of Corn Stover Removal on Soil Properties and Crop Production”. Both study chapters will include an abstract, introduction, materials and methods, results and discussion, and conclusion section. Tables, figures, and references can be found at the end of each study chapter. Chapter 5 will synthesize the results of both the erosion and physical properties chapters, and discuss the overall implications of corn stover removal as bioenergy feedstock in Kansas.

Chapter 2 - Review of Related Research

Crop residues are the inedible, above-ground, non-grain portion of crops remaining on the field after harvest (Lal, 2005). Residues have direct and indirect roles in enhancing and conserving the soil resource by increasing desirable characteristics and reducing erosion of fertile topsoil (Karlen et al., 1994; Lal, 2005; Mann et al., 2002). Residues shield the soil surface from the damaging impact of raindrops and reduce soil erosion, fluctuations in soil temperature, and evaporation. Crop residues are the main source of soil organic matter, which affects soil fertility, aggregate stability, infiltration, microbial activity, and other soil properties (Flerchinger et al., 2003; Lal, 2005; Andrews, 2006; Blanco-Canqui and Lal, 2009). There are many competing uses for residue, however, including household fuel and construction material, animal bedding, fodder, and, more recently, bioenergy production (Lal, 2004).

Crop residue can be utilized both as a combustion source for electricity generation and as a feedstock for the production of cellulosic ethanol due to advances in cellulosic conversion technology. Many countries are becoming interested in the utilization of residues for the production of alternative fuels in order to meet the rising global need for the reduction of greenhouse gas emissions and fossil fuel dependence, and to provide energy to an ever-increasing population (DiPardo, 2000; Gray et al., 2006; Energy Information Administration, 2009). In fact, it has recently been mandated that a minimum of 162 to 208 million hectoliters of cellulosic ethanol be produced from crop residue in the U.S.A. by 2022 according to the Renewable Fuels Standard (USDA, 2010).

Corn is one of the most widely-grown crops in the U.S. Consequently, corn stover, in particular, is being considered as a prime feedstock for cellulosic ethanol in this region due to its abundance and perceived availability. Furthermore, corn stover is produced domestically and, unlike grain-based bioenergy feedstock, does not compete with food production. However, the large-scale harvest of corn stover for bioenergy production may come at the expense of agricultural sustainability and environmental quality in some regions.

The impacts of stover removal on crop yields, soil and water conservation, and C sequestration have not been well documented in Kansas. Excessive removal of stover may increase risks of soil erosion, reduce soil organic matter and nutrient pools, degrade soil quality, and reduce crop yields. On some soils, a fraction of stover produced may be available for removal without adversely impacting crop yields and soil and water resources, but data on permissible stover removal rates are limited for rain-fed and irrigated corn in Kansas. Regional studies assessing the potential implications of stover removal for bioenergy feedstock are warranted.

Crop Residue Removal and Soil Erosion

The erosion of sediment and nutrients from agricultural fields is a serious hindrance to goals of long-term agricultural sustainability and environmental conservation. The removal of crop residues for off-farm uses can promote runoff and soil erosion from agricultural fields. Runoff has the ability to erode the soil surface and transport sediment and nutrients off-site, resulting in soil degradation and non-point source pollution (Rhoton et al., 2002; Mann et al., 2002). The use of crop residues as mulch can limit the extent of erosion by absorbing the impact energy of raindrops, decreasing runoff velocity, and altering soil properties in ways that favor water infiltration and increase aggregate stability (Lal, 2009).

Infiltration

Soil erosion is most likely to occur when rainfall rates exceed the infiltration capacity of the soil. Previous research has indicated variability in the effect of crop residue removal on water infiltration into soil. Triplett et al. (1968) observed increased infiltration rates and total infiltration with 70% corn stover cover as compared to 12 and 45% cover on a Wooster silt loam in Ohio, which was attributed to the positive impact of stover on soil structural stability. Blanco-Canqui and Lal (2007) conducted infiltration experiments in Ohio on a Celina silt loam (2% slope), a Rayne silt loam (6% slope), and a Hoytville clay loam (<1% slope) subjected to five rates (0, 25, 50, 75, and 100%) of corn stover removal. They observed negative impacts of stover removal on infiltration rates on the Celina and Rayne silt loams, but no effect on the Hoytville clay loam. This differential response was attributed to a higher amount of surface crusting on the silt loam soils with low amounts of stover than on the clay loam. Additionally, the low-stover treatments had fewer earthworm channels, which serve as conduits for infiltrating water.

Similar effects of residue removal on infiltration were observed in Illinois. Simulated rainfall at a rate of 70 mm h^{-1} for 90 min was used to examine infiltration rates in Illinois on a Corwin silt loam with corn stover and a Saybrook silt loam with soybean residue, both managed under no-till with residues either removed or retained (Bradford and Huang, 1994). Soil cover was 0 and 100% for the corn stover and 0 and 60% for the soybean residues for the removed and retained treatments, respectively, with the retained treatments corresponding to 11.2 Mg ha^{-1} of corn residue and 6.4 Mg ha^{-1} of soybean residue. For both soils and crop residue types, a decrease in infiltration rate was observed with residue removal. Infiltration rate was >70 mm h^{-1} when both corn and soybean residue was retained, and decreased to 52.9 mm h^{-1} when corn stover was removed and 41.2 mm h^{-1} when soybean residue was removed.

In some instances, however, residue removal has little impact on infiltration. On a Pullman clay loam with < 1% slope in Texas, Unger (1992) conducted rainfall simulations on no-till treatments with dryland grain sorghum and winter wheat residues either removed or retained. The surface cover for the removed and retained treatments was 2.1 and 9.6% for sorghum, and 15.6 and 68.4% for wheat, respectively. Rainfall was applied at an intensity of 52 mm h^{-1}. No differences in infiltration rate were observed between the residue removed and retained treatments for both crops. Similarly, a study by Moebius-Clune et al. (2008) found no adverse effects of complete corn stover removal on the infiltration rates of a Raynham silt loam (slope unknown) in Chazy, NY, managed under no-till.

Sediment Loss

While the impact of residue removal on infiltration rates can be variable, the effects of complete removal of crop residue from agricultural fields on sediment loss are more consistent. The magnitude of these losses varies according to soil type, slope, tillage practices, and precipitation intensity. A majority of the studies involving residue removal have compared runoff and soil erosion rates between various tillage systems with no removal or complete removal of residue. For instance, a decrease in surface residue cover resulted in a large sediment loss in spite of lack of differences in water infiltration rates in the study described previously by Unger (1992). Likewise, Bradford and Huang (1994) found that soil loss increased from 0.01 to 0.13 kg m^{-2} h^{-1} when corn stover was removed and from 0.01 to 0.16 kg m^{-2} h^{-1} when soybean residue was removed as compared to no removal.

Studies examining multiple levels of residue cover on disturbed soil found that even small rates of residue cover considerably reduced soil erosion (Meyer et al., 1970; Gilley et al., 1986a,b; Adekalu et al., 2007) and nutrient loss (Avalos et al., 2009). Laflen and Colvin (1981) conducted rainfall simulations in Iowa on a Clarion sandy loam and a Monona silt loam soil with different tillage practices and stover levels. The simulations consisted of three separate runs which were conducted at different times throughout the year. The percentage of the soil surface covered by stover varied throughout the year, and therefore differed for each of the three rainfall simulations; stover covered 42, 24, and 30% of the sandy loam, and 29, 36, and 43% of the silt loam soil surface during runs 1, 2, and 3, respectively. Rainfall was applied at a constant rate of 63 mm h^{-1} for a 90 min run. For the no-till treatments, the authors found that decreases in corn stover cover resulted in increased soil erosion, with higher magnitudes of runoff and erosion on the silt loam than on the sandy loam soil. During the rainfall simulations, the authors also observed that stover created small ponds of water which allowed sediment deposition, reducing soil erosion.

Few erosion experiments have been conducted with multiple residue levels on minimally disturbed soil. Lindstrom (1986) studied the effects of tillage and three levels corn stover on runoff and erosion from an Egan-Wentworth silty clay loam (5.8% slope) in South Dakota under natural rainfall events. The three stover treatments consisted of 1.12, 2.24, and 4.48 Mg ha^{-1} stover, which correlated to 33, 46, and 56% soil cover, respectively. Within the no-till treatments, the author observed increased sediment losses with increased stover removal. During a storm that produced 52 mm of precipitation, sediment losses of 5.87, 1.66, and 0.92 kg ha^{-1} occurred with 33, 46, and 56% stover cover, respectively. The losses were greatest early in the growing season and diminished as the crop canopy cover developed. Blanco-Canqui et al. (2009) conducted 115 mm h^{-1}-intensity rainfall simulations on a Harney silt loam (6% slope) with varying amounts (0, 25, 50, 75, and 100%) of no-till wheat residue removal. The wheat field had been under no-till management for 20 yr, and residue removal treatments were imposed just before rainfall simulations. While no differences in runoff rate were observed between no-till wheat residue removal treatments, an exponential increase in sediment loss occurred with increases in wheat residue removal. Complete removal increased sediment loss from 0.9 to 7.2 Mg ha^{-1}.

One study in particular has suggested that the relationship between residue removal and sediment loss may not always be linear. In a rainfall simulation study that took place on a silt loam with winter wheat residue cover, Jin et al., (2009) observed increased sediment loads with increasing rainfall intensities, and a threefold increase in sediment loss with complete removal of residue. However, it was observed that compared to bare soil, sparse residue cover actually served to promote sediment loss by the creation of concentrated flow paths that were more effective at detaching and transporting sediment.

Erosion of Carbon and Nutrients

When left on the soil surface, crop residues provide two benefits to the soil organic C (SOC) pool: they are a source of organic carbon, and also help to protect organic-rich soil aggregates from erosion. Because water erosion most easily carries away smaller-sized particles, runoff tends to be enriched in particulate organic carbon, dissolved organic carbon, and clay sized particles (Starr et al., 2000). Carbon that is transported by rill and interrill erosion may be more likely to undergo mineralization and be transferred from soil to atmospheric pools (Kuhn et al., 2009). Jin et al. (2009) studied losses of SOC from a silt loam with four rates of wheat residue (0, 25, 50, and 75%) cover and three rainfall intensities (65, 85, and 105 mm h^{-1}) in a laboratory setting. The authors observed an increase in sediment and SOC loss with increased rainfall intensity, as well as a decrease in sediment and SOC loss with increased residue cover. Additionally, they observed that finer particles (0-20μm) were preferentially eroded from the plots, which are more likely to contain SOC than coarser-textured particles. Soil organic carbon concentration in runoff is correlated with sediment amount (Owens et al., 2002; Starr et al., 2008). Therefore, management practices which reduce sediment loss have also a large potential of reducing SOC loss and transference of SOC to atmospheric C (Owens et al., 2002).

Studies examining SOC and nutrient losses as a function of corn stover removal are sparse. Lindstrom (1986) studied the effects of tillage and three levels corn stover consisting of 1.12, 2.24, and 4.48 Mg ha^{-1} stover, which correlated to 33, 46, and 56% ground cover, respectively, on losses of N, P, and K in runoff and eroded soil. Within the no-till treatments, the author observed increased losses of nutrients with increased stover removal. Soils with 33% stover cover increased N, P, and K loss by 98, 37, and 29 kg ha^{-1}, respectively, compared to soils with 46% stover cover. Blanco-Canqui et al. (2009) report an exponential increase in SOC loss and increases in total N and P loss with increased no-till wheat residue removal rates. Complete residue removal resulted in a 200 kg ha^{-1} increase in SOC loss compared to no removal, while total N and P loss increased with wheat residue removal rates in excess of 75%. Wheat residue removal did not significantly impact losses of PO_4-P, NH_4-N, and NO_3-N in runoff water.

Significant amounts of C and soluble nutrients may exist in runoff even from fields with adequate stover cover. In a laboratory rainfall simulation experiment, Schreiber (1999) observed that nutrient leachate concentrations increased with increasing rates of corn stover cover. Nutrients were leached in the decreasing order of TOC >> PO_4-P > NO_3-N > NH_4-N, which may be due to the longer contact time between water and stover. The highest concentrations of nutrients were leached at the start of simulated rainfall, possible attributed to the rapid detachment of easily-desorbed nutrients on the stover surface.

Estimating Water Erosion with RUSLE2

The Revised Universal Soil Loss Equation 2 (RUSLE2) is a soil erosion model that takes into account several variables in order to estimate long-term average annual soil loss from cultivated land (Wischmeier and Smith, 1965). The factors that influence the magnitude of soil loss are described by the basic RUSLE equation:

$$A = (R)\ (K)\ (LS)\ (C)\ (P)$$

where: A = average annual soil loss,

R = erosivity of the particular climate

K = inherent soil erodibility

LS = slope length and steepness

C = cover management

P = supporting practices

The cover management (C) factor of the RUSLE2 is the variable that is most easily manipulated in order to decrease soil loss. The amount of residue existing on a field directly affects the cover management factor of the RUSLE2, and thus contributes to the estimated soil loss.

Estimates of U.S. corn stover available for harvest have been made with soil erosion as the limiting factor. These studies were conducted using the Revised Universal Soil Loss Equation (RUSLE) and the Wind Erosion Equation (WEQ) for prediction of water and wind erosion, respectively. These equations were used to predict how much stover could be harvested without exceeding the tolerable soil loss limit (T), a set amount of soil loss that, if exceeded, is considered intolerable. Using these models, Nelson (2002) estimated that an average of over 42 million Mg of corn stover were available for harvest in the U.S. from 1995-1997, with 1.8 million Mg of corn stover available in Kansas. Graham et al. (2007) estimated that over 100 million Mg of harvestable corn stover were available in the U.S. annually from 1995-2000, with 597,000 Mg of stover available in Kansas.

RUSLE2 software can also be used to obtain estimates of soil erosion and the Soil Conditioning Index (SCI). The SCI uses soil texture, erosion estimates, and field operation information to predict trends in soil organic matter to a depth of 10 cm; an SCI of 0 indicates that soil organic matter is likely to be maintained, while positive or negative SCI values indicate that organic matter is likely to increase or decrease, respectively, over time.

Implications of Residue Management-Induced Runoff

Soil erosion from crop fields can have detrimental effects for both agriculture and the environment. Removal of crop residues from the soil surface induces changes in soil properties which promotes runoff occurrence from agricultural fields. The C- and nutrient-rich topsoil is preferentially transported during erosion events, reducing soil fertility in and increasing CO2 emissions from agricultural systems. Producers would therefore need to add extra amounts of fertilizers to offset the losses that occurred via erosion. Furthermore, nutrients lost in runoff from agricultural fields can become non-point source pollutants, reducing water quality (Rhoton et al., 2002). The enriched nutrient content of the water bodies fuels growth of non-desirable flora such as blue-green algae and cyanobacteria, which can be lethal to humans and animals. Increased erosion from agricultural fields due to stover removal additionally has the potential to overload lakes and reservoirs with sediment, creating unfavorable habitats for aquatic organisms and undesirable recreation areas for humans. Crop residues limit the extent of erosion by absorbing the impact energy of falling raindrops, preventing soil crust formation, decreasing runoff velocity, and altering soil properties in ways that favor water infiltration and increase aggregate stability (Karlen et al., 1994). Adequate residue cover, therefore, is necessary in order to minimize runoff and limit the transport of sediment, C, and nutrients from agricultural fields into neighboring waterways.

Crop Residue Removal Effects on Soil Properties and Crop Production

Soil Properties

Bulk Density

Previous research has indicated that the impacts of corn stover removal on soil bulk density are variable. Karlen et al. (1994) studied the effects of three stover levels (removed, normal, and double) on a variety of properties of Rozetta and Palsgrove silt loam soils (10-13% slope) under no-till management after 10 yr in Wisconsin. They observed no differences in soil bulk density to a depth of 50 cm between stover removal, and normal and double stover treatments. Likewise, Moebius-Clune et al. (2008) investigated the impact of complete stover removal on the physical properties of a Raynham silt loam, managed under no-till for 32 yr in Chazy, NY, and observed no changes in bulk density due to complete stover removal.

While no effects of stover removal on bulk density were observed on silt loam soils in Wisconsin and New York, significant changes have been documented on silt loam soils in Ohio. Blanco-Canqui and Lal (2007) studied the impacts of 0, 25, 50, 75, and 100% stover removal rates on various physical properties of a Rayne silt loam (6% slope), Celina silt loam (2% slope), and a Hoytville clay loam (1% slope) managed under no-till after 2.5 yr in Ohio. Unlike Karlen et al. (1994) and Moebius-Clune et al. (2008), the authors found that increases in stover removal resulted in increased soil bulk density at 0-10 cm depth for the silt loams, but not for the clay loam. Relative to no stover removal, removal rate of 50% significantly increased bulk density by about 0.12 Mg m^{-3} on the Rayne silt loam, while removal of 75% stover increased bulk density by 0.15 Mg m^{-3} on the Celina silt loam. Changes in bulk density due to stover removal may concomitantly affect soil porosity. These results indicate that stover removal effects on soil properties such as bulk density may depend on soil type and ecoregion.

Water-Stable Aggregates

The effects of corn stover removal on aggregate stability are more consistent than those on bulk density. Karlen et al. (1994) found that double stover treatments had greater macroaggregate stability with wet sieving compared to normal stover and stover removed treatments in the surface 5 cm of the soil. Double stover treatments increased macroaggregate stability by 18% relative to stover removal. Blanco-Canqui et al. (2006) determined the impact of 1 yr of stover removal on water-stable aggregates from the soils described previously (Blanco-Canqui and Lal, 2007), and observed decreases in mean-weight diameter (MWD) of water-stable aggregates with increases in stover removal. In this study, removal rates as low as 25% significantly decreased MWD on the Celina silt loam. Additionally, the distribution of WSA was impacted by stover removal; higher percentages of macroaggregates sized >4.75 mm were observed with low rates of removal, while higher percentages of microaggregates sized <0.25 mm were observed with high rates of stover removal. They observed that removing 100 and 75% of stover resulted in an 86% increase in microaggregates as compared to no removal on the Rayne silt loam. Microaggregates increased 1.3 fold with 100% stover removal compared to lower rates of removal on the Hoytville clay loam. Removal rates as low as 25% resulted in a 48% decrease in macroaggregates sized >4.75 mm relative to no stover removal on the Celina silt loam. Likewise, Moebius-Clune et al., (2008) observed that complete stover removal from no-till soil reduced water-stable aggregates by 0.08 g g^{-1} (16%) as compared to stover retention.

Carbon and Nitrogen

Crop residues provide the soil with a source of C when they remain on the field after harvest or are used as mulch. The presence of SOC in agricultural fields is good for both soil and the environment for a number of reasons. First, the decomposition of crop residues and subsequent incorporation of C into the soil reduces C losses to the atmosphere, serving as a C sink. Second, residue-derived SOC is essential for filtering pollutants (e.g. pesticides) in runoff (Blanco-Canqui and Lal, 2009). Third, organic matter improves the ability of the soil to absorb and retain water. Finally, the presence of SOC often improves soil infiltration and drainage by promoting the development of stable aggregates (Blanco-Canqui and Lal, 2004). Soil C and biota aid in the formation of stable aggregates by releasing substances that act like natural glue, binding soil particles together. Indeed, aggregate stability is a property that can directly affect soil erodibility.

Based on previous research, soil C has decreased with increases in corn stover removal. Karlen et al. (1994) observed an increase in total C of approximately 8 and 24 g kg^{-1} (50 and 150% increase) in aggregates of the top 5 cm of no-till, silt loam soil with normal and double corn stover treatments, respectively, compared to stover removal after 10 yr of stover management. Blanco-Canqui and Lal (2007) found that increases in stover removal rates resulted in decreases in SOC on Rayne and Celina silt loams, but had no effect on a Hoytville clay loam over 2.5 yr of stover management in Ohio. Removal rate of 75% significantly decreased SOC in the top 2 cm of soil by 1.95 Mg ha^{-1} for the Rayne silt loam, while 50% removal on the Celina silt loam decreased SOC by approximately 0.70 Mg ha^{-1}, relative to no stover removal.

Soil Temperature and Moisture

Corn stover removal also affects soil temperature and moisture content. Blanco-Canqui and Lal (2007), in the study described earlier, observed that maximum daytime soil temperature of the top 5 cm of soil increased with increases in stover removal for the three soils specified. Average daytime soil temperatures of the 0, 25, 50, 75, and 100% stover removal treatments were 23.6, 25.6, 27.4, 29.4, and 30.7 °C, respectively, on the Rayne silt loam in Ohio. Larger fluctuations in soil temperature have been observed in soils with low stover cover as compared to greater stover cover in Minnesota (Sharratt, 2002). Increases in gravimetric water content of 5.7 and 11% was observed in the top 5 cm of soil with normal and double stover treatments, respectively, as compared to stover removal in Wisconsin (Karlen et al., 1994). Evaporation was observed to be greater on bare soils than soil with 95% flat stover cover (Flerchinger et al., 2003).

Repeated freezing and thawing of the soil during winter seasons can physically disrupt soil aggregates and result in decreases in aggregate stability. Soils with complete stover removal are more susceptible to repeated freeze-thaw cycles and deeper frost depths than soils covered with flat stover (Flerchinger et al., 2003). Additionally, soils with low stover cover have been shown to freeze earlier and thaw later than soils with greater stover cover (Sharratt, 2002).

Soil Water Retention

Soil water retention tests directly measure how much water a particular soil can retain, and can also be used to determine the relative distribution of large and small pores. Stover removal degrades soil structure and alters pore-size distribution. These changes have the potential to limit the quantity of water that the soil can hold and that is available for plant root uptake. Therefore, stover removal may not be advisable in areas where water availability is an issue as it can potentially limit crop yields. Soil water retention characteristics have been observed to be negatively impacted by corn stover removal. Karlen et al. (1994) observed that double stover treatments increased plant available water by 2.6% in the top 7.5 cm of soil compared to stover removal treatments. Likewise, Blanco-Canqui and Lal (2007) observed that plant available water in the top 6 cm of soil decreased linearly for silt loam soils and quadratically for clay loam soils with increases in stover removal rate. Plant available water decreased by 0.50 cm on the Rayne silt loam and by 0.26 cm on the Celina silt loam with 75% removal, and by 0.66 cm on the Hoytville clay loam with 50% removal compared with no stover removal. Additionally, Moebius-Clune et al. (2008) observed that available water content of no-till soil decreased by 0.05 mm^{-3} when stover was harvested.

Crop Production

Crop residue may have direct and indirect impacts on crop production parameters. High rates of residue cover can deter seed-to-soil contact during planting and slow early-season soil warming in temperate regions, resulting in decreased germination rates and delayed seedling emergence. Indirect impacts of crop residue removal on crop production include alterations in soil physical properties that may impair root growth and seedling emergence, and lower nutrient and organic matter inputs into the soil. It is important to note, however, that impacts of residue removal on crop production can be highly variable (Blanco-Canqui and Lal, 2009).

Two studies in particular have found stover removal to negatively impact corn yield. Triplett et al. (1968) observed increases in yields with increased corn stover amounts over a three yr period on a Wooster silt loam in Ohio managed under no-till. Corn yields of the removed (5% soil cover), normal (45% cover), and double (70% cover) stover treatments were 4.49, 5.72, and 6.29 Mg ha^{-1}, respectively, averaged over three yr. Blanco-Canqui and Lal (2007), in the study described previously, observed a linear decrease in corn yield with increases in stover removal rate on the Rayne silt loam, but not on the Celina silt loam or Hoytville clay loam. Removal rates of 50 and 75% resulted in a 1.95 Mg ha^{-1} decrease in grain yield, and 100% removal decreased yield by 3.32 Mg ha^{-1} on the Rayne silt loam.

Some studies found mixed results concerning the impact of stover removal on corn yield. Karlen et al. (1994), in the study mentioned previously, monitored the effects of three stover levels (removed, normal, and double) on corn grain yield over a period of ten yr. They observed differences in grain yield between the treatments in three out of the ten yr. In 1981, the double stover treatment reduced yield by 2.05 Mg ha^{-1} relative to the removed and normal stover treatments. In 1983, normal and double stover treatments reduced yield by 0.5 and 1.0 Mg ha^{-1}, respectively, compared to stover removal. In 1989, however, the normal and double stover treatments increased grain yield by an average of 2.75 Mg ha^{-1} compared to stover removal.

Research Needs

Large-scale harvesting of corn stover as a bioenergy feedstock may occur in Kansas in the near future. To date, however, few studies have examined the effects of multiple rates of stover removal on runoff, erosion, soil physical properties, and crop production independent of tillage system. Even fewer studies concerning residue removal have been conducted in the arid and semiarid environments existing in Kansas. As the cellulosic ethanol industry gains popularity, data concerning stover-dependent soil characteristics, crop yields, and erosion are necessary in order to help determine acceptable rates of stover removal that maintain desirable soil properties and result in agricultural sustainability (Cruse and Herndl, 2009). Investigation of the impacts of stover removal on soil moisture is particularly needed in dry regions where crop production relies heavily upon irrigation systems that use water from dwindling aquifers. Furthermore, the effects of stover removal on soil properties and crop yields have been shown to vary geographically, increasing the need for site-specific research.

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Chapter 3 - Effects of Corn Stover Removal on Soil Erosion by Water

Abstract

Large-scale harvesting of corn (*Zea mays* L.) stover for bioenergy feedstock may occur in the near future. Indiscriminate removal of corn stover, however, can accelerate soil erosion and adversely affect agricultural sustainability and environmental quality. Soil-specific stover removal rates that minimize the erosion of soil, carbon, and nutrients from agricultural fields and limit the extent of soil and environmental degradation must be established. This study investigates the effects of removing multiple levels of stover from continuous no-till and strip-till corn systems on runoff, sediment, sediment-carbon (C), total nitrogen (N), total phosphorus (P), phosphate (PO_4-P), ammonium (NH_4-N), and nitrate (NO_3-N) loss on a regional scale across three soils at Colby, Hugoton, and Ottawa in Kansas, USA. The soils were a Ulysses silt loam (Fine-silty, mixed, superactive, mesic Aridic Haplustolls) at Colby, Hugoton loam (Fine-silty, mixed, superactive, mesic Aridic Argiustolls) at Hugoton, and a Woodson silt loam (Fine, smectitic, thermic Abruptic Argiaquolls) at Ottawa, all with slopes ≤1%. Five stover treatments that consisted of removing 0, 25, 50, 75, and 100% of stover after harvest were studied. Simulated rainfall was applied in spring 2010 at rates representing 5 yr return intervals at each site and included a dry and wet run. Runoff increased with an increase in stover removal at Colby and Hugoton, but not at Ottawa. At Colby, stover removal rates as low as 25% caused runoff to occur 16 min sooner and increased sediment loss. At this site, runoff and sediment-C loss increased as removal rates exceeded 25%. At Hugoton, complete stover removal increased loss by total N by 0.34, total P loss by 0.07, PO_4-P by 0.003 and NO_3-N by 0.007 kg ha^{-1}. At Ottawa, PO_4-P loss decreased by 0.001 kg ha^{-1} with 25% removal and by 0.003 kg ha^{-1} with 50% removal. Results from this study suggest that stover removal rates as low as 25% can increase losses of sediment, while rates >25% can increase sediment-C and nutrient loss from agricultural fields, potentially resulting in soil and environmental degradation.

Introduction

Crop residue is not a useless byproduct of grain production, but in fact has a variety of competing uses including soil and water conservation, livestock feed and bedding, and as household fuel and construction material for small landholders in developing countries (Lal, 2004; Johnson et al., 2010). The demand for crop residue has widened recently due to an increased need for renewable sources of energy. Corn stover in particular has been identified as a prime feedstock for bioenergy production in the U.S. because of its perceived ubiquitousness and availability (Wilhelm et al., 2004). Corn stover is produced domestically, does not compete with food production like grain-based ethanol, and can be utilized for energy, either as cellulosic ethanol or as a combustion source for electricity generation. It has recently been mandated that a minimum of 4.3 to 5.5 billion gallons of cellulosic ethanol be produced from crop residue by 2022 according to the Renewable Fuels Standard (USDA, 2010).

The removal of corn stover for bioenergy production, however, induces changes in soil properties which promote the runoff of precipitation from agricultural fields. Runoff erodes fertile topsoil and transports sediment, carbon, and nutrients off-site, resulting in soil degradation, non-point source pollution, and potential carbon dioxide emissions (Rhoton et al., 2002; Mann et al., 2002; Kuhn et al., 2009). Thus, the erosion of sediment and nutrients from agricultural fields is a serious hindrance to goals of long-term agricultural sustainability and environmental conservation. While complete removal of corn stover from agricultural fields for bioenergy production may jeopardize crop productivity as well as soil and environmental quality, partial removal without adverse effects may be possible on some soils.

Estimates of U.S. corn stover available for harvest have been made using models, with sediment loss as the limiting factor. Graham et al. (2007) estimated that over 100 million Mg of harvestable corn stover were available in the U.S. annually from 1995-2000, which corresponds to about 50% of total annual stover production. Few field studies, however, have examined the impacts of different stover levels on runoff and erosion. In an experiment investigating the effects of three levels of stover cover on soil erosion from no-till soils in Iowa, Laflen and Colvin (1981) found that decreases in corn stover cover resulted in increased sediment loss from a silt loam and a sandy loam. Lindstrom (1986) observed increased losses of sediment, N, P, and K with decreasing stover cover from no-till soil in Wisconsin.

Experimental data on the effects of various rates of stover removal on losses of sediment, carbon, and nutrients are lacking. Furthermore, runoff and erosion characteristics are not consistent geographically, but depend upon local climate, soil type, initial field conditions, and crop management (Gilley et al., 1986). Therefore, studies on a regional scale are needed to determine soil-specific residue removal rates that will minimize the erosion of soil, carbon, and nutrients from agricultural fields and limit the extent of soil and environmental degradation. Thus, the objectives of this study were to determine the effects of variable levels of corn stover removal on losses of sediment, sediment-C, total N, total P, PO_4-P, NH_4-N, and NO_3-N in runoff across three representative soils in Kansas.

Materials and Methods

Description of Study Sites and Soils

This rainfall simulation study was performed on three ongoing corn stover management experiments in Kansas in spring 2010. The three experimental sites were at the (1) Kansas State University (KSU)-Northwest Research Extension Center in Colby (39°23’ N, 101°03’ W, 969 m above sea level), (2) a private producer’s field near Hugoton (37°21’ N, 101°20’ W, 940 m above sea level), and (3) KSU-East Central Experiment Field in Ottawa (38°32' N, 95°15' W, 294 m above sea level) (Fig 3.1). These sites differ in soil texture, climate, and management practices (Table 3.1).

Two sites (Ottawa and Colby) are managed under no-till while the site at Hugoton is strip-tilled. Furthermore, the site at Ottawa is rain-fed while the sites at Colby and Hugoton are irrigated with center-pivot systems. Management practices prior to the experiment establishment varied among sites. Conventionally tilled, irrigated sunflower, corn, and soybeans were grown at Colby in 2006, 2007, and 2008, respectively. The site at Hugoton has been in strip-tilled, irrigated, continuous corn production since 2006. The Ottawa site has been in rainfed, no-till, continuous corn production since 2004.

Slope, determined using a clinometer, was ≤ 1% at all three sites. The texture (Table 3.2), depth, drainage class, runoff risk, and saturated hydraulic conductivity of the soils at the three study sites differed substantially. Texture was determined using the pipette method (Gee and

Bauder, 1986). The soil at Colby is a very deep, well drained, low-to-medium runoff risk soil with a moderately high saturated hydraulic conductivity and was formed in calcareous loess. The soil at Hugoton is a very deep, well drained, negligible runoff risk soil with a moderate saturated hydraulic conductivity and developed in loamy, Holocene-aged calcareous loess deposits. The soil at Ottawa is a deep, somewhat poorly drained, medium runoff risk soil with a very low saturated hydraulic conductivity that formed in silty and clayey sediments (USDA-NRCS, 2006).

A randomized complete block design with five treatments in triplicate was laid out in 6 by 6 m plots at each site. The five treatments consisted of removing 0, 25, 50, 75, and 100% of corn stover after harvest. At project initiation in 2009, corn stover remaining on the field from the previous year was redistributed for the plots on March 6 at Colby, March 15 at Hugoton, and March 20 at Ottawa. Corn stover was subsequently redistributed following harvest at each site in fall 2009. At harvest, plants were cut with shears leaving 15 cm of stalk above the soil surface to simulate common combine stalk cutting heights. Percent residue removal was estimated by dividing each plot into four quadrants, removing residue from the appropriate number of quadrants in each plot, and thoroughly redistributing the remaining residue across the whole plot to obtain a uniform surface cover. It is important to note that 100% stover removal was not achieved in this study, as 15 cm of stalk was left in the field on all plots. The dry mass of stover removed for each site is presented in Table 3.3. Plots were demarcated using colored flags placed at the corners of each plot.

Description of Field Management

Corn was planted with 76.2 cm row spacing at all sites in May 2009. At Colby, DeKalb corn DKC62-29 was planted at 76,601 seeds ha^{-1} with a four row John Deere 7300 no-till planter equipped with a Yetter residue manager/coulter attachment. Fertilization included broadcasting 202 kg of N, 7.85 kg of Zn, and 25.8 kg S ha^{-1}. A pre-emergence herbicide was applied approximately 48 h prior to planting, and consisted of 1.12 kg atrazine ha^{-1}, 1.40 kg S-metolachlor ha^{-1}, and 0.867 kg glyphosate ha^{-1}. The center-pivot irrigation system applied 38.1 mm of water approximately every 144 h, resulting in a total of 572 mm applied during the growing season.

At Hugoton, DeKalb corn DKC61-69 was planted with a John Deere 1770 planter at 85,250 seeds ha^{-1}. The soil was strip-tilled prior to planting using an Orthman 1-Tripper tillage implement, and fertilized with 10-34-0 (liquid ammonium phosphate) at 118 L ha^{-1} and 82-0-0 (anhydrous ammonia) at 22.4 kg N ha^{-1}. Initial herbicide application, which occurred approximately 3 wk after planting, included 1.82 kg ammonium sulfate ha^{-1}, 0.825 kg atrazine ha^{-1}, 1.03 kg S-metolachlor ha^{-1}, 1.12 kg glyphosate ha^{-1}, and .309 oz dicamba ha^{-1}. A second herbicide application occurred approximately 6 wk after planting and included 1.82 kg ammonium sulfate ha^{-1}, and 1.11 kg glyphosate ha^{-1}. The center-pivot irrigation system applied 31.8 mm of water after the initial herbicide application, and 31.8 mm every 108 h resulting in a total of 635 mm applied during the remainder of the growing season.

At Ottawa, DeKalb corn DKC50-44 was planted with a no-till planter at 63,258 seeds ha^{-1}. Fertilization consisted of applying 134 kg N ha^{-1}, 33.6 kg P_2O_5 ha^{-1}, and 11.2 kg K_20 ha^{-1}, using a mixture of liquid 28-0-0 (urea ammonium nitrate) and 7-21-7 fertilizer, which was band applied 6.35 cm to the side and 6.35 cm below the seed row at planting. Herbicide application consisted of 1.06 kg glyphosate ha^{-1} one wk prior to planting, 1.12 kg atrazine ha^{-1} and 1.40 kg S-metolachlor ha^{-1} one d after planting, and an additional application of 1.06 kg glyphosate ha^{-1} approximately 3 wk after planting. The center two rows of the plots were hand-harvested on Sept 20 at Hugoton, Oct. 19 at Ottawa, and Oct 26 at Colby in 2009.

Rainfall Simulation

Simulated rainfall was used in the spring of 2010 to determine runoff, sediment, sediment-C, and nutrient losses from all treatment plots across the three study sites. Simulation occurred on March 17 at Colby, April 8 at Hugoton, and April 14 at Ottawa in 2010. A rainfall simulator with a 30WSQ stainless steel nozzle (Teejet Corp., Dillsburg, PA; Miller, 1987) inside an aluminum frame applied rain on 2.5 m^2 runoff subplots established inside the 36 m^2 main plots from a 2.5 m height (Fig 3.2). The runoff subplots were bordered with 0.5 cm-thick steel plates inserted into the soil to a depth of 5 cm. Borders were visually monitored for leakages between the soil-plate interface during simulations. A V-shaped runoff collector was installed at the down slope end of each runoff plot to funnel runoff into plastic 4 L graduated buckets. The V-shaped runoff collectors were designed with a slight slope to better facilitate natural runoff flow from the plots. The runoff collectors and collection pits were covered with Plexiglas sheets during simulations to avoid direct collection of simulated rain.

Water was supplied to the simulator from a 3,785 L tank through an electric pump. Simulated rainfall was applied for 30 min with an intensity of 91.4 mm h^{-1} at Ottawa, and 76.2 mm h^{-1} at Colby and Hugoton. These intensities represented storms with a 5 yr return interval for the three sites (Hershfield, 1961). Rainfall intensity was regulated through a timer in an electric control box (Miller, 1987). Average wind speed during rainfall simulations was about 3.1 m s^{-1} at Hugoton and 4.9 m s^{-1} at Colby and Ottawa. The relatively strong winds during simulations were a major constraint for this study and reflected the typical weather conditions in Kansas. Even the use of plastic tarps to shield the simulator was not possible as it caused instability of the whole simulator. Dry and wet runs were performed in each plot. Dry runs were done 24 h before wet runs in order to ensure that antecedent soil water content was similar in all treatment plots, and thus would not impact runoff results. Soil samples to a depth of 5 cm were collected prior to dry runs in order to determine gravimetric water content for each plot (Table 3.4).

Runoff was collected separately in 10 min intervals after initiation of rainfall. This resulted in a maximum of three samples for each 30 min simulation, depending on the time to runoff initiation. The volume of runoff during each sampling period was measured using the 4 L graduated buckets. The volume of runoff in the 4 L graduated buckets was noted and then poured into a larger container. Samples of water used for rainfall simulations were collected and tested for background nutrient concentrations. At each sampling period, an 1 L runoff subsample was taken for sediment concentration determination, and two subsamples were taken for chemical analysis: a 100 mL unfiltered sample for total N and P, and a separate 15 mL sample passed through a 0.45 µm filter for PO_4-P, NH_4-N, and NO_3-N determination. The subsamples were placed on ice in an insulated cooler, transported to the lab, and analyzed within two weeks after simulations.

Sediment concentration was determined gravimetrically by oven drying runoff subsamples at 60°C. The mass of oven-dried sediment was used to calculate sediment loss from each treatment and sampling period. The sediment of all three sampling periods from the same plot was combined and subjected to dry combustion (Nelson and Sommers, 1996) to determine sediment-C concentration of the total sediment load. Total N and P were measured by the potassium persulfate digestion method. The filtered 15-mL samples were utilized to determine

PO_4-P, NH_4-N, and NO_3-N using a Lachat flow injection analyzer (Lachat Quickchem methods 10-107-04-1-A, 10-107-06-2A, and 10-115-01-1-A).

Modeling Soil Loss with RUSLE2

The Revised Universal Soil Loss Equation 2 (RUSLE2) was used to estimate soil loss under different rates of residue removal. While the one-time rainfall application used in this study is not easily comparable to the long-term average annual soil loss predicted by RUSLE2, it was nonetheless prudent to apply this model to the conditions present at the three study sites. RUSLE2 software was also used to obtain estimates of soil erosion and the Soil Conditioning Index (SCI) for each of the study sites. Detailed climate, soil, and management operation data specific to each site were entered into the RUSLE2 model, and each stover removal treatment was run separately for comparison. The stover removal treatments were established in the model by adjusting the field operations in such a way as to simulate various amounts of stover remaining in the field after harvest. For example, field operations that include harvesting corn while leaving 20% stubble, mowing and swathing the stubble, followed by windrowing and baling the corn stover resulted in 75% removal, while operations that only included leaving 70% stubble and baling stover resulted in a total of 25% removal.

Statistical Analysis

All data were transformed using the logarithmic function to achieve normal distribution, and analyzed using the PROC MIXED feature of SAS 9.2 (SAS Institute, 2008). For those measurements collected by sampling period, treatment means were analyzed separately by sampling period due to a significant time effect. Differences between least squares means within sampling periods were tested using 0.05 probability level (SAS Institute, 2008). Treatment comparisons were made only within each site, due to soil, climate, and management variation among sites.

Results

Runoff Initiation and Loss

Dry Runs

Runoff occurred sooner with 100% stover removal relative to 0% removal at Colby and Hugoton during dry runs (Table 3.5). At Colby, no runoff was observed with 0% removal for the entire duration of the dry run. At this site, runoff started over 16 min sooner with 25% stover removal compared to no removal. At Hugoton, time to runoff initiation was consistently reduced with increased stover removal. Time to runoff initiation decreased significantly at Hugoton when stover removal rates exceeded 75%. At Ottawa, stover removal had no effect on time to runoff initiation.

At Colby, no runoff occurred during the dry run simulation for 0% removal (Fig 3.3). Differences in runoff depth among stover treatments became more pronounced as the dry run progressed. Runoff depth increased as stover removal increased at Colby and Hugoton (Fig 3.4). One exception is that the 50% removal treatment at Colby experienced more runoff than the 75% removal treatment throughout the duration of the dry run simulation. At Ottawa, more runoff was observed in the complete stover removal treatment compared to no removal, but there were no differences among the 25, 50, and 75% removal treatments (Fig 3.5).

Wet Runs

Runoff consistently occurred sooner with increased stover removal at both Colby and Ottawa (Table 3.5). Time to runoff initiation was four times faster at Colby and about 2 times faster at Hugoton and Ottawa with 100% removal relative to 0% stover removal. At Colby, runoff occurred 10 min sooner with 25% removal compared to no stover removal. At both Hugoton and Ottawa, time to runoff decreased by about 3 min with 75% removal compared to no stover removal. Compared to 0% removal, time to runoff decreased with removal rates above 25% at Colby and 50% at Ottawa.

Depth of runoff increased from dry run to wet run simulations across all treatments and sites. Similar trends in runoff depth were observed between the dry and wet runs. A fairly linear increase in runoff depth occurred with increased stover removal throughout all three sampling periods at both Colby (Fig 3.3) and Hugoton (Fig 3.4), and during the first sampling period at Ottawa (Fig 3.5). At Ottawa, runoff loss appeared to diminish for removal rates greater than 50% in the second sampling period and 75% during the third sampling period. At Colby, runoff depth increased by 0.57 cm with 50% removal during the last 10 min of the wet runs, relative to no removal.

Sediment and Sediment-C Loss

Dry Runs

Sediment loss generally increased with increased stover removal at all sites. No sediment loss occurred with 0% removal during the first sampling period of the dry run. At Colby, 100% removal increased sediment loss by 0.003, 0.064, and 0.098 Mg ha^{-1} in the first, second, and third sampling periods, respectively, as compared to no removal (Fig 3.6). While no sediment loss occurred for the first sampling period at Hugoton, large differences in sediment loss were observed between 0 and 100% removal rates for the remainder of the simulation (Fig 3.7). At this site, complete removal of stover increased sediment loss by 0.02 and 0.09 Mg ha^{-1} in the second and third sampling periods, respectively, as compared to no removal. At Ottawa, 100% removal increased sediment loss by 0.10 Mg ha^{-1} in the second sampling period, while 75% removal resulted in a 0.23 Mg ha^{-1} increase in sediment loss in the third sampling period, relative to no removal (Fig 3.8).

Stover removal promoted the loss of sediment-C during dry runs. No sediment-C loss occurred with 0% removal during dry runs at Colby (Fig 3.9). While stover removal at any rate resulted in increases in sediment-C loss, loss of sediment-C increased when stover removal rates exceeded 25% at Colby and Ottawa, and 75% at Hugoton (Fig 3.10) compared to no removal. Sediment-C loss increased with increases in stover removal rates up to 50% at Colby and 75% at Ottawa (Fig 3.11), after which sediment-C losses remained constant. Losses of sediment-C remained constant with increased removal rates up to 75% at Hugoton, after which sediment-C loss increased almost five-fold with 100% stover removal. Removal rates of 50% increased sediment-C loss by 0.96 kg ha^{-1} at Colby and 0.55 kg ha^{-1} at Ottawa, while complete removal resulted in a 0.89 kg ha^{-1} increase at Hugoton relative to no removal.

Wet Runs

Loss of sediment in the first and second sampling periods was greater during the wet runs compared to the dry runs across all treatments and sites. Sediment loss increased by 0.04 Mg ha^{-1} with 25% removal during the last 10 min of the wet runs, relative to no stover removal at Colby (Fig 3.6). When compared to no removal, 50% stover removal increased sediment loss by 0.07 Mg ha^{-1} in the second period and 0.09 Mg ha^{-1} in the third sampling period at Colby. Complete removal resulted in 0.08, 0.15, and 0.16 Mg ha^{-1} increases in sediment loss in the first, second and third sampling periods, respectively, relative to no removal at Colby. At Hugoton, a complete removal of stover resulted in increased sediment loss of 0.03, 0.10, and 0.12 Mg ha^{-1} for sampling periods 1, 2, and 3, respectively (Fig 3.7). A gradual increase in sediment loss with increased rates of stover removal was observed at Ottawa (Fig 3.8). Removal rates of 25, 50, 75, and 100% at Ottawa increased sediment loss by 0.01, 0.04, 0.10, and 0.11 Mg ha^{-1} in the first sampling period, 0.02, 0.11, 0.13, and 0.17 Mg ha^{-1} in the second sampling period, and 0.02, 0.07, 0.15, and 0.17 Mg ha^{-1} in the third sampling period, respectively, relative to no removal.

Sediment-C loss generally increased with stover removal during wet runs at Hugoton and Ottawa. Differences in sediment-C loss were most pronounced between 0 and 100% removal treatments at Hugoton (Fig 3.10) and Ottawa (Fig 3.11). Significant increases in sediment-C loss were observed when removal rates exceeded 50% at Hugoton and 25% at Ottawa, relative to no removal. No statistically significant differences in sediment-C loss were observed at Colby between treatments due to a high variability in data (SE ± 0.250 kg ha^{-1}). Highest losses of sediment-C occurred with 100% stover removal at Hugoton (0.898 kg ha^{-1}) and Ottawa (1.01 kg ha^{-1}) during wet runs.

Total N and Total P Loss

Dry Runs

Total N loss increased with high rates of stover removal at Hugoton, while total P loss increased with high stover removal at Hugoton and Ottawa during dry runs (Table 3.6). At Colby, however, no significant increases in total N and total P loss were observed with increased stover removal. At Hugoton, complete stover removal increased total N loss by 0.34 kg ha^{-1} and total P loss by 0.06 kg ha^{-1}. At Ottawa, stover removal rates of 75 and 100% increased total P loss by 0.03 and 0.06 kg ha^{-1}, respectively, relative to no removal. Losses of total N were generally greater than total P with all removal rates at all sites.

Wet Runs

Total N and total P losses were highly variable throughout the study sites during wet runs (Table 3.7). High variability in total N loss may have resulted from sample contamination at Hugoton. While complete residue removal had greater total N losses compared to no residue removal at Colby and Ottawa, large losses occurred with 50% removal at these sites. At Colby, total N loss followed the same trend as total P loss, with relatively large values at 50% removal rate. Relative to no residue removal, complete removal increased total P loss 126-fold, while 50% removal increased total P loss 155-fold at Colby. At Hugoton, complete removal increased total P loss by 85% compared to no removal. At Ottawa, total P loss tended to increase steadily with residue removal rate up to 75%, and declined with complete removal.

Loss of Soluble Nutrients

Dry Runs

Soluble nutrient loss was virtually non-existent at all sites during the first sampling period. No PO_4-P loss was observed for the entire duration of the dry run at Colby (Table 3.8). Soluble nutrient loss appears to increase between sampling periods at all sites, but losses did not always increase with increased stover removal within sampling periods. At Colby, complete removal significantly increased NH_4-N loss by 0.0012 kg ha^{-1} during the second sampling period, while NH_4-N loss increased by 0.0022 kg ha^{-1} with 50% removal during the third period. At Hugoton, complete stover removal increased PO_4-P loss by 0.0028 kg ha^{-1} and NO_3-N loss by 0.0073 kg ha^{-1} during the second sampling period (Table 3.9). At Ottawa, however, PO_4-P loss decreased by 0.0011 kg ha^{-1} with 25% removal during the second period, and decreased by 0.0025 kg ha^{-1} with 50% removal during the third period (Table 3.10).

Wet Runs

Losses of PO_4-P, NH_4-N, and NO_3-N were also variable throughout the wet runs. NO_3-N and NH_4-N losses at Hugoton and NH_4-N losses at Ottawa may not be reliable due to possible contamination during simulations. While no PO_4-P loss was observed during wet runs at Colby, complete removal resulted in a 0.0012 kg ha^{-1} increase in NH_4-N loss during the first sampling period (Table 3.11). Losses of NO_3-N increased with stover removal during the first sampling period at Colby, but were variable during the second and third periods. At Hugoton, the effects of stover removal on PO_4-P loss varied throughout the sampling periods (Table 3.12). Losses of PO_4-P tended to increase with stover removal during the first period, were variable in the second period, and were on average threefold higher with no stover removal in the third period relative to other stover removal rates. It is probable that NH_4-N and NO_3-N sample contamination occurred at Hugoton. At Ottawa, PO_4-P loss decreased by an average of 0.0016 kg ha^{-1} with removal rates >25% relative to no stover removal (Table 3.13).

RUSLE2 Estimations

Predicted average annual sediment loss increased with increased stover removal at all sites (Table 3.14). However, estimated sediment loss values were low even with complete stover removal at all sites, with a maximum loss of 1.75 Mg ha^{-1} yr^{-1} occurring at Ottawa. Complete stover removal increased estimated average annual sediment loss by 0.88 Mg ha^{-1} yr^{-1} at Colby, 0.86 Mg ha^{-1} yr^{-1} at Hugoton, and 1.41 Mg ha^{-1} yr^{-1} at Ottawa. Soil conditioning index (SCI) values decreased with increased stover removal at all sites (Table 3.14). It is important to note that SCI values remained positive, meaning overall C gains, even with complete stover removal. This result may be due to the inability to remove 100% of stover within the RUSLE2 model. This demonstrates the technical limitations pertaining to modeling the impacts of multiple rates of stover removal on runoff and soil erosion.

Discussion and Conclusions

The data obtained from this regional study in Kansas show that certain rates of corn stover removal from no-till and strip-till soils can have rapid and significant effects on runoff and soil erosion. At Colby and Hugoton, an increase in stover removal reduced time to runoff and thus increased runoff amount. This is most likely due to a) more soil surface exposure to raindrop impact that dispersed soil particles and formed surface seals and b) reduced surface roughness to intercept runoff and pond on the soil surface, effectively reducing the opportunity for infiltration.

Increases in sediment and sediment-C loss with increased stover removal rate are attributed to the concurrent increases in runoff under low stover conditions. The unrestricted flow of large amounts of runoff leads to a greater potential loss of sediment and sediment-C. These results agree with the findings of Savabi and Stott (1994), who observed a direct relationship between the amount of residue on a soil surface and the amount of rainfall intercepted, and with Blanco-Canqui et al. (2009), who found that runoff volume, sediment, and SOC losses tended to increase with increase in residue removal from no-till wheat plots in Kansas. Increased movement of sediment-C via erosion exposes more C to the air, potentially resulting in rapid C mineralization and emissions of carbon dioxide to the atmosphere (Kuhn et al., 2009). Consequently, the harvesting of corn stover for bioenergy may in fact lead to increased greenhouse gas emissions, which is in contrast with the overall goals of bioenergy production.

In this study, there was a trend of increased total N and P loss with high rates of stover removal at all sites during the initial dry run, with significant losses of total N at Hugoton and total P at Hugoton and Ottawa. This is in agreement with results observed by Lindstrom (1986) with no-till corn in South Dakota, who found that concentrations of N, P, and K in sediment contained in runoff increased with increase in stover removal rate. However, total N and total P losses during wet runs were more variable, with increases in total N loss at Ottawa, and an increase in both total N and P loss at Colby with moderate rates of removal (50%) as compared with low and high rates of removal. Impacts of stover removal on PO_4-P, NH_4-N, and NO_3-N concentrations in runoff water were variable in this study. Even though concentrations of soluble nutrients in runoff water were relatively low, important trends were observed. Losses of NO_3-N and NH_4-N were generally lowest when no stover was removed. In contrast, losses of PO_4-P were generally highest when no stover was removed. These results may be attributed to a) inherent field variability, or b) the leaching of nutrients from stover due to the prolonged contact between water and stover (Schreiber, 1999).

While, in some instances, stover removal significantly impacted sediment, sediment-C, and nutrient loss, the magnitude of loss was considerably lower compared to previous studies (Lindstrom, 1986; Blanco-Canqui et al., 2009). Losses were low in this study most likely because of the intensity of simulated rainfall and the minimal topographic field variation existing at these sites. Rainfall simulations with intensities representing 5 yr return periods were used in this study in an attempt to simulate a frequent storm scenario likely to occur shortly after stover removal begins. These intensities are relatively low compared to other rainfall simulation studies. Moreover, the current study included regions with climates that contrast greatly with previous studies.

Results from this study, however, suggest that corn stover removal in Kansas at rates as low as 25% can cause runoff to occur sooner and lead to increased sediment loss on some soils. Stover removal rates of 50% can significantly increase losses of sediment-C, while removal rates exceeding 50% can impact nutrient loss even on soils with minimal slope. Further long-term investigation of stover removal on a wider range of soils, crops, and climates are needed in order to better determine threshold removal levels on a regional scale.

Figures and Tables

Figure 3.1 Location of the study sites within the precipitation gradient of Kansas.

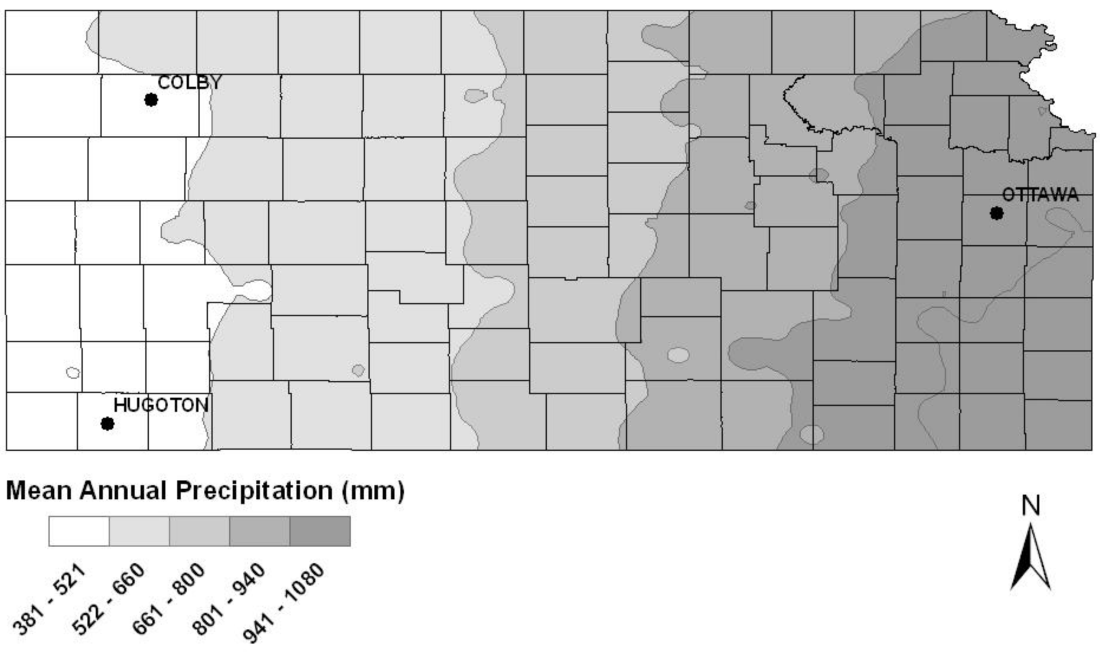


Figure 3.2 Diagram of runoff subplot and method of runoff collection (not to scale).

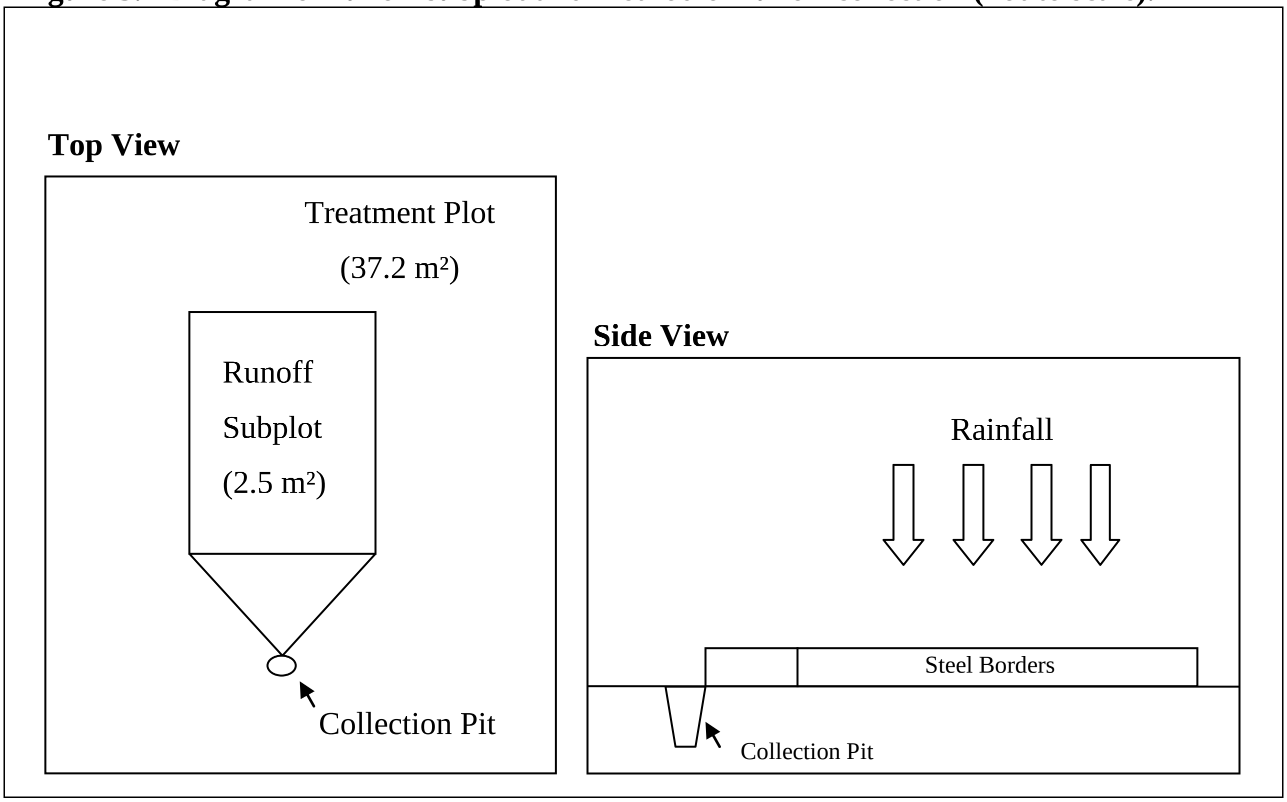


Figure 3.3 Runoff depth as impacted by stover removal during dry and wet runs at Colby. Treatments within the same sampling period with different letters are significantly different.

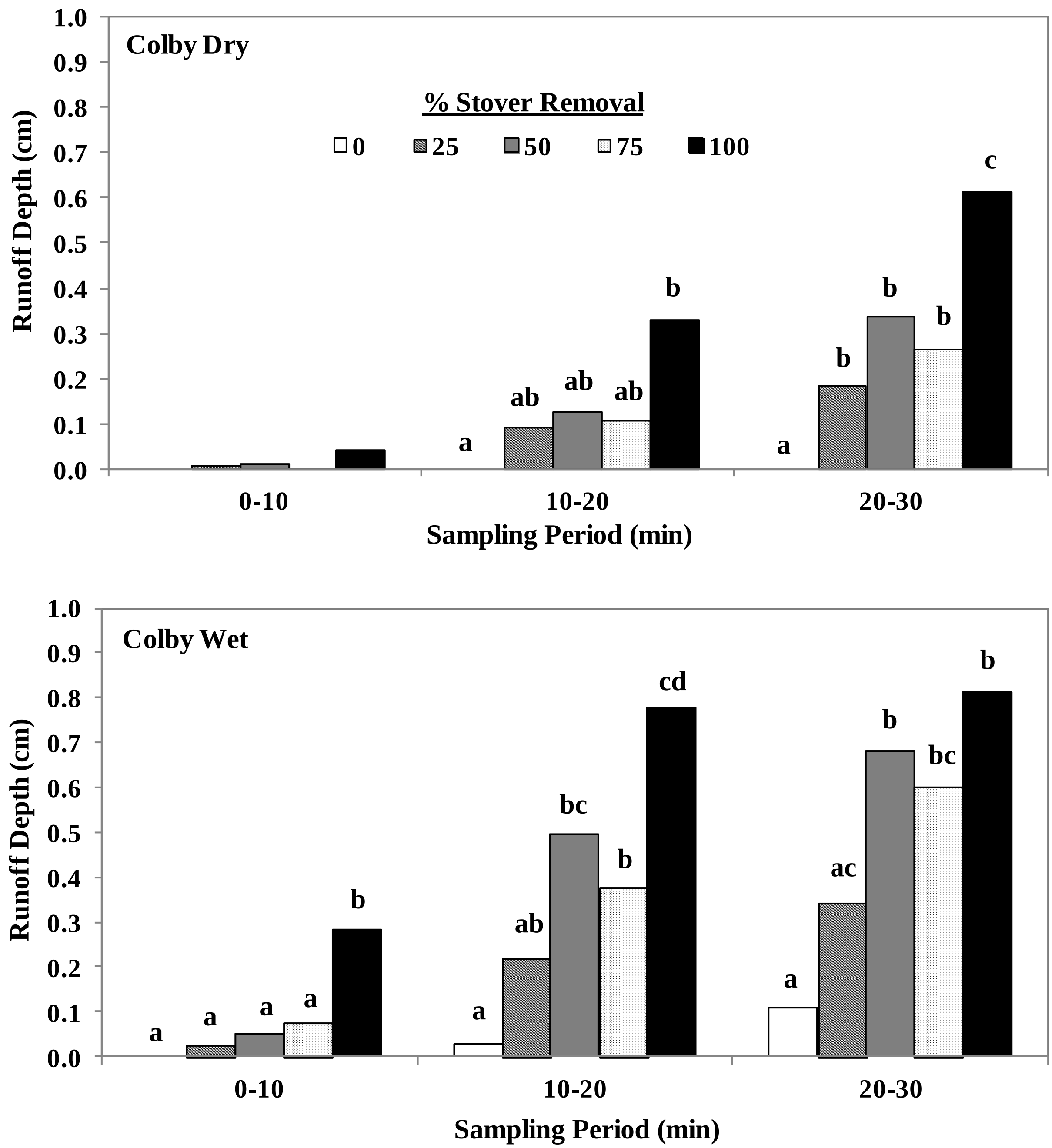
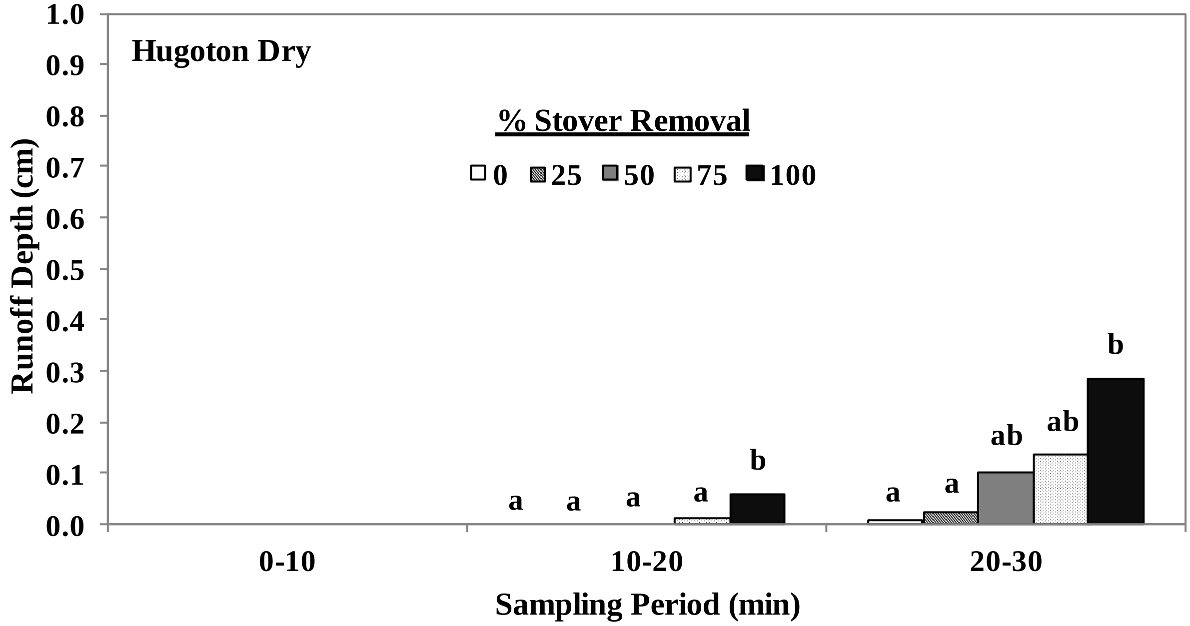


Figure 3.4 Runoff depth as impacted by stover removal during dry and wet runs at Hugoton. Treatments within the same sampling period with different letters are significantly different.



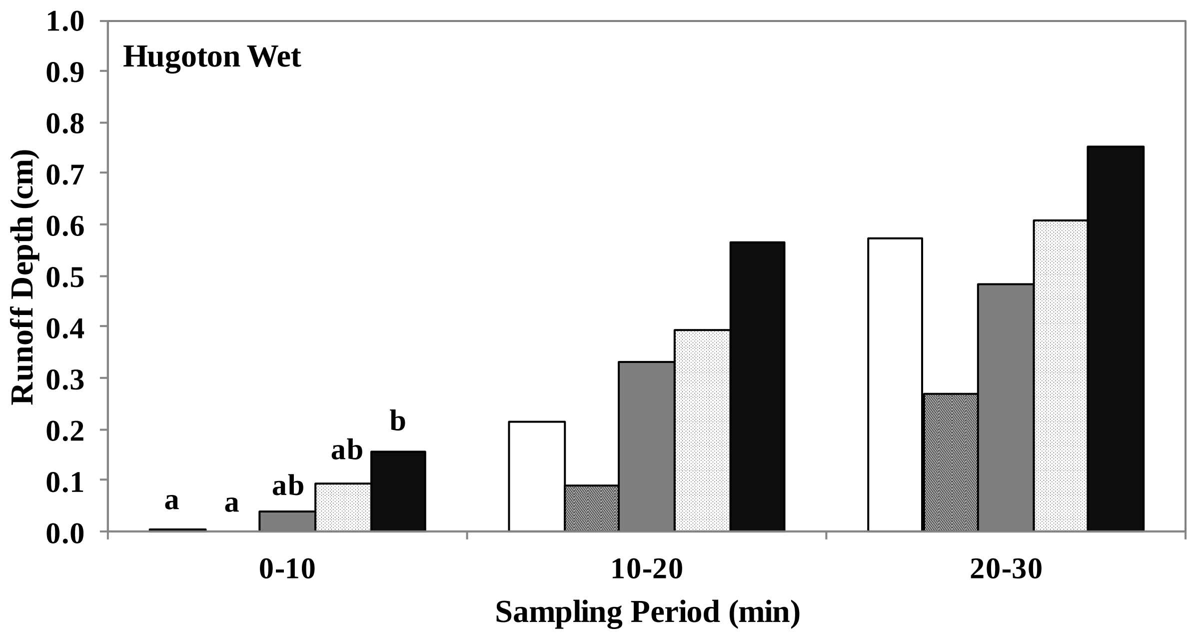
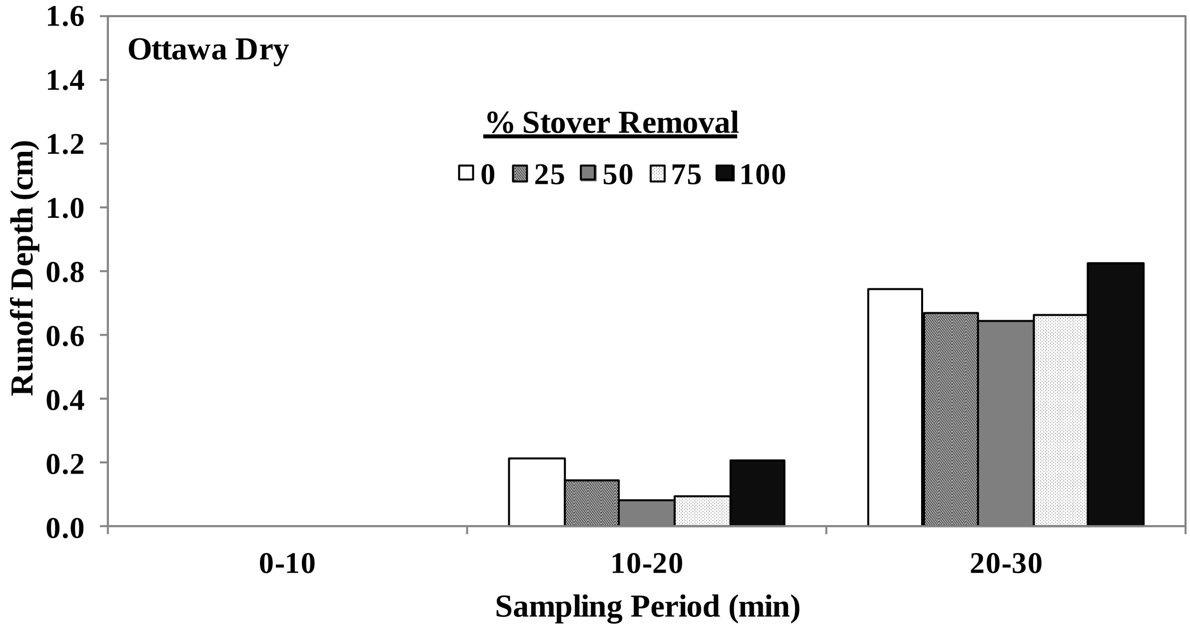


Figure 3.5 Runoff depth as impacted by stover removal during dry and wet runs at Ottawa. Treatments within the same sampling period with different letters are significantly different.



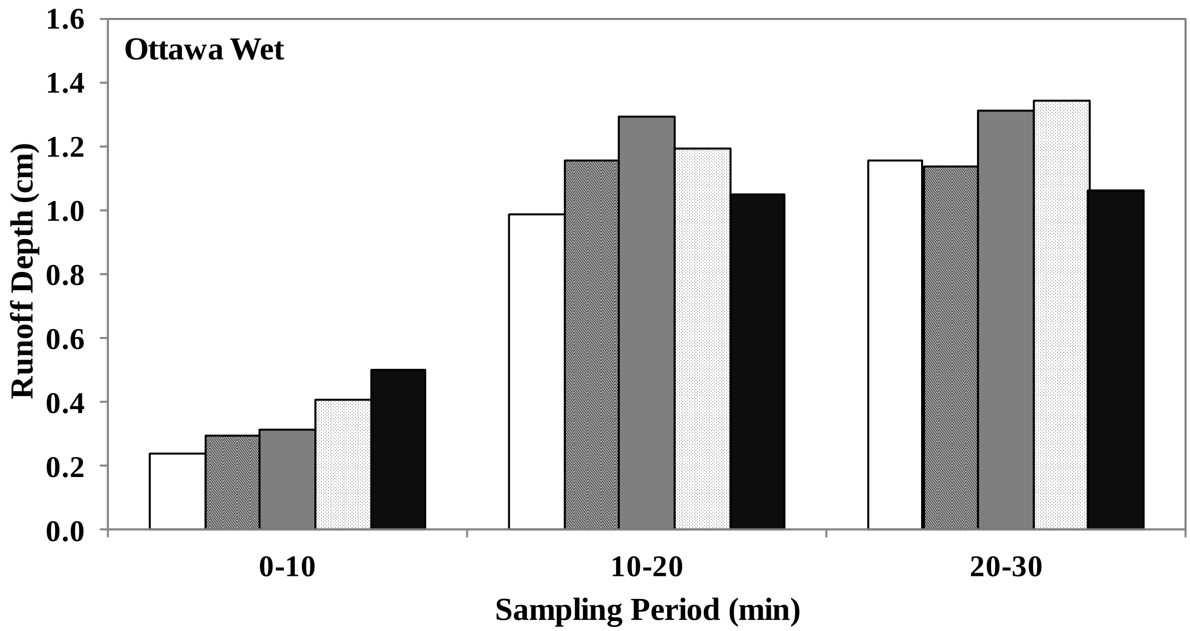


Figure 3.6 Effect of stover removal on sediment loss during dry and wet runs at Colby. Treatments within the same sampling period with different letters are significantly different.

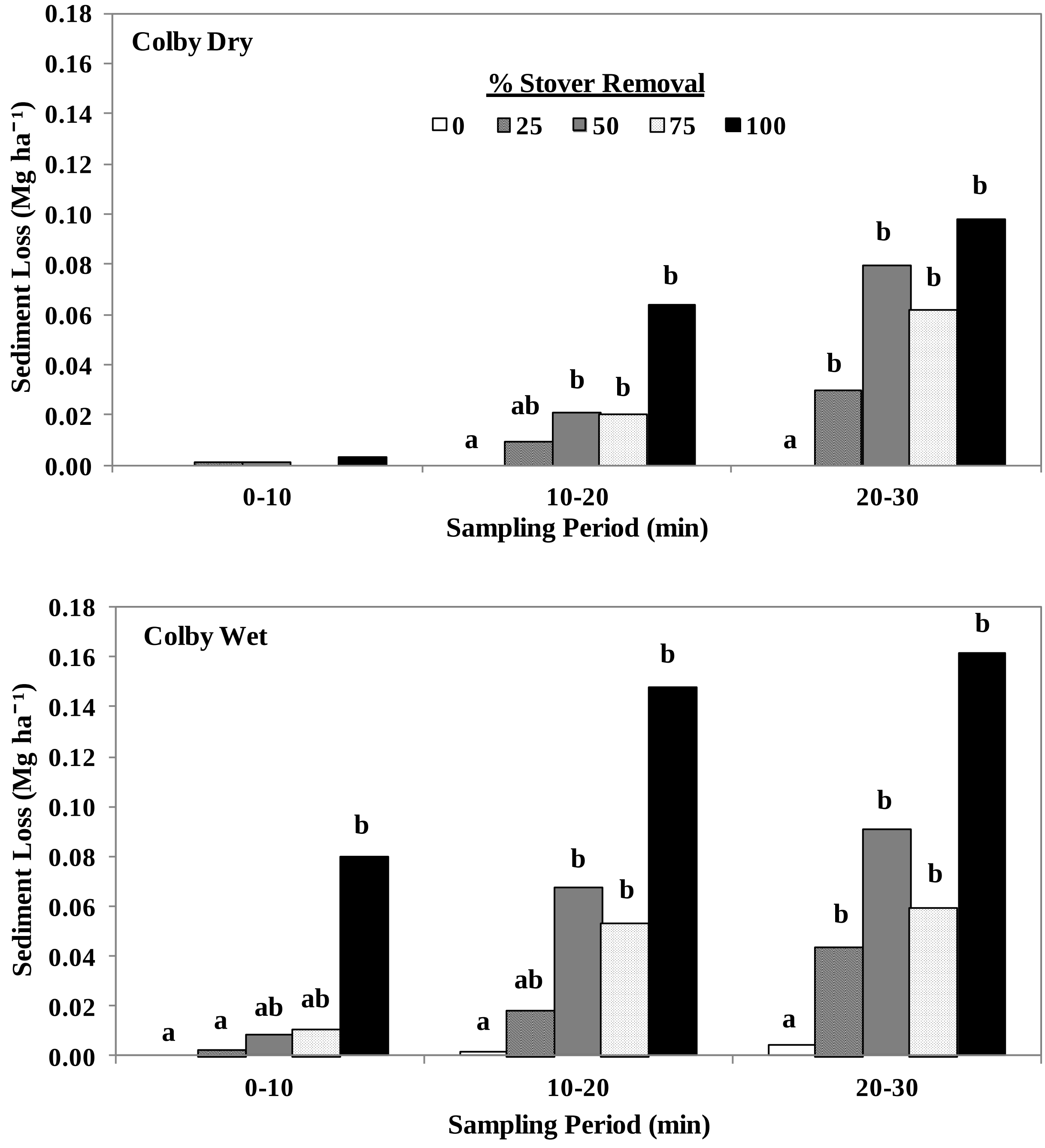


Figure 3.7 Effect of stover removal on sediment loss during dry and wet runs at Hugoton. Treatments within the same sampling period with different letters are significantly different.

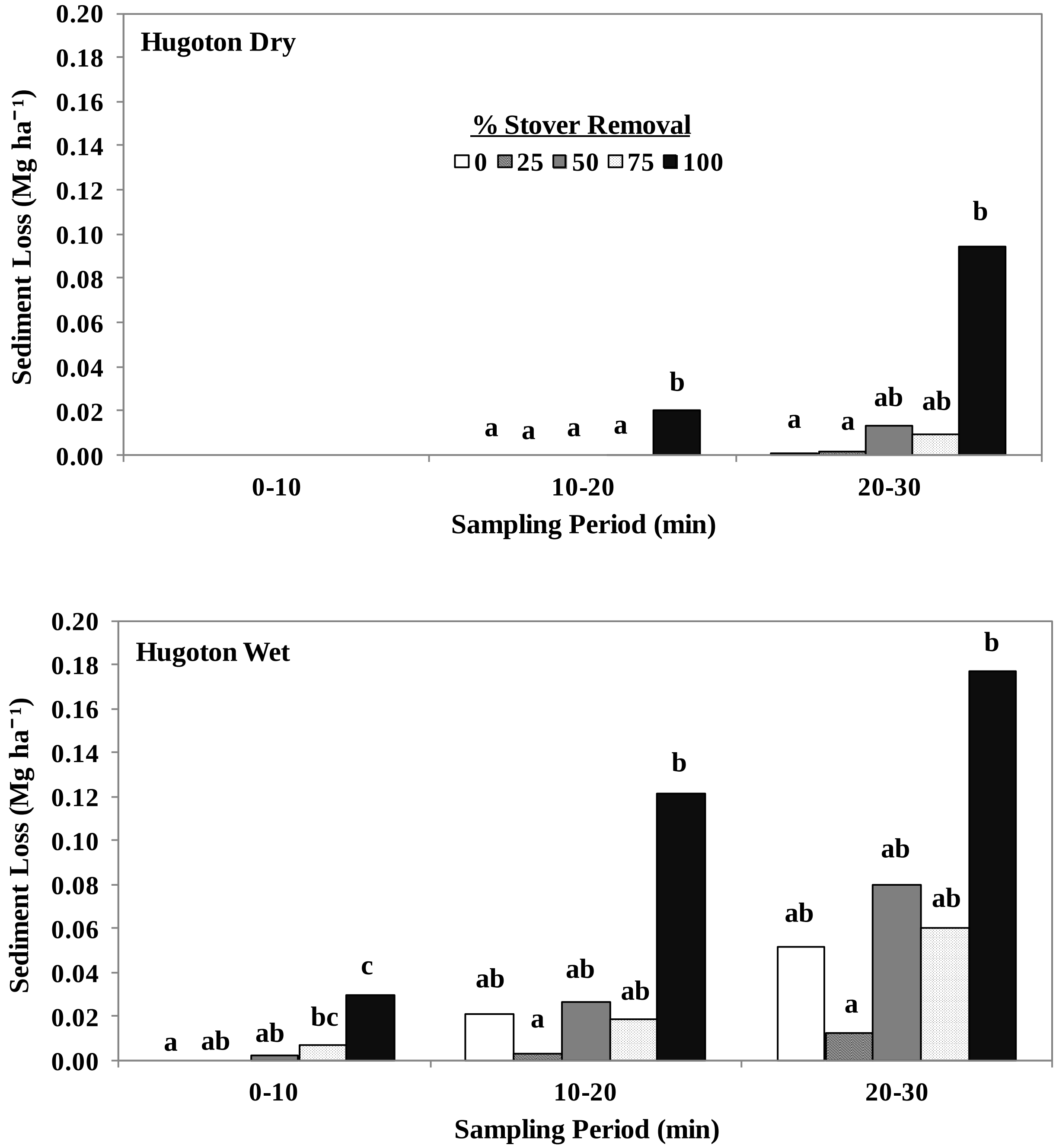


Figure 3.8 Effect of stover removal on sediment loss during dry and wet runs at Ottawa. Treatments within the same sampling period with different letters are significantly different.

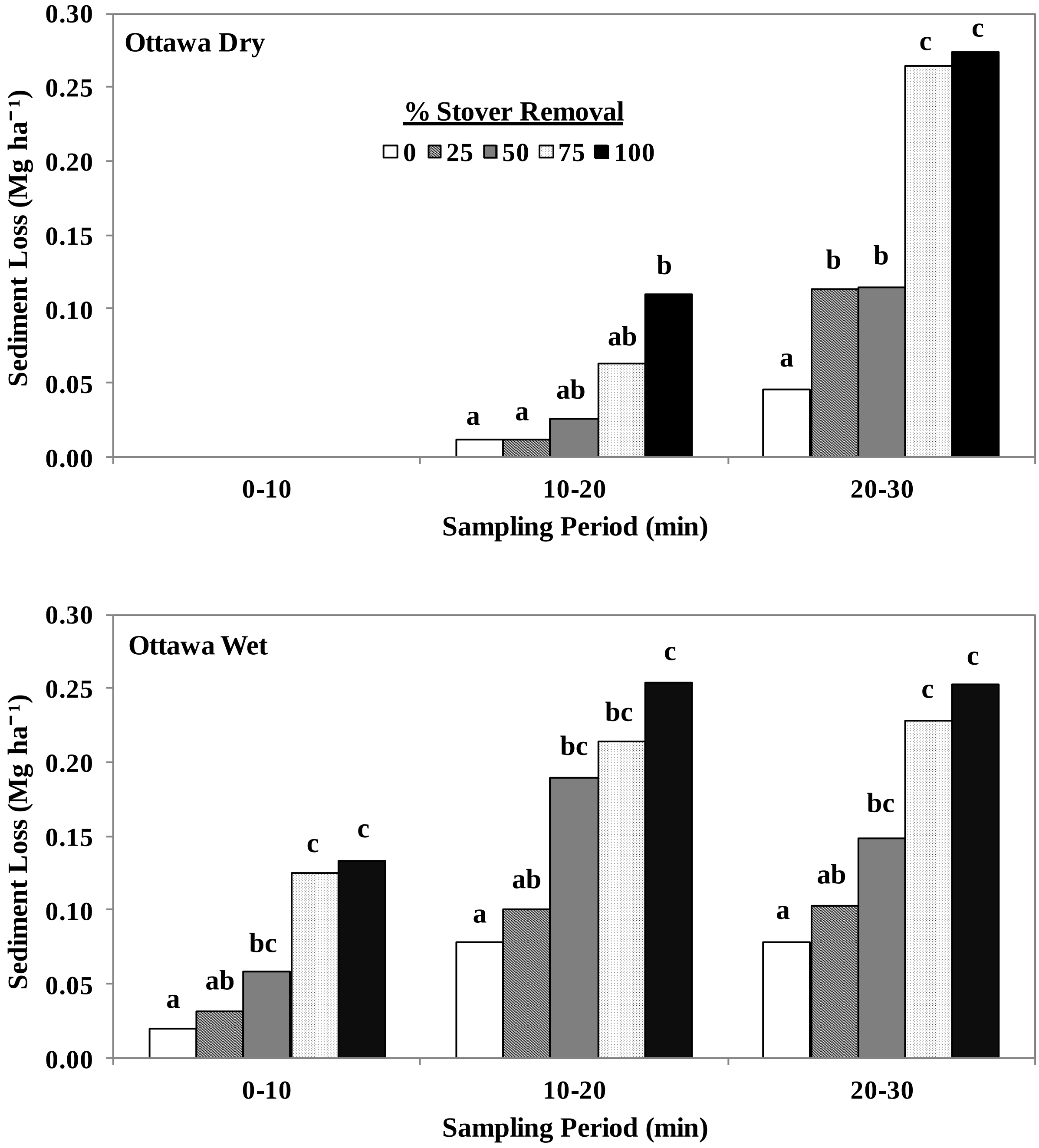
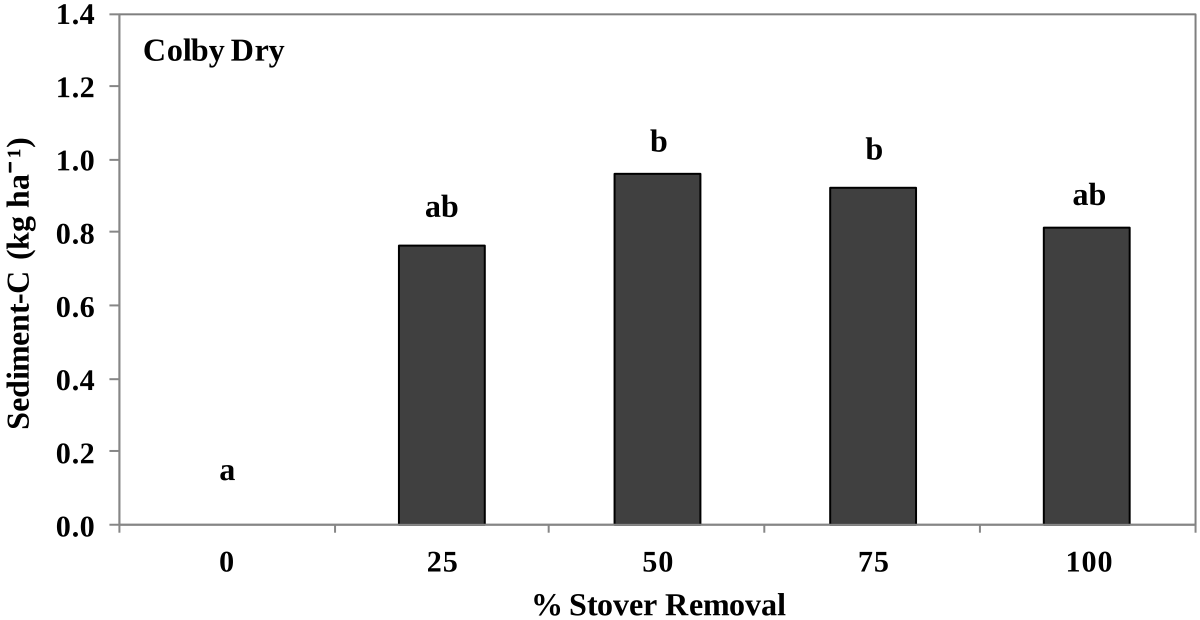


Figure 3.9 Effect of stover removal on sediment-carbon loss during dry and wet runs at Colby. Treatments with different letters are significantly different.



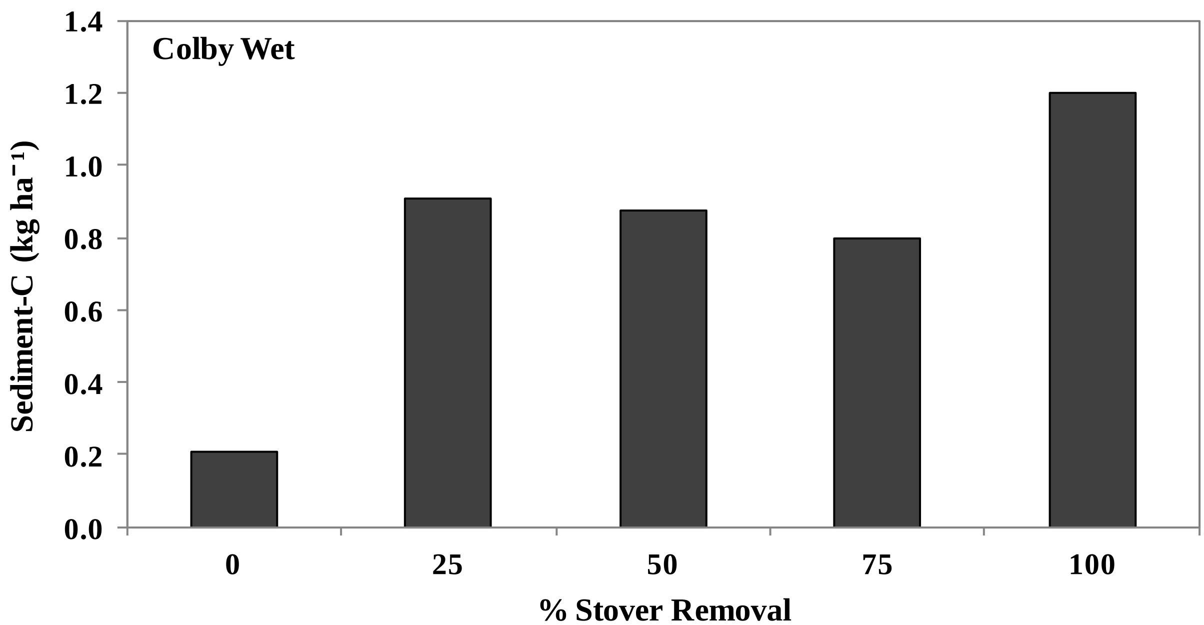


Figure 3.10 Effect of stover removal on sediment-carbon loss during dry and wet runs at Hugoton. Treatments with different letters are significantly different.

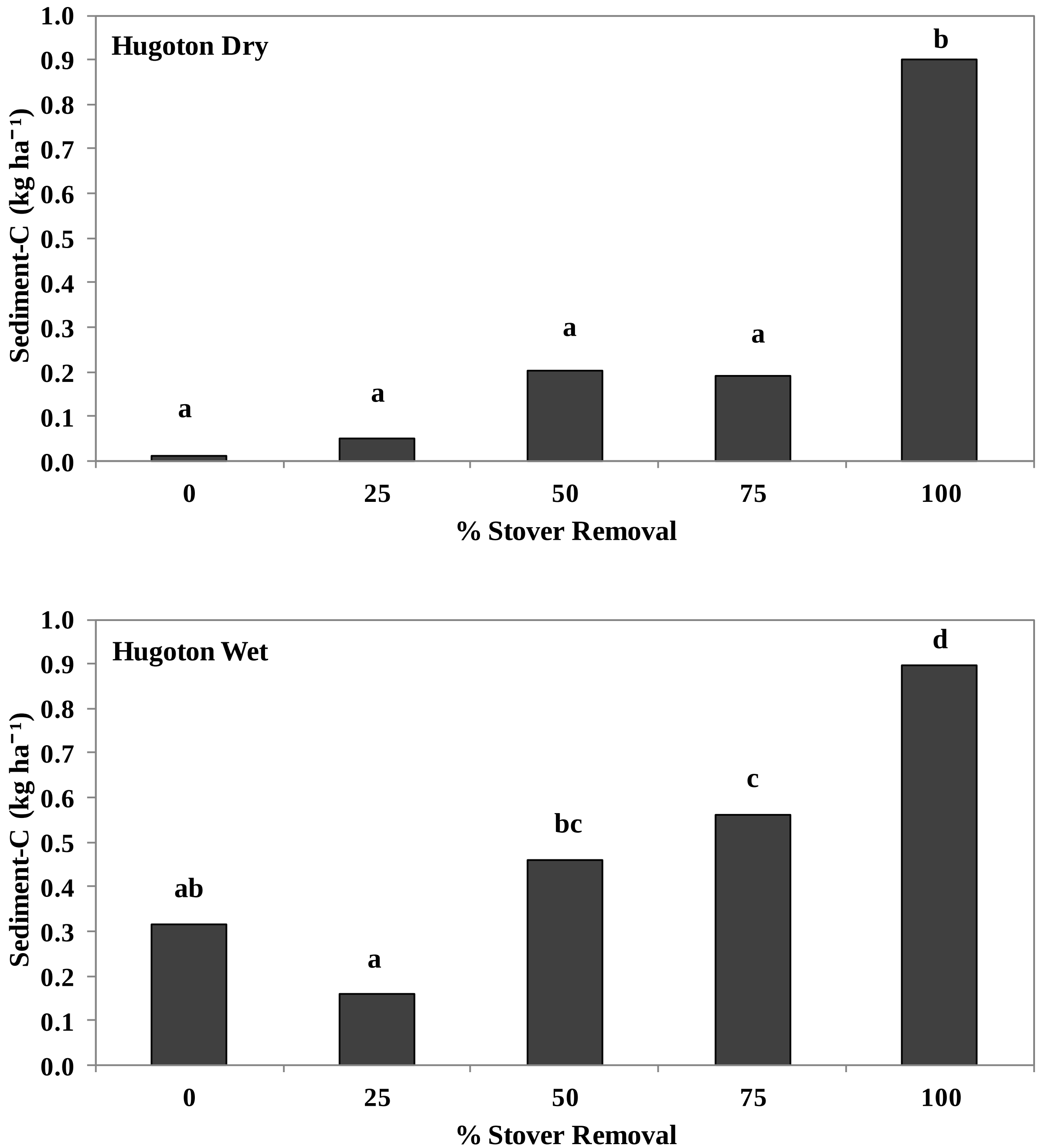


Figure 3.11 Effect of stover removal on sediment-carbon loss during dry and wet runs at Ottawa. Treatments with different letters are significantly different.

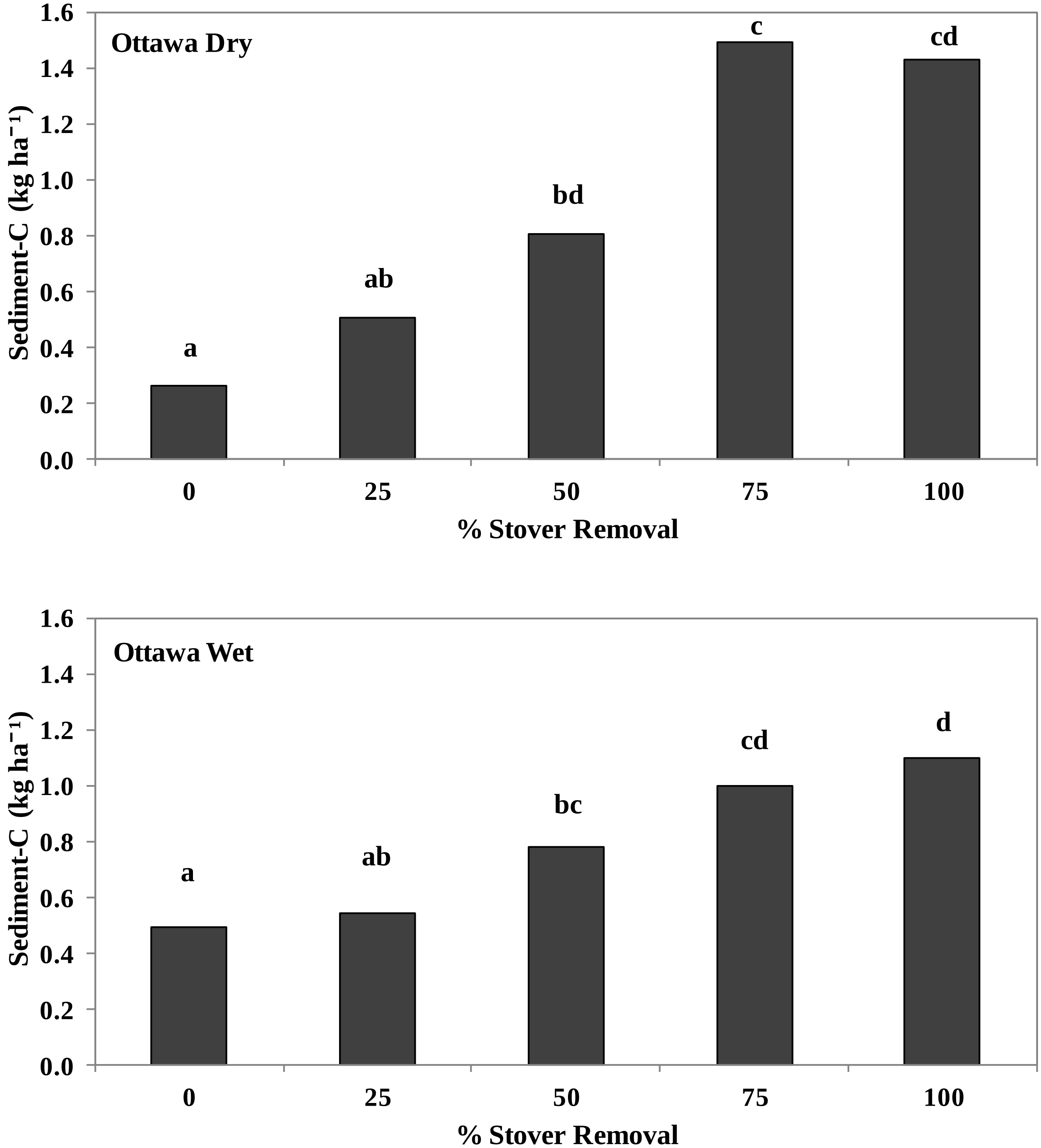


Table 3.1 Management, climate, and soil characteristics of the three study sites.

Study Site	Management	Avg. daily min. and max. temp. (°C)	Avg. annual precipitation (mm)	Soil series	Taxonomic classification
Colby	No-till continuous corn Irrigated	3.0 17.7	470	Ulysses silt loam†	Fine-silty, mixed, superactive, mesic Aridic Haplustolls
Hugoton	Strip-till continuous corn Irrigated	5.9 19.8	457	Hugoton loam	Fine-silty, mixed, superactive, mesic Aridic Argiustolls
Ottawa	No-till continuous corn Rain-fed	6.3 18.4	953	Woodson silt loam	Fine, smectitic, thermic Abruptic Argiaquolls

† Soil slope was ≤ 1% at all sites.

Table 3.2 Soil particle size analysis of the three study sites to a depth of 20 cm.

Study Site	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture
Colby	0-5	24.2	59.6	16.2	Silt Loam
	5-10	24.8	56.5	18.7	Silt Loam
	10-20	20.0	59.6	20.4	Silt Loam
Hugoton	0-5	30.6	47.3	22.1	Loam
	5-10	25.9	50.2	23.9	Silt Loam
	10-20	32.4	40.3	27.3	Clay Loam
Ottawa	0-5	6.6	71.8	21.6	Silt Loam
	5-10	5.6	86.9	7.5	Silt
	10-20	4.1	72.7	23.2	Silt Loam

Table 3.3 Dry mass of stover removed (Mg ha^{-1}) from each stover treatment in fall 2009.

	% Stover Removal				
Study Site	**0**	**25**	**50**	**75**	**100**
			---Mg ha^{-1}---		
Colby	0.00	1.35	3.33	4.22	5.27
Hugoton	0.00	1.98	3.04	4.96	5.74
Ottawa	0.00	0.92	2.17	3.26	4.99

Table 3.4 Soil water content (kg kg^{-1}) of treatments prior to dry runs for the 0-5 cm depth.

	% Stover Removal				
Study Site	**0**	**25**	**50**	**75**	**100**
			---Soil Water Content (kg kg^{-1})---		
Colby	0.309	0.240	0.226	0.225	0.218
Hugoton	0.185	0.172	0.154	0.091	0.104
Ottawa	0.228	0.210	0.212	0.189	0.191

Table 3.5 Effect of stover removal on time to runoff initiation (min) during dry and wet runs. Treatments within the same site and run with different letters are significantly different.

		% Stover Removal				
Study Site	**Run**	**0**	**25**	**50**	**75**	**100**
		---Time to Runoff Initiation (min)---				
Colby	Dry	30.0 a	13.7 b	10.0 b	12.7 b	9.2 b
	Wet	20.0 a	9.3 ab	8.1 b	7.0 b	4.4 b
Hugoton	Dry	28.8 a	26.9 a	25.6 a	24.3 a	15.0 b
	Wet	13.1 ab	19.6 a	11.0 ab	8.8 ab	6.5 b
Ottawa	Dry	15.6	16.2	16.4	15.3	13.6
	Wet	6.6 a	5.4 ab	5.1 ab	3.8 b	3.7 b

Table 3.6 Effect of stover removal on total N and total P loss (kg ha^{-1}) during dry runs. Treatments with different letters within the same site and nutrient column are significantly different. Highlighted data are likely a result of sample contamination.

		% Stover Removal				
Site	**Nutrient**	**0**	**25**	**50**	**75**	**100**
		---Nutrient Loss (kg ha^{-1})---				
Colby	Total N	0.000	0.152	0.168	0.202	0.283
	Total P	0.000	0.140	0.160	0.153	0.290
Hugoton	Total N	0.003 a	0.023 a	0.052 a	0.143 ab	0.348 b
	Total P	0.000 a	0.003 a	0.011 a	0.014 a	0.066 b
Ottawa	Total N	0.367	0.427	1.304	0.655	1.114
	Total P	0.030 a	0.030 a	0.035 ab	0.057 b	0.095 c

Table 3.7 Effects of stover removal on total N and total P loss (kg ha⁻¹) during wet runs. Treatments with different letters within the same sampling period for the same nutrient are significantly different. Highlighted data are likely a result of sample contamination.

Site	Nutrient	Sampling Period	% Stover Removal 0	25	50	75	100
			---Nutrient Loss (kg ha⁻¹)---				
Colby	Total N	1	0.000 ab	0.052 ab	0.023 ab	0.053 b	0.250 a
		2	0.003	0.196	0.087	0.116	0.239
		3	0.004	0.169	0.443	0.095	0.279
	Total P	1	0.000 a	0.036 a	0.015 a	0.042 ab	0.187 b
		2	0.001	0.174	0.075	0.094	0.236
		3	0.005	0.136	0.553	0.090	0.298
Hugoton	Total N	1	0.092 a	0.000 a	0.259 ab	0.000 a	0.935 b
		2	1.053 ab	0.001 a	1.612 ab	0.000 a	2.840 b
		3	2.054 ab	0.307 a	2.214 ab	0.091 a	3.190 b
	Total P	1	0.000 a	0.000 a	0.004 a	0.008 ab	0.018 b
		2	0.025 ab	0.010 a	0.028 ab	0.029 ab	0.097 b
		3	0.093	0.031	0.050	0.058	0.104
Ottawa	Total N	1	0.092	0.206	0.698	0.341	0.895
		2	0.308	0.432	2.209	0.525	1.622
		3	0.279 a	0.318 a	1.886 ab	0.493 ab	3.267 b
	Total P	1	0.007 a	0.010 ab	0.011 ab	0.029 b	0.020 ab
		2	0.023	0.029	0.056	0.043	0.045
		3	0.020	0.020	0.032	0.042	0.167 a

Table 3.8 Losses of soluble nutrients in runoff water as affected by stover removal during dry runs at Colby. Treatments with different letters within the same sampling period for the same nutrient are significantly different.

Nutrient	% Stover Removal	*0-10 min*	*10-20 min*	*20-30 min*
	0	0	0	0
PO_4-P	**25**	0	0	0
	50	0	0	0
(kg ha^{-1})	**75**	0	0	0
	100	0	0	0
	0	0	0 a	0 a
NH_4-N	**25**	0.0001	0.0005 ab	0.0006 ab
	50	0.0001	0.0008 ab	0.0022 b
(kg ha^{-1})	**75**	0	0.0010 ab	0.0023 b
	100	0.0002	0.0012 b	0.0010 ab
	0	0	0	0
NO_3-N	**25**	0	0	0
	50	0	0.0022	0.0158
(kg ha^{-1})	**75**	0	0.0033	0.0148
	100	0	0	0

Table 3.9 Losses of soluble nutrients in runoff water as affected by stover removal during dry runs at Hugoton. Treatments with different letters within the same sampling period for the same nutrient are significantly different.

Nutrient	% Stover Removal	*0-10 min*	*10-20 min*	*20-30 min*
	0	0	0 a	0.0004
PO_4-P	**25**	0	0 a	0.0020
	50	0	0 a	0.0078
(kg ha^{-1})	**75**	0	0.0004 a	0.0039
	100	0	0.0028 b	0.0077
	0	0	0	0.0001
NH_4-N	**25**	0	0	0.0053
	50	0	0	0.0033
(kg ha^{-1})	**75**	0	0.0028	0.0336
	100	0	0.0048	0.0196
	0	0	0 a	0.0008
NO_3-N	**25**	0	0 a	0.0062
	50	0	0 a	0.0184
(kg ha^{-1})	**75**	0	0.0023 ab	0.0166
	100	0	0.0073 b	0.0253

Table 3.10 Losses of soluble nutrients in runoff water as affected by stover removal during dry runs at Ottawa. Treatments with different letters within the same sampling period for the same nutrient are significantly different. Highlighted data likely contaminated.

Nutrient	% Stover Removal	*0-10 min*	*10-20 min*	*20-30 min*
	0	0	0.0014 a	0.0048 a
PO_4-P	**25**	0	0.0003 b	0.0029 ab
	50	0	0.0003 b	0.0023 b
(kg ha^{-1})	**75**	0	0 b	0.0002 c
	100	0	0 b	0 c
	0	0	0.0030	0.0050
NH_4-N	**25**	0	0.0038	0.0142
	50	0	0.1256	0.7278
(kg ha^{-1})	**75**	0	0.0006	0.0037
	100	0	0.0036	0.0128
	0	0	0.0012	0
NO_3-N	**25**	0	0.0020	0.0021
	50	0	0	0
(kg ha^{-1})	**75**	0	0	0
	100	0	0.0002	0.0003

Table 3.11 Losses of soluble nutrients in runoff water as affected by stover removal during wet runs at Colby. Treatments with different letters within the same sampling period for the same nutrient are significantly different.

Nutrient	% Stover Removal	*0-10 min*	*10-20 min*	*20-30 min*
PO_4-P (kg ha^{-1})	**0**	0	0	0
	25	0	0	0
	50	0	0	0
	75	0	0	0
	100	0	0	0
NH_4-N (kg ha^{-1})	**0**	0 a	0.0002 a	0.0004 a
	25	0.0001 a	0.0004 a	0.0009 ab
	50	0.0003 a	0.0017 ab	0.0011 ab
	75	0.0007 ab	0.0030 b	0.0018 b
	100	0.0012 b	0.0015 ab	0.0013 ab
NO_3-N (kg ha^{-1})	**0**	0	0.0002	0
	25	0	0.0008	0.0004
	50	0.0001	0.0022	0.0032
	75	0.0003	0.0005	0.0016
	100	0.0016	0.0009	0.0005

Table 3.12 Losses of soluble nutrients in runoff water as affected by stover removal during wet runs at Hugoton. Treatments with different letters within the same sampling period for the same nutrient are significantly different. Marked data likely contaminated.

Nutrient	% Stover Removal	*0-10 min*	*10-20 min*	*20-30 min*
PO_4-P	**0**	0.0001	0.0190	0.0466 a
	25	0	0.0050	0.0142 b
	50	0.0018	0.0149	0.0213 b
(kg ha^{-1})	**75**	0.0029	0.0094	0.0119 b
	100	0.0035	0.0117	0.0141 b
NH_4-N	**0**	0.0158 a	0.1752 a	0.3797 ab
	25	0 b	0 a	0.0509 a
	50	0.0446 b	0.3807 ab	0.5115 ab
(kg ha^{-1})	**75**	0 b	0 a	0.0171 a
	100	0.1770 b	0.6432 b	0.7235 b
NO_3-N	**0**	0.0088 a	0.2668 ab	0.5428 ab
	25	0 a	0.0072 a	0.0798 a
	50	0.0613 ab	0.4434 ab	0.5769 ab
(kg ha^{-1})	**75**	0.0071 a	0.0024 a	0.0176 a
	100	0.2056 b	0.6959 b	0.7775 b

Table 3.13 Losses of soluble nutrients in runoff water as affected by stover removal during wet (W) runs at Ottawa. Treatments with different letters within the same sampling period for the same nutrient are significantly different. Marked data likely contaminated.

Nutrient	% Stover Removal	*0-10 min*	*10-20 min*	*20-30 min*
PO_4-P	**0**	0.0007	0.0025 a	0.0019 a
	25	0.0010	0.0013 ab	0.0010 ab
	50	0.0004	0.0018 ab	0.0003 b
(kg ha^{-1})	**75**	0.0002	0.0001 b	0.0002 b
	100	0.0001	0.0008 ab	0.0003 b
NH_4-N	**0**	0.0082	0.0303	0.0147
	25	0.0194	0.0406	0.0192
	50	0.5649	1.3719	1.3014
(kg ha^{-1})	**75**	0.0240	0.0274	0.0190
	100	0.5805	0.8681	0.8698
NO_3-N	**0**	0.0010	0.0031	0
	25	0.0016	0	0
	50	0.0002	0	0
(kg ha^{-1})	**75**	0	0	0
	100	0	0	0

Table 3.14 Impact of stover removal on sediment loss and soil conditioning index (SCI) values estimated from RUSLE2.

Study Site	Parameter	% Stover Removal 0	25	50	75	100
Colby	Sed Loss (Mg ha^{-1} yr^{-1})	0.13	0.22	0.36	0.92	1.01
	SCI	0.72	0.66	0.55	0.37	0.35
Hugoton	Sed Loss (Mg ha^{-1} yr^{-1})	0.13	0.21	0.36	0.90	0.99
	SCI	0.84	0.74	0.61	0.41	0.39
Ottawa	Sed Loss (Mg ha^{-1} yr^{-1})	0.34	0.49	0.76	1.64	1.75
	SCI	0.61	0.54	0.45	0.29	0.28

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Chapter 4 - Effects of Corn Stover Removal on Soil Properties and Crop Production

Abstract

The harvest of corn (*Zea mays* L.) stover as feedstock for bioenergy production will likely occur in the near future. However, stover removal can impact soil physical properties important for soil conservation and crop growth, depending upon site and soil. Therefore, stover harvest rates that limit the negative impacts on agriculture and the environment must be established on a regional basis. This project assessed the effects of variable levels of corn stover removal from continuous no-till and strip-till corn systems on soil properties and crop production on a regional scale across three soils at Colby, Hugoton, and Ottawa in Kansas, USA. The soils were a Ulysses silt loam (Fine-silty, mixed, superactive, mesic Aridic Haplustolls) at Colby, Hugoton loam (Fine-silty, mixed, superactive, mesic Aridic Argiustolls) at Hugoton, and a Woodson silt loam (Fine, smectitic, thermic Abruptic Argiaquolls) at Ottawa, all with slopes ≤1%. Five stover treatments that consisted of removing 0, 25, 50, 75, and 100% of corn stover after harvest were studied for changes in bulk density, mean weight diameter (MWD), soil carbon (C), soil water content, soil temperature, and water retention over time. Stover removal had no effect on bulk density. The MWD of wet aggregates decreased with stover removal rates ≥50% on all soils. Stover removal rates ≥50% reduced the proportion of water-stable macroaggregates (>4.75 mm) and increased the proportion of microaggregates (<0.25 mm) in some instances. Soil C concentration of the top 5 cm at Ottawa was reduced by 1.57 Mg ha^{-1} with 75% stover removal relative to no removal. Soil water content decreased with stover removal at Colby and Ottawa, but was variable at Hugoton. Soil temperature tended to increase with stover removal during summer months and decrease during winter months, while temperature fluctuated more widely with stover removal, resulting in more freeze-thaw events. No effect of stover removal on soil water retention was observed on any of the soils. In 2009, removal rates ≥50% resulted in greater grain yield at Colby, while removal rates ≥75% resulted in greater grain yields at Ottawa in 2009 and 2010. Results from the first two years of stover management suggest that stover removal rates ≥50% can negatively impact soil properties and

positively impact crop yield in Kansas. However, further monitoring is warranted to assess long-term impacts on environmental quality and agricultural sustainability.

Introduction

Crop residue is not a useless byproduct of grain production; it has a number of competing uses including soil and water conservation, livestock feed and bedding, and as household fuel and construction material for small landholders in developing countries (Lal, 2004; Johnson et al., 2010). Residues play an important role in enhancing and conserving the soil resource of cropping systems by increasing desirable soil characteristics (Karlen et al., 1994; Lal, 2005; Mann et al., 2002). Residues shield the soil surface from the damaging impact of raindrops; provide a buffer from diurnal and annual fluctuations in temperature; are a source of soil organic carbon (SOC) and nutrients; increase aggregate stability, water infiltration, and microbial biomass; and decrease soil compaction and limit evaporative losses of water (Flerchinger et al., 2003; Lal, 2005; Andrews, 2006; Blanco-Canqui and Lal, 2009).

The demand for crop residue has risen recently due to an increased need for renewable sources of energy. Corn stover in particular has been identified as a prime bioenergy feedstock in the U.S. because of its perceived abundance and availability (Wilhelm et al., 2004). Corn stover is produced domestically and can be utilized for energy either as cellulosic ethanol or as a combustion source for electricity generation. It has recently been mandated that a minimum of 4.3 to 5.5 billion gallons of cellulosic ethanol be produced from crop residue by 2022 according to the Renewable Fuels Standard (USDA, 2010). However, large-scale harvesting of corn stover from agricultural fields for bioenergy production may have direct and indirect impacts on soil physical properties that can jeopardize crop productivity as well as soil and environmental quality.

The impact of stover removal on soil moisture is particularly important in regions that depend upon irrigation for crop production. Much of the irrigation water used in the western region of the Corn Belt comes from the Ogallala Aquifer, which is quickly diminishing in volume due to overconsumption. Therefore, management practices that conserve soil moisture and reduce irrigation rates are tremendously beneficial in terms of agricultural sustainability. However, stover decomposition rates are low in the dry regions of the Corn Belt, and the high yielding corn production results in a build-up of corn stover over time. The accumulation of large amounts of stover inhibits seed-to-soil contact during planting and slows soil warming in the spring, causing delayed germination. It is therefore feasible that a partial removal of stover without adverse effects may be possible in some regions.

Estimates of U.S. corn stover available for harvest have been made with soil erosion as the limiting factor (Nelson, 2002; Graham et al., 2007). However, the amount of stover needed to maintain certain soil properties may be higher than that required to keep soil loss below the tolerable limit (Wilhelm et al., 2007). While some studies show the impacts of stover removal on bulk density to be negligible (Karlen et al., 1994; Moebius-Clune et al., 2008), other studies report increases in bulk density with increased stover removal (Blanco-Canqui and Lal, 2007). This may indicate that stover removal effects on soil properties such as bulk density can vary geographically.

Stover removal has more consistent impacts on wet aggregate stability and C content. Soil has been shown to have less aggregate stability and less soil C when stover is removed for 10 yr (Karlen et al., 1994), and decreases in mean weight diameter (MWD) have been observed with stover removal rates as low as 25% after 1 yr (Blanco-Canqui et al., 2006). Decreases in C of 1.95 Mg ha^{-1} in the top 2 cm of soil have been observed with stover removal rates of 75% (Blanco-Canqui and Lal, 2007). Increases in stover removal have resulted in increased average daytime soil temperatures (Blanco-Canqui and Lal, 2007), increased fluctuations in soil temperature (Sharratt, 2002), decreased soil water content (Karlen et al., 1994), increased evaporation (Flerchinger et al., 2003), and decreased plant available water (Karlen et al., 1994; Blanco-Canqui and Lal, 2007; Moebius-Clune et al., 2008). The impact of stover removal on crop yield has been variable, with findings showing decreases in yield (Triplett et al., 1968; Blanco-Canqui and Lal, 2007) while other studies show more mixed results (Karlen et al., 1994).

Previous research has indicated that the effects of stover removal are site and soil-specific, and therefore stover harvest rates that limit the negative impacts on agriculture and the environment must be established on a regional basis. Thus, the objective of this study is to determine the effects of variable levels of corn stover removal on selected soil physical properties and crop yields at three contrasting sites in Kansas.

Materials and Methods

Description of Study Sites and Soils

This study, initiated in March 2009, was performed on three contrasting sites in Kansas including (1) Northwest Research Extension Center in Colby (39°23' N, 101°03' W, 969m above sea level), (2) a private producer's field near Hugoton (37°21' N, 101°20' W, 940m above sea level), and (3) East Central Experiment Field in Ottawa (38°32' N, 95°15' W, 294m above sea level) (Fig 4.1). These sites differ in soil texture, climate, and management (Table 4.1).

Two sites (Ottawa and Colby) are managed under no-till while the site at Hugoton is strip-tilled. Furthermore, the site at Ottawa is rain-fed while the sites at Colby and Hugoton are irrigated with center-pivot systems. Management practices prior to the current experiment establishment vary between sites. Conventionally tilled, irrigated sunflower, corn, and soybeans were grown at Colby in 2006, 2007, and 2008, respectively. The site at Hugoton has been in strip-tilled, irrigated, continuous corn production since 2006. The Ottawa site has been in no-till, dryland corn production since 2004.

The slope, determined using a clinometer, measured $\leq$ 1% at all three sites. The texture (Table 4.2), depth, drainage class, runoff risk, and saturated hydraulic conductivity of the soils at the three study sites differ substantially. Texture was determined using the pipette method (Gee and Bauder, 1986). The soil at Colby is a very deep, well drained, low-to-medium runoff risk soil with a moderately high saturated hydraulic conductivity and was formed in calcareous loess. The soil at Hugoton is a very deep, well drained, negligible runoff risk soil with a moderate saturated hydraulic conductivity and developed in loamy, Holocene-aged calcareous loess deposits. The soil at Ottawa is a deep, somewhat poorly drained, medium runoff risk soil with a very low saturated hydraulic conductivity that formed in silty and clayey sediments (USDA-NRCS, 2006).

A randomized complete block design with five treatments in triplicate was laid out in 6 x 6 m plots at each site. The five treatments consisted of removing 0, 25, 50, 75, and 100% of corn stover after harvest. At project initiation in 2009, corn stover remaining on the field from the previous year was redistributed for the plots on March 6 at Colby, March 15 at Hugoton, and

March 20 at Ottawa. Corn stover was subsequently redistributed following harvest at each site in fall 2009 and 2010. At harvest, plants were cut with shears leaving 15 cm of stalk above the soil surface to simulate common combine stalk cutting heights. Percent residue removal was estimated by dividing each plot into four quadrants, removing residue from the appropriate number of quadrants in each plot, and thoroughly redistributing the remaining residue across the whole plot to obtain a uniform surface cover. It is important to note that 100% stover removal was not achieved in this study, as 15 cm of stalk was left in the field on all plots. The dry mass of stover removed for each site and year, as well as the stover mass existing on the field in spring 2011 is presented in Tables 4.3 and 4.4, respectively. Plots were demarcated using colored flags placed at the corners of each plot.

Description of Field Management

Corn was planted with 76.2 cm row spacing at all sites in May 2009 and 2010. At Colby, DeKalb corn DKC62-29 was planted at 76,601 seeds ha^{-1} with a four row John Deere 7300 no-till planter equipped with a Yetter residue manager/coulter attachment. Fertilization included broadcasting 202 kg of N, 7.85 kg of Zn, and 25.8 kg S ha^{-1}. A pre-emergence herbicide was applied approximately 48 h prior to planting, and consisted of 1.12 kg atrazine ha^{-1}, 1.40 kg S-metolachlor ha^{-1}, and 0.867 kg glyphosate ha^{-1}. The center-pivot irrigation system applied 38.1 mm of water approximately every 144 h, resulting in a total of 572 mm applied during the two growing seasons.

At Hugoton, DeKalb corn DKC61-69 was planted with a John Deere 1770 planter at 85,250 seeds ha^{-1}. The soil was strip-tilled prior to planting using an Orthman 1-Tripper tillage implement, and fertilized with 10-34-0 (liquid ammonium phosphate) at 118 L ha^{-1} and 82-0-0 (anhydrous ammonia) at 22.4 kg N ha^{-1}. Initial herbicide application, which occurred approximately 3 wk after planting, included 1.82 kg ammonium sulfate ha^{-1}, 0.825 kg atrazine ha^{-1}, 1.03 kg S-metolachlor ha^{-1}, 1.12 kg glyphosate ha^{-1}, and .309 oz dicamba ha^{-1}. A second herbicide application occurred approximately 6 wk after planting and included 1.82 kg ammonium sulfate ha^{-1}, and 1.11 kg glyphosate ha^{-1}. The center-pivot irrigation system applied

31.8 mm of water after the initial herbicide application, and 31.8 mm every 108 h resulting in a total of 635 mm applied during the remainder of each growing season.

At Ottawa, DeKalb corn DKC50-44 was planted with a no-till planter at 63,258 seeds ha^{-1}. Fertilization consisted of applying 134 kg N ha^{-1}, 33.6 kg P_2O_5 ha^{-1}, and 11.2 kg K_20 ha^{-1}, using a mixture of liquid 28-0-0 (urea ammonium nitrate) and 7-21-7 fertilizer, which was band applied 6.35 cm to the side and 6.35 cm below the seed row at planting. Herbicide application consisted of 1.06 kg glyphosate ha^{-1} one wk prior to planting, 1.12 kg atrazine ha^{-1} and 1.40 kg S-metolachlor ha^{-1} one d after planting, and an additional application of 1.06 kg glyphosate ha^{-1} approximately 3 wk after planting.

Soil Sampling and Analysis

Bulk Density

Intact soil cores of 4.8 cm diameter were collected at 0 to 5 and 5 to 10 cm depths from each treatment plot periodically throughout the study using a hammer-driven core sampler (AMS Inc., American Falls, ID). The soil cores were placed into pre-labeled metal tins, weighed within the same day, and dried at 105°C for 48 h for gravimetric water content determination. Bulk density was determined by the core method (Blake and Hartge, 1986). Volumetric water content was determined as the product of bulk density and gravimetric water content.

Wet Aggregate Stability

Composite samples were collected prior to planting in 2009 from the three replications at each study site for baseline measurements. Additional samples were collected in the spring of 2009, 2010, and 2011, and in the fall of 2009 and 2010 to determine the effect of stover removal on aggregate stability. Samples from the top 0 to 5 cm soil depth were air-dried and sieved to collect aggregates >4.75 and <8 mm in size for determination of percent water-stable aggregates (WSA) and MWD following the wet-sieving method of Kemper and Rosenau (1986). A 40 g subsample of >4.75 mm aggregates was oven dried at 105°C for 24 h to obtain gravimetric moisture content. A 50 g subsample was subjected to wet-sieving with a mechanical device that oscillated four sets of nested sieves through a vertical displacement of 35 mm at 30 oscillations

min^{-1} (Grainger, Inc., Lake Forest, IL). Each nest had five sieves of 127 mm diam. and 40 mm depth with wire mesh openings of 4.75, 2.00, 1.00, 0.50, and 0.25 mm (Newark Wire Cloth Company, Clifton, NJ). The air-dry aggregates were placed on the top (4.75 mm) sieve, saturated by capillarity with water for 10 min, and then mechanically sieved in water for 10 min. The soil remaining on each sieve after oscillation was washed into pre-weighed glass jars and oven dried at 105°C for 48 h to obtain soil mass. The oven-dry soil was soaked in a 13.9 g L^{-1} sodium hexametaphosphate solution for 24 h to facilitate the separation of soil particles and coarse fragments. The dispersed samples were then washed through the corresponding sieves in order to collect and account for coarse fragment content. Percent WSA and MWD were calculated in accord with Stone and Schlegel (2010) as:

$$\text{WSA} = (m_m - m_f)/(m_t - m_f)$$

where m_m is the oven-dry mass of material on a sieve after sieving, m_f is dry mass of fragments on the same sieve after dispersion, and m_t is total sample dry mass, and:

$$\text{MWD} = \Sigma \text{ (i=1, to 6) } (w_i/m_a)x_i$$

where w_i represents the oven-dry mass of aggregates (w_1 through w_5) determined for each of the five sieve sizes (aggregates and fragments after sieving [m_m] minus fragments on the same sieve after dispersion [m_f]) and dry mass (w_6) of material passing through the sieve with 0.25 mm openings during sieving (Kemper and Rosenau, 1986), x_i represents the mean diameter of each of the six size fractions (size of smallest fraction [x_6] was calculated as 0.25 mm/2), and m_a is the total dry mass of aggregates (sum of w_1 through w_6).

Soil Water Retention

Soil water retention tests were conducted on undisturbed soil cores (7.3 cm dia. by 7.5 cm length) taken in spring 2011 (Dane and Hopmans, 2002; McVay et al., 2006). Soil cores were obtained from the 0 to 7.5 cm soil depth and were stored at 4°C until analysis. Tempe pressure cells with 60 kilopascal (kPa) membrane papers (600 millibars, Soil Measurement Systems, Tucson, AZ) were constructed around each core sample. Samples were initially saturated with 0.01 *M* $CaCl_2$ from the bottom by applying a constant head of around -0.8 kPa (about -8 cm H_2O). Samples were sequentially desaturated using compressed air in a pressure sequence of -1.4, -3.0, -6.0, -9.2, -18.4, and -36.8 kPa. Pressure cell mass was recorded daily, and final equilibrium weights for a pressure setting were determined by a daily weight loss of <0.5 g, which typically required 4 to 5 d to achieve. Samples were then dried at 105°C for 48 h to determine bulk density and porosity (assuming a particle density of 2.65 g cm^{-3}). A constant laboratory temperature of 20°C was maintained throughout the analyses.

Water retention at higher tension was determined on disturbed samples sieved through 2 mm wire mesh and placed in a 5.5 cm ring on -0.5 and -1.5 MPa ceramic pressure plates inside a 1500F1 15 bar pressure plate extractor (SoilMoisture Equipment, Santa Barbara, CA). Samples were first saturated with 0.01 *M* $CaCl_2$ and pressure was produced using 220 psi compressed N_2 gas. Soil samples were considered at equilibrium after 5 d. Gravimetric water content was determined and converted to a volumetric basis using bulk density values from the respective undisturbed cores. Water holding capacity was estimated as the difference in water content between -36.8 kPa and -1.5 MPa.

Soil water retention curves were created by plotting the volumetric water content of each sample when equilibrium was achieved at each pressure step. Data points were fitted to the equation described by van Genuchten (1980) using the RETC software (J.E. Brown Jr. Salinity Laboratory, Riverside, CA). Saturated water content (θ_s), residual water content (θ_r), and two shape factors, α and N, were fitted in RETC with initial values appropriate for a silt loam for Ottawa and Colby, and a loam for Hugoton. In some cases RETC estimated $\theta_r < 0.0$ cm^3 cm^{-3}, in which case θ_r was set equal to 0.0 cm^3 cm^{-3} and RETC fit the remaining three parameters. The mean R^2 for the fit of soil water retention curves at Colby, Hugoton, and Ottawa was 0.995, 0.995, and 0.996, with a minimum R^2 of 0.988, 0.993, and 0.993, respectively.

Total Carbon and Nitrogen

Bulk soil samples obtained in fall 2010 and spring of 2010 and 2011 from 0 to 5 cm depth were air-dried, sieved to 4 mm, removed of visible organic materials, ground with mortar and pestle, and sieved to 0.25 mm for measurement of total C and N using dry combustion with a LECO TruSpecCN analyzer (LECO Corp., St. Joseph, MI) (Nelson and Sommers, 1996). The percentage of C and N for each treatment was used in conjunction with the respective bulk density values to calculate the mass, in megagrams, of soil C and N per hectare.

Soil Temperature and Moisture

Soil temperature and moisture of the top 0 to 5 cm of soil was monitored *in situ* using Stevens Hydraprobe II SDI-12 sensors (Stevens Water Monitoring Systems, Inc., Portland, OR). The sensors convert the signal response of a reflected electromagnetic radio wave into dielectric permittivity, which can then be translated into soil moisture and electrical conductivity using patented algorithms. Due to financial limitations, the sensors were installed only in the 0, 50, and 100% stover removal treatments, resulting in 9 sensors per site. Installation of the sensors included digging a small hole, inserting the sensors horizontally into the top 0 to 5 cm of the soil pit face, and carefully backfilling the pit. Sensors were wired to a CR1000 datalogger (Campbell Scientific, Inc., Logan, UT) connected to a solar panel-powered battery and took measurements every 60 min. Dataloggers and batteries were housed in water-tight plastic electrical enclosures which were mounted onto stands constructed from PVC tubing (Fig 4.2).

Crop Production

Corn grain and stover was hand-harvested from an area measuring 0.0004 ha from the two center rows of each plot in 2009 and 2010. To demarcate the area to be harvested, a PVC pipe measuring 2.67 m in length was tossed in between the two rows to randomly capture variability, and plants lying within the pipe length were harvested. Plants were cut with shears leaving 15 cm of stalk above the soil surface to simulate common combine stalk cutting heights. Corn ears were harvested from the plants and weighed in the field with a portable scale. Total stover mass was measured and a subsample of 1 to 2 plants was taken back to the lab. Corn grain and stover were dried in an oven at 65°C for 72 h. After drying, the grain was shelled and stover moisture content was determined using a DICKEY-john GAC 2100 Agri grain moisture meter (DICKEY-john Corp., Minneapolis, MN). Grain mass was adjusted to 155 g kg^{-1} water content for yield comparison.

Stand counts were performed approximately one month after planting in 2009 and 2010 to determine the impacts of stover removal on early-season crop growth. A stick measuring 0.61 m was thrown between two rows to randomly capture variability. Plants lying within the length of the stick were counted and height was measured using the tip of the whirl leaf as the uppermost plant height. Stand counts were extrapolated to plants ha^{-1}. Plant height was not measured at Hugoton in 2010. Additionally, the mass of stover existing on the soil surface after 2 yr of treatment application was determined in spring 2011. Stover was collected from a 1 m^2 area from each plot and moisture content determined by drying at 65 °C for 72 h.

Statistical Analysis

All data were analyzed using the PROC MIXED feature of SAS 9.2 (SAS Institute, 2008). Differences between least squares means were tested using 0.05 probability level (SAS Institute, 2008). Treatment comparisons were made only within each site due to soil, climate, and management variation among sites.

Results

Bulk Density

The impact of stover removal on soil bulk density was highly variable at all study sites throughout the duration of the study (Table 4.5, 4.6, 4.7). However, a single exception occurred at Colby, where bulk density values at 5 to 10 cm depth significantly decreased with increases in stover removal in June 2009 (Table 4.5). In this case, bulk density decreased by an average of 0.13 Mg m^{-3} with 50 and 75% removal, and by 0.21 Mg m^{-3} with complete stover removal relative to no removal.

Wet Aggregate Stability

Mean Weight Diameter

The MWD of water-stable aggregates tended to decrease with increased rates of stover removal at all sampling dates and sites. In spring of 2010, a removal rate of 50% decreased MWD by 0.56 mm (26%) compared to no stover removal at Colby (Fig 4.3). At Hugoton, complete removal of stover reduced MWD by 1.13 mm (58%) compared to no removal (Fig 4.4). Removal of 75% of stover resulted in a 0.68 mm (36%) decrease in MWD at Ottawa in spring 2010 (Fig 4.5).

In fall 2010, no difference in MWD was observed between 0% and higher rates of removal at Colby (Fig 4.3). However, removal rates of 50, 75 and 100% resulted in a decrease in MWD of about 1.17 mm (34%) compared to 25% removal rate. At Hugoton, 75% removal reduced MWD by 0.63 mm (29%) compared to no stover removal (Fig 4.4). MWD decreased by 0.76 mm (34%) with complete stover removal relative to no removal at Ottawa in fall 2010 (Fig 4.5).

The impacts of stover removal on MWD of aggregates appeared to be less pronounced in spring 2011 than the previous sampling dates. No differences were found in MWD between stover removal rates at Colby and Hugoton. At Ottawa, 75% removal reduced MWD by 0.77 mm (37%) compared to no removal.

Percentage of Water-Stable Aggregates by Size Fraction

One year after stover removal (spring 2010), at Colby, stover removal had the largest effect on <0.25, 0.25 to 0.50, and >4.75 mm aggregate size fractions (Fig 4.6). It reduced the percentage of >4.75 mm aggregate size fraction. Conversely, high rates of stover removal increased the proportion of 0.25 to 0.50 and <0.25 mm aggregate size fractions. Compared with no stover removal, stover removal at rates of 50 and 100% reduced >4.75 mm WSA by 8.9 and 13.2%, respectively. There existed 2.4% more 0.25 to 0.50 mm WSA with 50% removal. Additionally, 10.4% more WSA were observed with complete stover removal in the <0.25 mm size fraction.

The same trend occurred at Hugoton in spring of 2010 (Fig 4.7). Complete stover removal featured 16.5% less WSA in the >4.75 mm fraction compared to no removal. Likewise, complete stover removal treatments featured 5.3% and 18.2% more aggregates in the 0.25 to 0.5 mm and <0.25 mm size fractions, respectively. At Ottawa in spring 2010, differences in percentage of WSA were only observed in the >4.75 mm and <0.25 mm size fractions (Fig 4.8). Stover removal rates of 75% resulted in 8.6% less WSA compared to no removal in the >4.75 mm fraction. Removal rates as low as 50% featured 6.1% more aggregates <0.25 mm in size, while 12.6% more WSA was observed with complete removal <0.25 mm compared to no removal.

In fall 2010, the impact of stover removal on WSA was only observed between 25% removal and higher rates of removal at Colby (Fig 4.6). In the >4.75 mm size fraction, removal rates greater than 25% resulted in an average of 18% less WSA compared to 25% removal. Over 5% more 0.25 to 0.50 mm WSA was observed with complete stover removal relative to 25% removal. Stover removal rates greater than 25% resulted in an average of 14.5% more <0.25 mm WSA at Colby in fall 2010 compared to 25% removal. At Hugoton, treatment differences were observed in four out of the six size fractions in fall 2010 (Fig 4.7). In the >4.75 mm fraction, removal rates >75% featured 8.5% fewer WSA compared to no stover removal. In the 2 to 4.75 mm fraction, 3.1% fewer WSA were observed with complete stover removal compared to no removal. A small, but significant, difference was observed in the 1 to 2 mm fraction, where complete stover removal featured 0.9% less WSA than no removal. In the <0.25 mm fraction, removal rates ≥75% featured 11.5% less WSA compared to no stover removal at Hugoton. Similar to Hugoton, differences in %WSA by treatment were observed in four of the six size fractions at Ottawa in fall 2010. In the >4.75 mm fraction, a complete removal of stover resulted in 9.3% less WSA compared to no removal. An average of 4.1% less WSA were observed with stover removal ≥75% compared to no removal in the 2 to 4.75 mm fraction. A small but significant difference was observed in the 1 to 2 mm fraction, where complete removal resulted in 0.9% less WSA compared to no stover removal at Ottawa (Fig 4.8). In the <0.25 mm fraction, stover removal rates of 75 and 100% resulted in 8.2 and 15% more WSA, respectively, relative to no stover removal.

In general, differences in WSA between treatments were less pronounced in spring 2011 than previous sampling dates. Compared to no stover removal, complete removal resulted in 6.7% more WSA in the 0.25 to 0.50 mm size fraction at Colby (Fig 4.6). At Hugoton, 2.05 and 3.1% more WSA were observed with 75% stover removal in the 1 to 2 mm and 0.50 to 1 mm size fractions, respectively, compared to no removal (Fig 4.7). However, WSA for complete stover removal did not differ from WSA from 0% removal treatments in any of the aggregate size fractions at Hugoton. At Ottawa, removal rates of 75 and 100% featured 11.4 and 6.3% less WSA, respectively, compared to no stover removal in the >4.75 mm fraction (Fig 4.8). In the remaining size fractions, no differences between complete removal and no removal were observed. However, complete stover removal resulted in 3.3% less WSA in the 2 to 4.75 mm fraction compared to 25% removal. Additionally, 75% stover removal featured 3.7% more WSA in the 0.25 to 0.50 mm fraction compared to 25% removal, while 75% removal resulted in 10.6% more WSA in the <0.25 mm fraction compared to both 0 and 25% stover removal rates at Ottawa in spring 2011.

Soil Water Retention

Stover removal did not impact soil water retention after 2 yr of this study. Differences among treatments were variable at all sites, possibly due to inherent field variation. At Colby, 50 and 75% stover removal rates held consistently more water than other rates from 0 to -9.2 kPa potential, after which no differences between removal rates were observed (Fig 4.9). This is reflected in the fitted saturated water content (θ_S) parameters of van Genuchten's model, where 50 and 75% removal rates feature significantly higher θ_S values (Table 4.8). No differences among treatments were observed at Hugoton for any of the pressure steps (Fig 4.10), which is also consistent with the van Genuchten's fitted parameters (Table 4.9). At Ottawa, more water was held in soils with 25% removal than soils with no stover removal from potentials of -1.4 to -6.0 kPa, while more water was held at -1500 kPa with 75% removal (Fig 4.11). Similarly, the effects of stover removal on available water content were variable at all study sites (Table 4.11). At Ottawa, 50% removal had higher available water content than 75 and 100% stover removal rates. While no significant differences in available water content among treatments were observed at Colby or Hugoton, soils with complete stover removal had lower available water content than soils with no removal.

Total Carbon and Nitrogen

No significant differences in total C were observed among stover removal rates except at Ottawa in spring 2011. A slight trend of decreasing total C concentration with increases in stover removal rates was observed at Colby in spring 2011, at Hugoton in spring 2010, and during all sampling dates at Ottawa (Fig 4.12). A significant decrease in total C with increased stover removal rate was observed at Ottawa in spring 2011, where 1.57 Mg ha^{-1} less total C was observed with 75% removal relative to no removal in the top 5 cm of soil. Additionally, no significant differences in total N were found among stover removal treatments (Fig 4.13). A slight trend in the observed values of decreased total N with increases in stover removal occurred at Ottawa throughout the study.

Soil Temperature and Water Content

Soil temperature of the top 5 cm was generally cooler in the summer months and warmer in the winter months with low rates of stover removal compared to high rates of removal at all study sites (Figure 4.14). Differences in soil temperature appear to be greatest during the spring, summer, and fall seasons, and least during the winter season. At Colby, stover removal rates of 50 and 100% increased soil temperature by 2.7 and 4.2 °C, respectively, compared to no removal in June 2010. Although not significant, removal rates of 50 and 100% featured soil temperatures 0.12 and 0.39 °C lower than no stover removal in January 2011 at Colby. At Hugoton, stover removal rates of 50 and 100% increased soil temperature by 2.0 and 3.5 °C, respectively, compared to no removal in June 2010. This trend is reversed in February 2010, where 100% stover removal decreased soil temperature by 0.43 °C compared to no removal. Soil temperature of the 100% removal treatments at Ottawa was 6.8 °C warmer during June 2010 and 0.61 °C cooler in December 2009 compared to treatments with no removal. The magnitude of winter soil temperature fluctuations increased with stover removal at all sites, resulting in more freeze-thaw events on soils with 50 and 100% stover removal (Fig 4.15, 4.16, 4.17). Additionally, the rate at which soils either cooled down or warmed up was greater with 50 and 100% stover removal as compared to no removal.

Trends in soil water content of the top 5 cm as affected by stover removal varied both between sites and months (Fig 4.18). At Colby, soil water content was always greatest when no stover was removed. In June 2010, removal rates of 50 and 100% decreased soil water content by 0.075 and 0.057 $m^3\ m^{-3}$, respectively, compared to no removal. In January 2011, 50 and 100% removal rates decreased soil water content by 0.048 and 0.028 $m^3\ m^{-3}$, respectively, relative to no removal. At Hugoton there existed a trend in soil water content similar to Colby, but only during the growing season (May 2010 through October 2010). During the winter months (November 2009 through April 2010 and January 2011 through April 2011), however, soil water content was either very similar between 0 and 50% stover removal treatments, and in some cases greater with 50% removal compared to no removal. In June 2010, soil water content decreased by an average of 0.044 $m^3 m^{-3}$ with 50 and 100% stover removal, while in February 2011 soil water content was increased by an average of 0.040 $m^3 m^{-3}$ with 50 and 100% removal rates compared to no removal. At Ottawa, soil water content was greatest with no stover removal in Dec, Jan, Feb, and Apr 2010. A decrease in soil water content only with removal rates of 100% occurred in Mar, June, July, Aug, and Dec 2010, and in Jan, Mar, and Apr of 2011. No difference in soil water content among stover removal rates was observed in Feb 2011. Similar to Hugoton, soil water content was greatest with 50% removal in both Sept and Oct 2010. In Jan 2010, removal rates of 50 and 100% reduced soil water content by an average of 0.085 $m^3 m^{-3}$ relative to no removal. In June 2010, complete stover removal reduced soil water content by 0.05 $m^3 m^{-3}$ compared to no removal. In Sept 2010, 50% stover removal increased soil water content by about 0.068 $m^3 m^{-3}$ relative to 0 and 100% removal.

Crop Production

The impact of stover removal on grain yield was variable for each site in 2009 and 2010 (Table 4.15). In 2009, an increase in grain yield of 4.75, 5.03, and 4.21 Mg ha^{-1} was observed at Colby with 50, 75, and 100% stover removal, respectively, compared to no removal. At Ottawa in 2009, an increase in grain yield of 1.94 Mg ha^{-1} was observed with 100% removal relative to no removal. The impact of stover removal on grain yield at Colby in 2010 was variable, with 50% removal having a 4 Mg ha^{-1} greater grain yield than 100% stover removal. At Ottawa, 75 and 100% removal rates increased grain yield by an average of 1.04 Mg ha^{-1} compared to both 0 and 25% removal. Differences in grain yield between stover removal treatments did not occur at Hugoton in 2009 or 2010. Stover yield was not impacted by stover removal rates at Colby or Hugoton both years (Table 4.16). Complete stover removal significantly increased stover production by 1.12 and 3.42 Mg ha^{-1} in 2009 and 2010, respectively, compared to no removal at Ottawa.

Early-season plant height was impacted by stover removal at Ottawa in 2009 and at Colby in both 2009 and 2010 (Fig 4.19). Plants were 12.1 and 19.5 cm taller with 25 and 50% removal, respectively, and 37.2 cm taller, on average, with 75 and 100% removal as compared to no removal at Colby in 2009. In 2010, plants were 4.33 cm taller with 25% removal, while removal rates >25% increased plant height by an average of 9.79 cm compared to no stover removal at Colby. At Ottawa in 2009, stover removal rates above 25% increased plant height by an average of 1.70 cm compared to no removal. Differences in early-season plant height between stover removal treatments were not observed in 2009 at Hugoton and at Ottawa in 2010.

Discussion and Conclusions

Effects of stover removal on soil properties and crop production depended upon site and soil in this regional study in Kansas. No relationship between stover removal rate and soil bulk density to a depth of 10 cm was observed after 2 yr. These results coincide with the findings of Karlen et al (1994), who observed no changes in soil surface bulk density over 10 yr of stover management in Wisconsin. The bulk density values for all rates of stover removal observed in this study are not considered large enough to limit root development.

Stover removal has been shown to decrease the percentage of water stable aggregates in regions throughout the U.S. (Karlen et al., 1994; Blanco-Canqui and Lal, 2009; Blanco-Canqui et al., 2009). Likewise, decreases in mean weight diameter of aggregates with increased stover removal occurred in this study. Furthermore, stover removal decreased the amount of large WSA and increased the amount of small WSA. Stover removal exposed the soil surface to the forces of wind and rain which dispersed soil particles and facilitated aggregate breakdown.

Soil C and N contents were not significantly impacted by stover removal at Colby or Hugoton throughout the study. This could be partially explained by the large variability in bulk density data, which will impact C and N density. However, excluding fall 2010 measurements, soil C generally tended to decrease with stover removal at Colby and Hugoton. A significant decrease in total C of 1.57 Mg ha^{-1} with 75% removal at Ottawa was observed in spring 2011, which closely resembles the 1.95 Mg ha^{-1} decrease with 75% removal observed in Ohio by Blanco-Canqui and Lal (2007). Changes in soil C as impacted by stover removal may be difficult to observe in this short-term study, as soil organic matter dynamics are relatively slow (Neill, 2011). The decrease in soil C at Ottawa after 2 yr may be explained by greater precipitation and thus greater decomposition of corn stover relative to the other sites. The lower amounts of soil C with high rates of stover removal may help to explain the decreases in aggregate stability. Soil organic matter binds soil particles together and is a substrate for soil microorganisms such as fungi, which also enhance aggregate formation via hyphae and excreted polysaccharides (Six et al., 2006).

Stover removal resulted in higher soil temperatures during summer months, and lower soil temperatures during winter months at all sites. Soil temperature also fluctuated more widely with stover removal as compared to no removal, which agrees with the findings of Sharratt (2002). Consistent reductions in soil water content with increased stover removal occurred at Colby, while results were more variable at Hugoton and Ottawa. At Hugoton, stover removal reduced soil water content during the growing season, while moisture varied more during the winter months. At Ottawa, stover removal generally reduced soil water content throughout the study. Lower soil temperatures may be due to the higher water contents observed with low rates of stover removal. Soils with higher water contents will generally take longer to heat up and cool down because of the high specific heat capacity of water. Evaporation is also more likely to occur where stover has been removed because the soil surface is directly exposed to the atmosphere. Therefore, adequate stover cover will reduce evaporation and result in higher soil water content. Greater soil water content during the growing season will benefit the corn crop, especially in years where moisture is limiting. However, the slower soil warming rates in spring associated with low stover removal may impair seed germination and early root growth, resulting in lower stand counts and potentially lower grain yield. The large fluctuations in soil temperature with stover removal increase occurrences of soil freezing and thawing, resulting in physical weathering and breakdown of aggregates.

Soil water retention and available water content were not affected by stover removal after 2 yr of this study. This may be explained by the lack of change in soil C with stover removal, as organic matter has the ability to hold a significant amount of water relative to its mass. It is possible that changes in soil water characteristics will only occur on longer time scales, similar to soil C.

No differences in grain yield were observed between stover removal rates at Hugoton throughout the study. However, slight increases in yield with increased stover removal were observed at Colby in 2009 and at Ottawa in 2009 and 2010. These results agree with the findings of Karlen et al. (1994) in Wisconsin, and contrast with results of Triplett et al. (1968) and Blanco-Canqui and Lal (2007) in Ohio. While stover removal did not impact stover production at Colby or Hugoton, complete stover removal at Ottawa resulted in higher stover yields than no stover removal both years. These results may be attributable to early-season plant height, which increased with stover removal in 2009 and 2010 at Colby, and in 2009 at Ottawa, while no differences in early-season plant height were observed at Hugoton. While different forms of nitrogen were not analyzed in this study, N immobilization may have occurred with low rates of stover removal, resulting in less plant available N. In order to break down the large amounts of C existing in corn stover, soil microorganisms will incorporate inorganic N into microbial biomass N which is not available for plant uptake. It is also possible that soil moisture was not limiting during the two years of this study, and that the decrease in moisture with stover removal was not enough to impact crop growth. Irrigation is used at both Colby and Hugoton, which will compensate for any impact of stover-dependent moisture loss.

Results from this study suggest that on certain soils, moderate rates of stover removal can adversely impact soil physical properties within 2 yr. Removal rates of 50% significantly reduced aggregate stability and soil moisture, and resulted in wider fluctuations in soil temperature across all three sites in Kansas. Removal of 75% of stover significantly decreased soil C after 2 yr on the silt loam at Ottawa. The alterations in soil properties have the potential to impair crop growth and increase the susceptibility of soil to water erosion. However, low rates of stover removal may come with negative short-term effects on yield. Long-term investigations of stover removal on a wide variety of soils and climates are warranted in order to better determine threshold removal levels on a regional scale.

Figures and Tables

Figure 4.1 Locations of study sites within the precipitation gradient of Kansas.

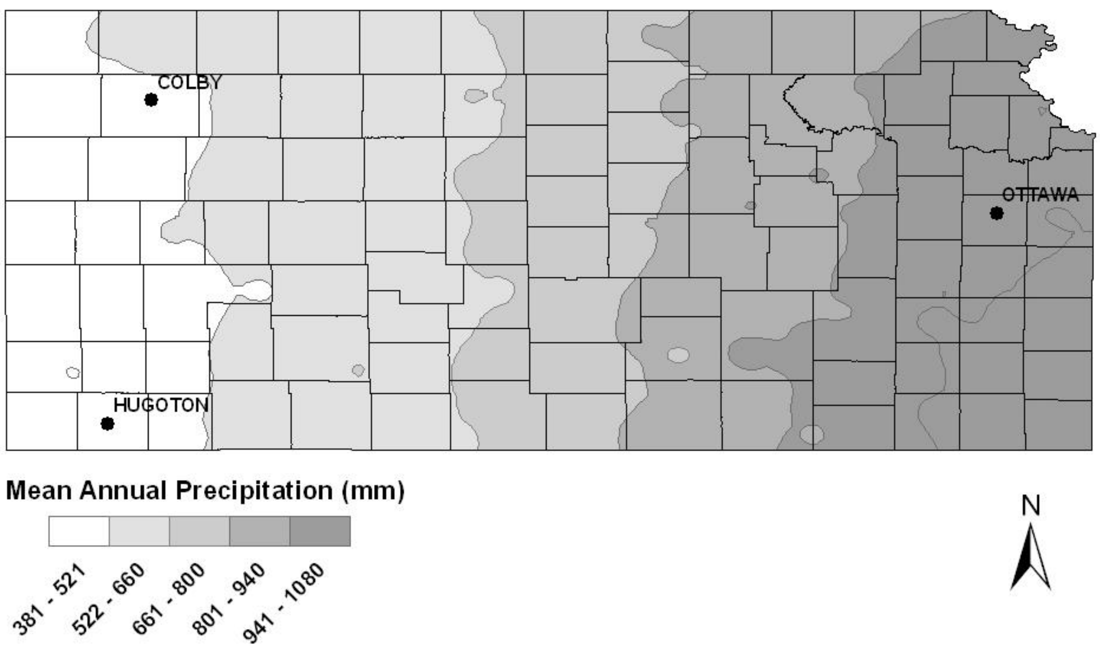


Figure 4.2 PVC structure and plastic enclosure for soil sensors.

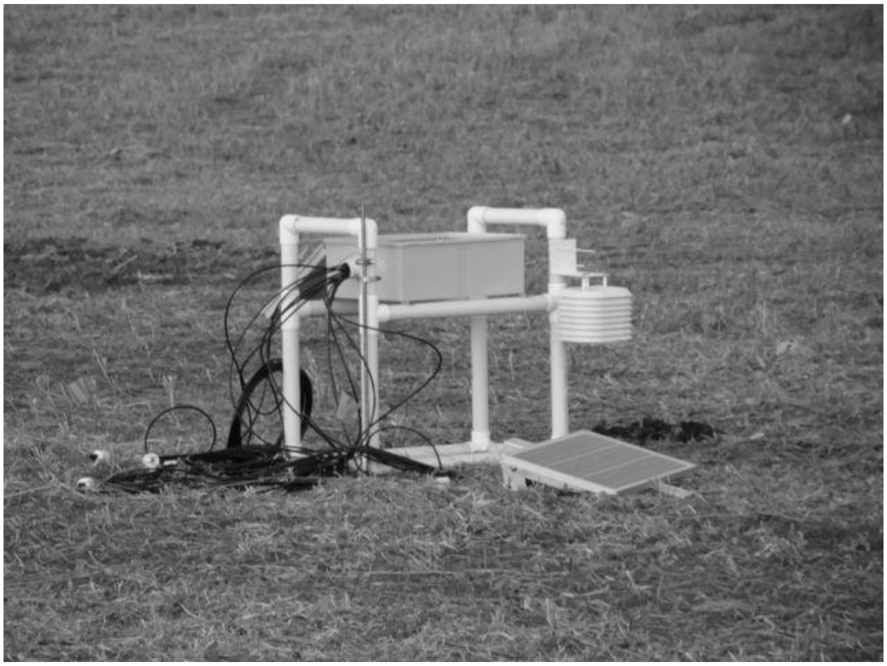


Figure 4.3 Mean weight diameter of water-stable aggregates as impacted by stover removal at various sampling dates at Colby. Treatments with different letters are significantly different.

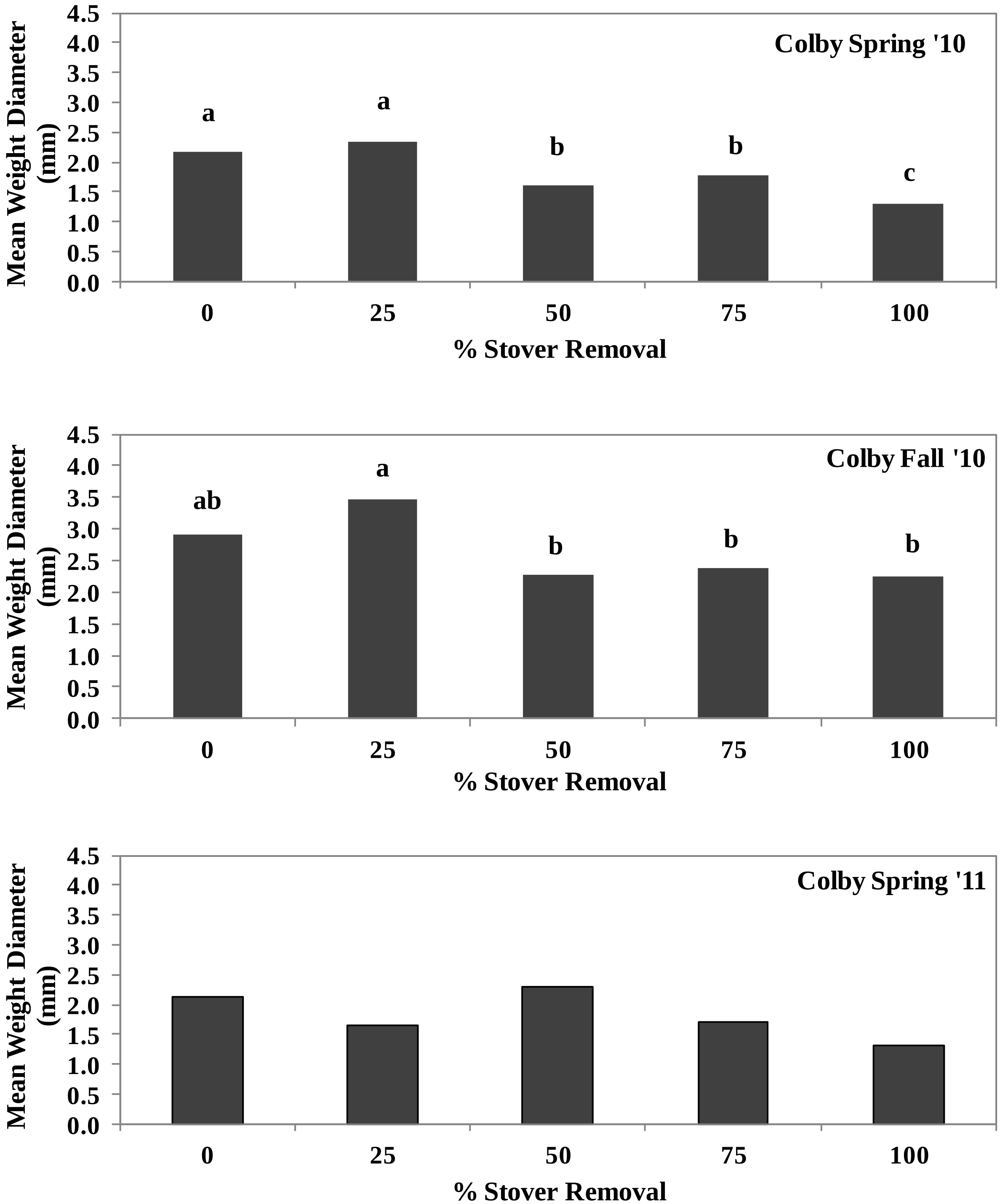


Figure 4.4 Mean weight diameter of water-stable aggregates as impacted by stover removal at various sampling dates at Hugoton. Treatments with different letters are significantly different.

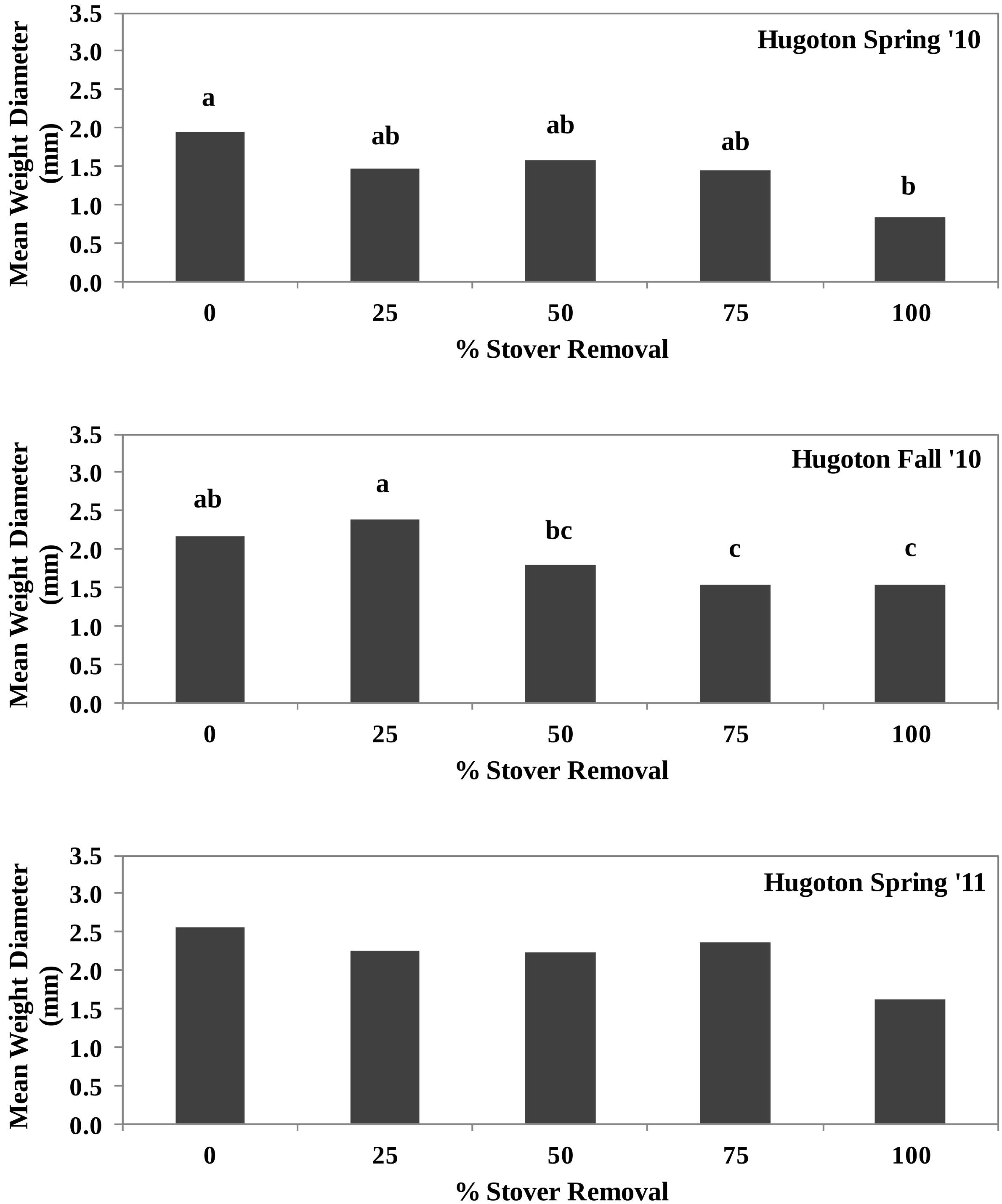


Figure 4.5 Mean weight diameter of water-stable aggregates as impacted by stover removal at various sampling dates at Ottawa. Treatments with different letters are significantly different.

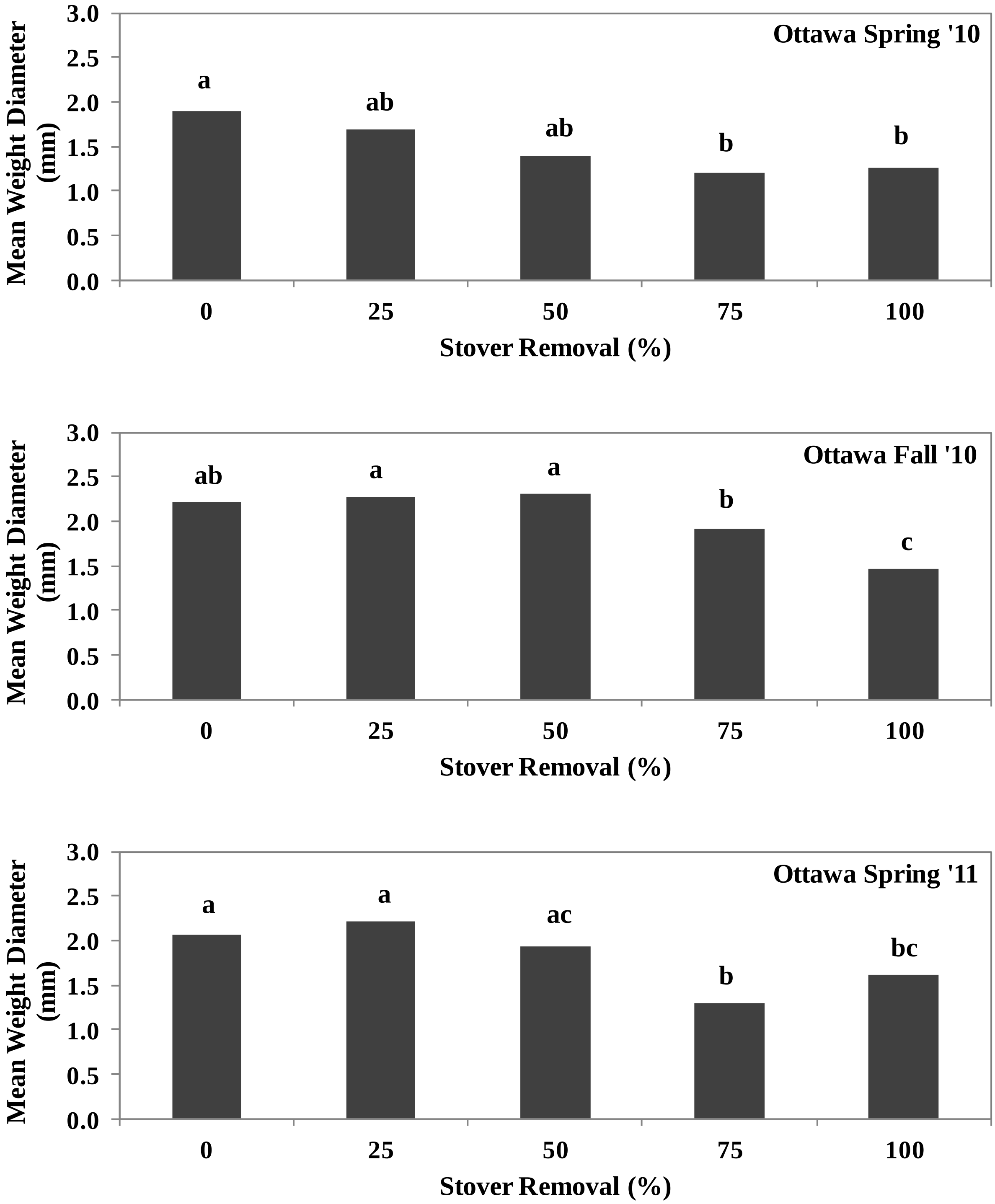


Figure 4.6 Distribution of water-stable aggregate fractions as impacted by stover removal at various sampling dates at Colby. Treatments within the same size fraction with different letters are significantly different.

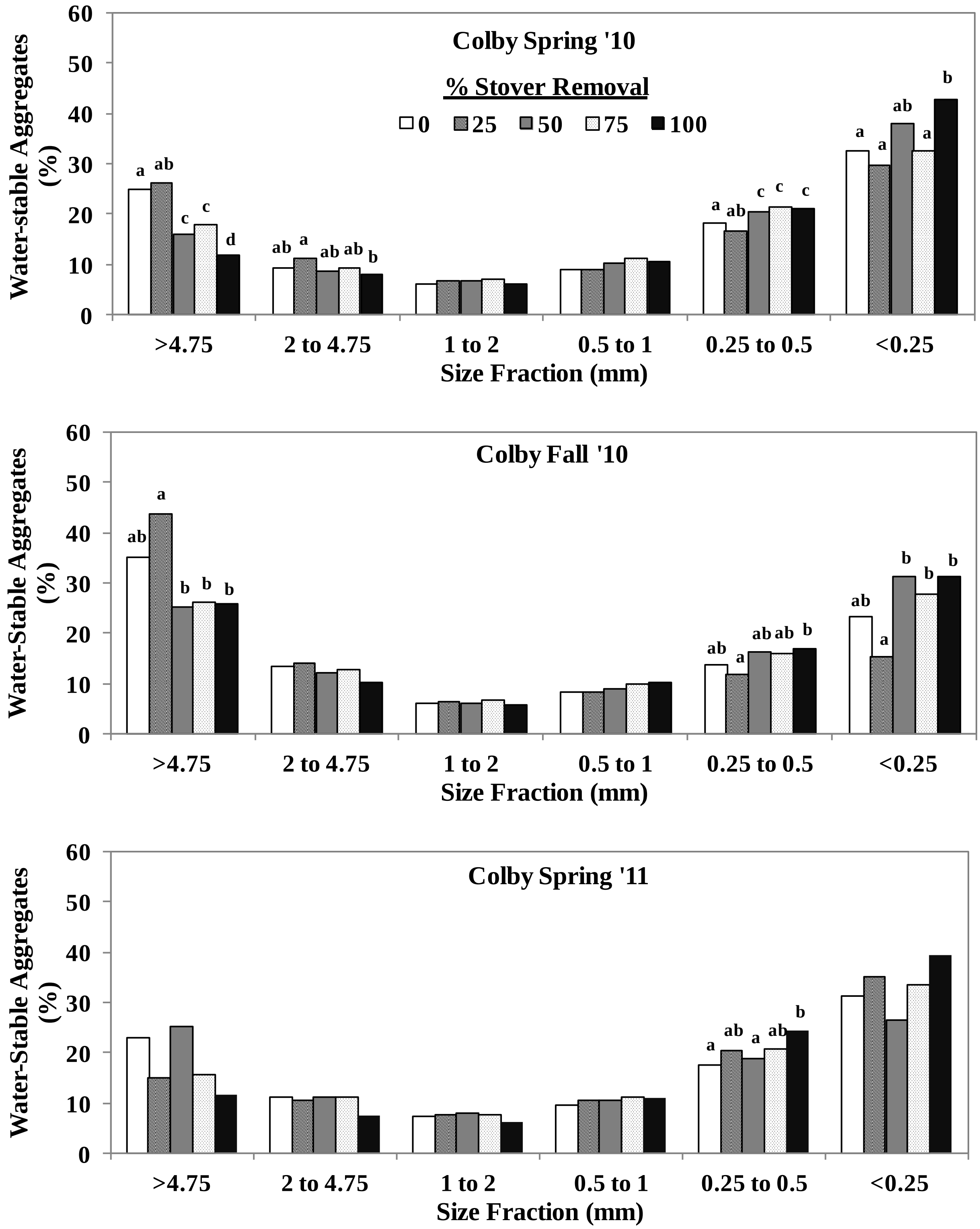


Figure 4.7 Distribution of water-stable aggregate fractions as impacted by stover removal at various sampling dates at Hugoton. Treatments within the same size fraction with different letters are significantly different.

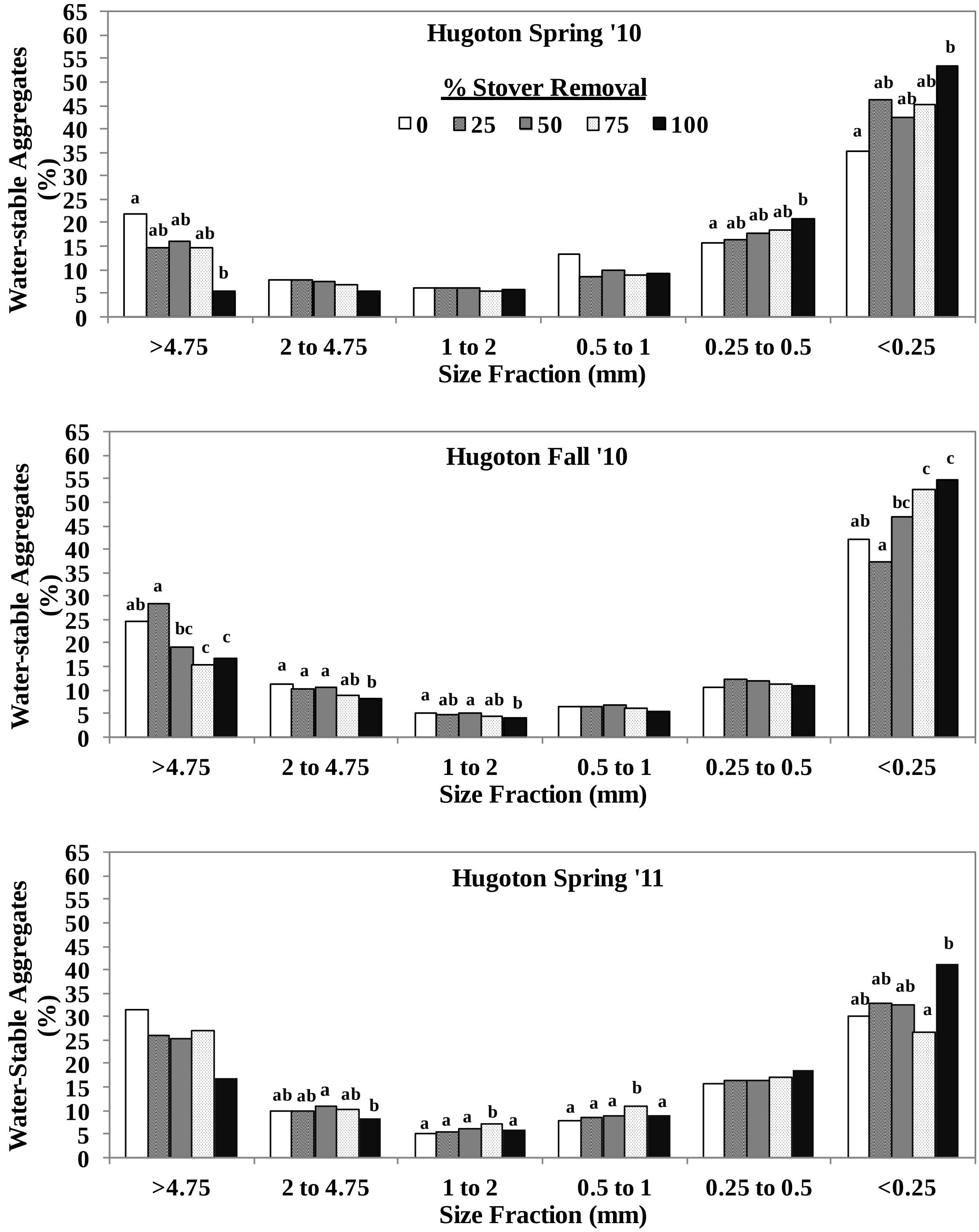


Figure 4.8 Distribution of water-stable aggregate fractions as impacted by stover removal at various sampling dates at Ottawa. Treatments within the same size fraction with different letters are significantly different.

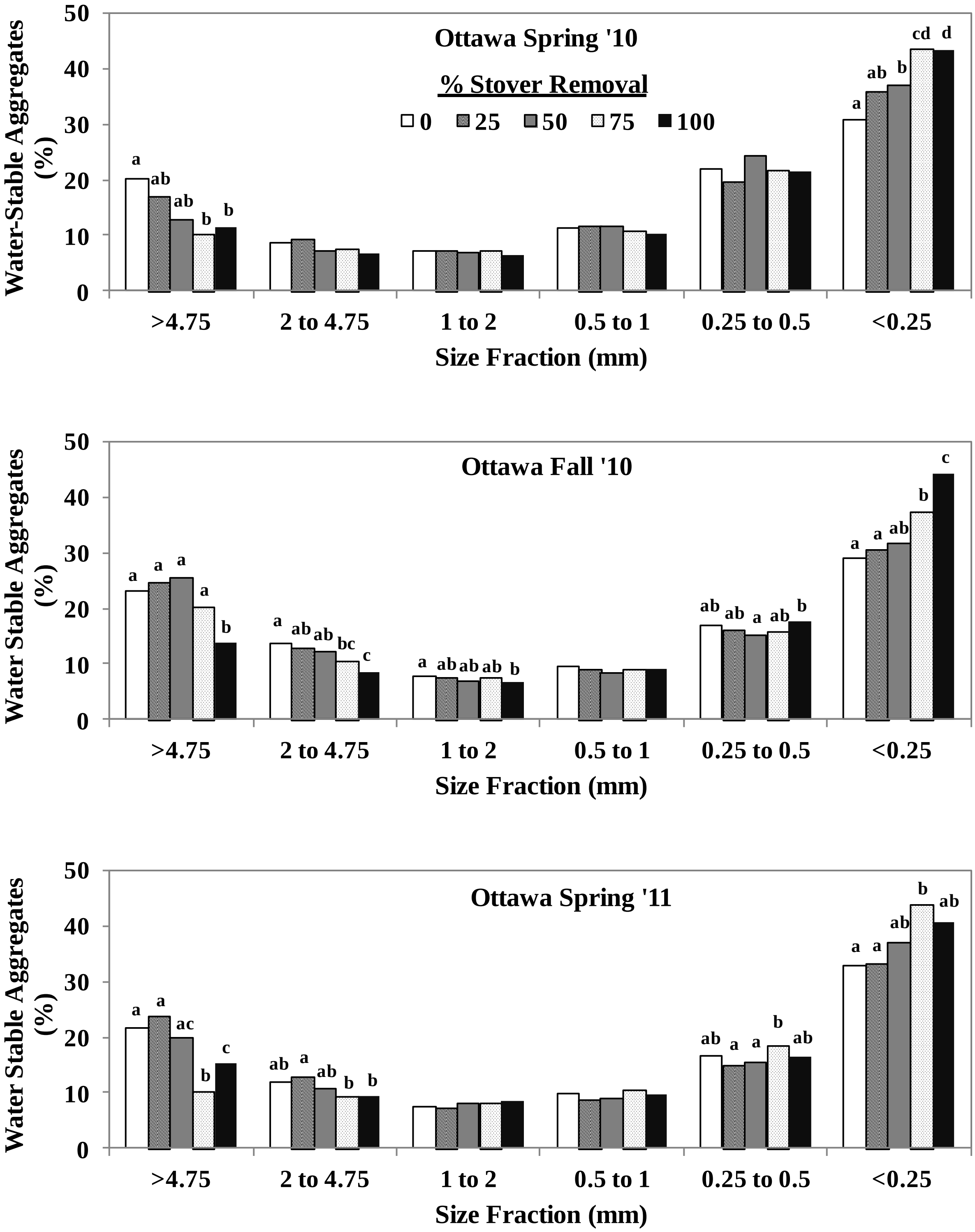


Figure 4.9 Water retention curves as impacted by stover removal at Colby.

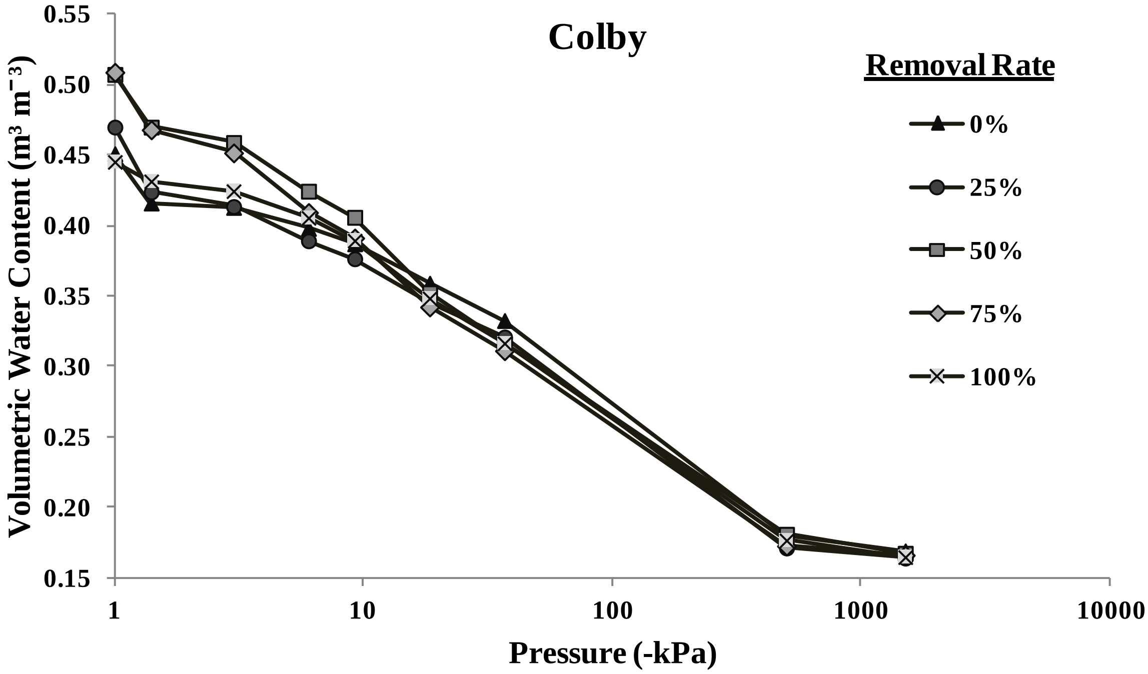


Figure 4.10 Water retention curves as impacted by stover removal at Hugoton.

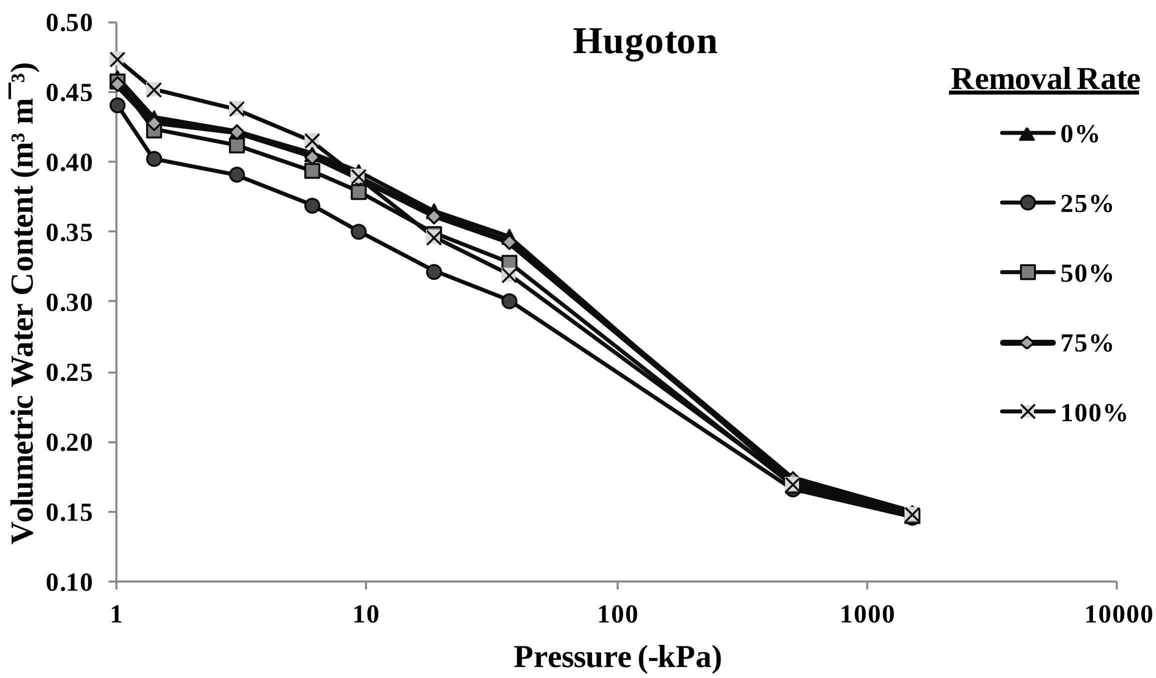


Figure 4.11 Water retention curves as impacted by stover removal at Ottawa.

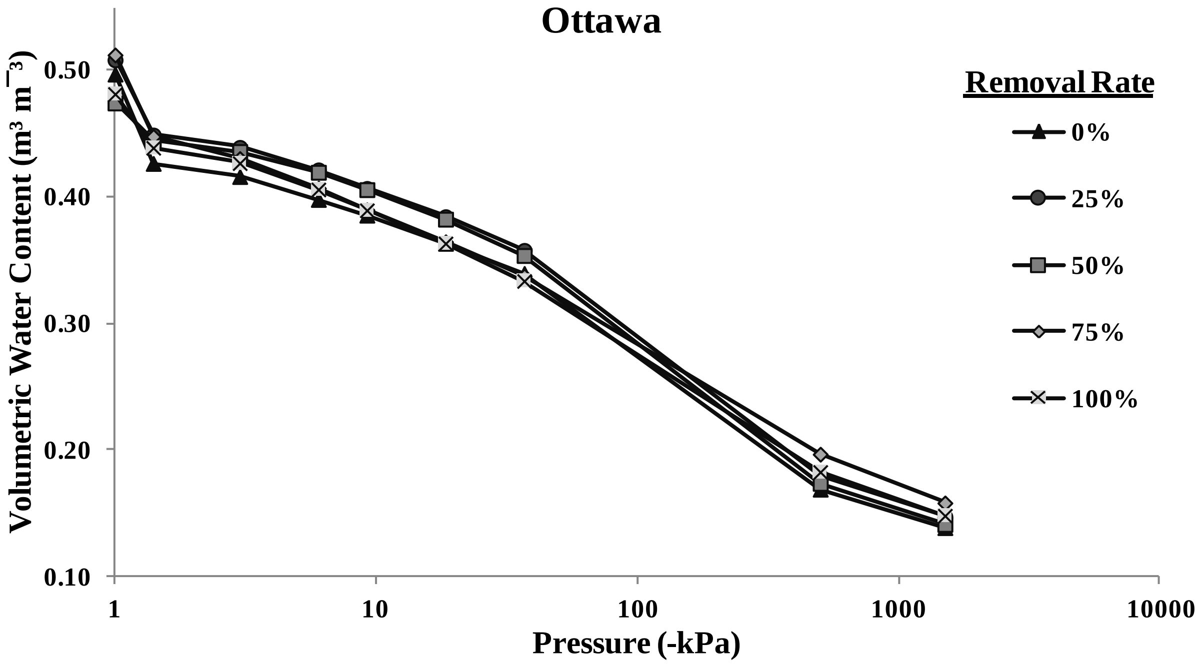


Figure 4.12 Impact of stover removal on total carbon of 0 to 5 cm soil depth. Treatments within the same sampling period with different letters are significantly different.

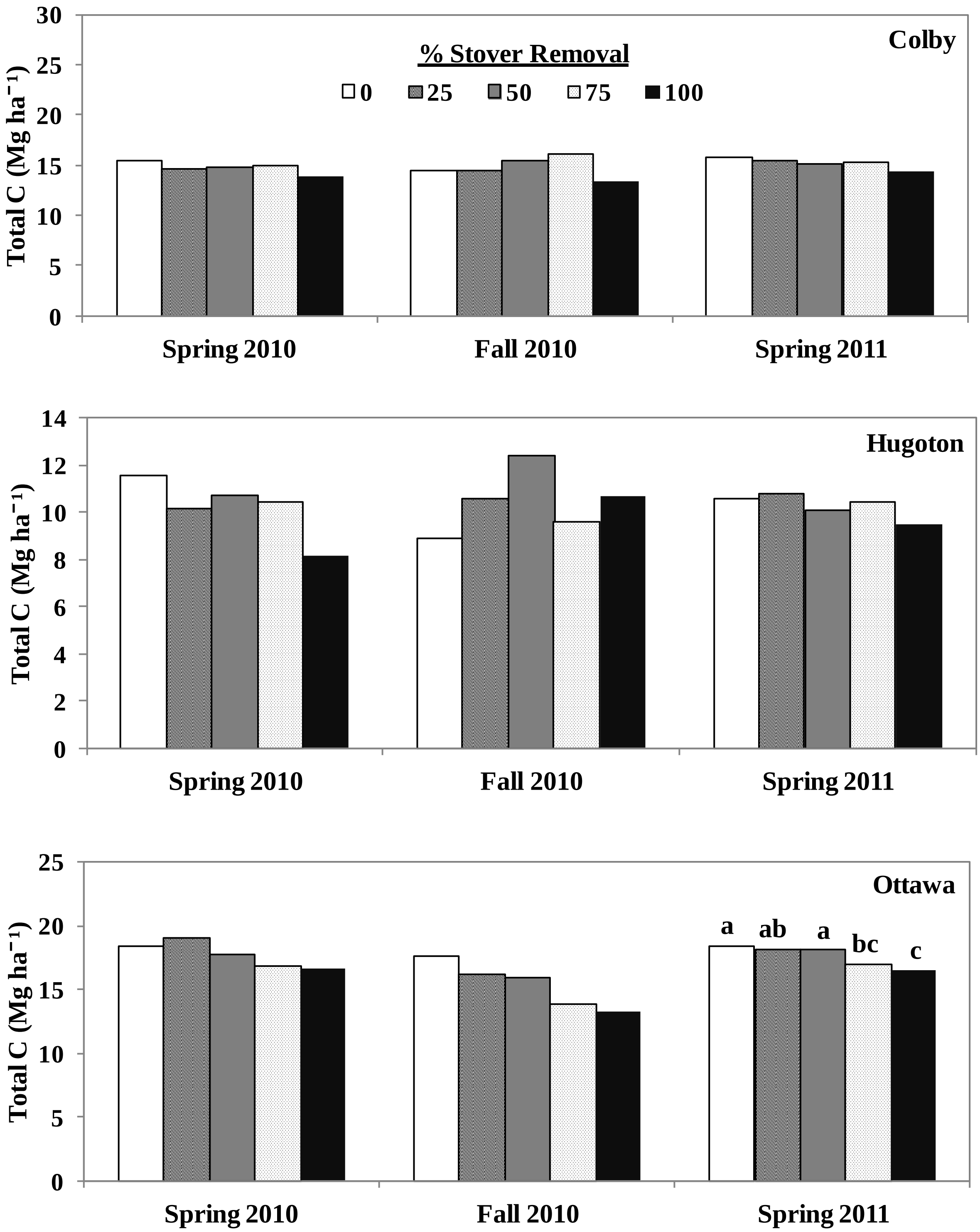


Figure 4.13 Impact of stover removal on total nitrogen of 0 to 5 cm soil depth. No differences in total N between treatments were observed.

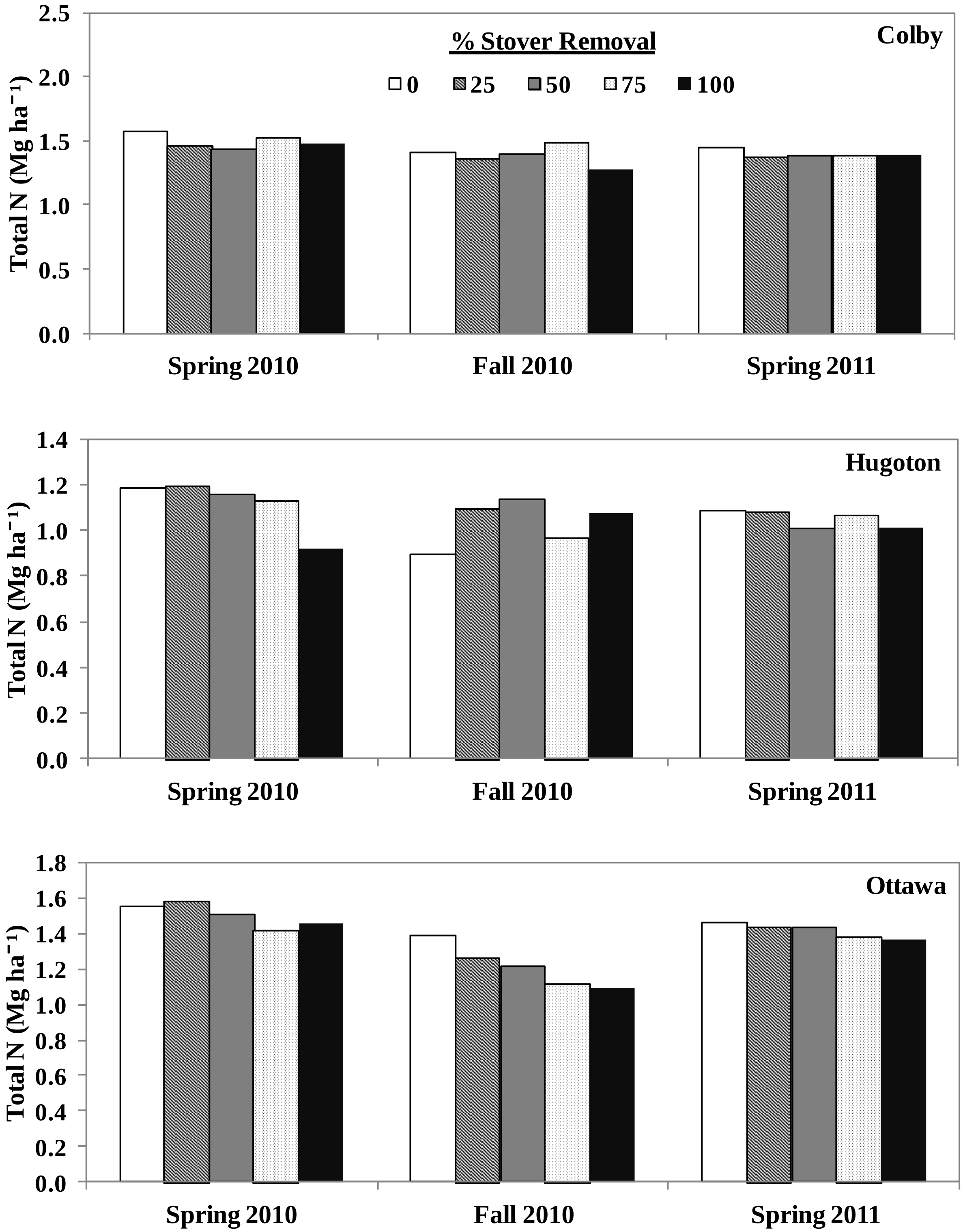


Figure 4.14 Impact of 0, 50, and 100% stover removal on mean noontime soil temperature at each site. Treatments within the same month with different letters are significantly different.

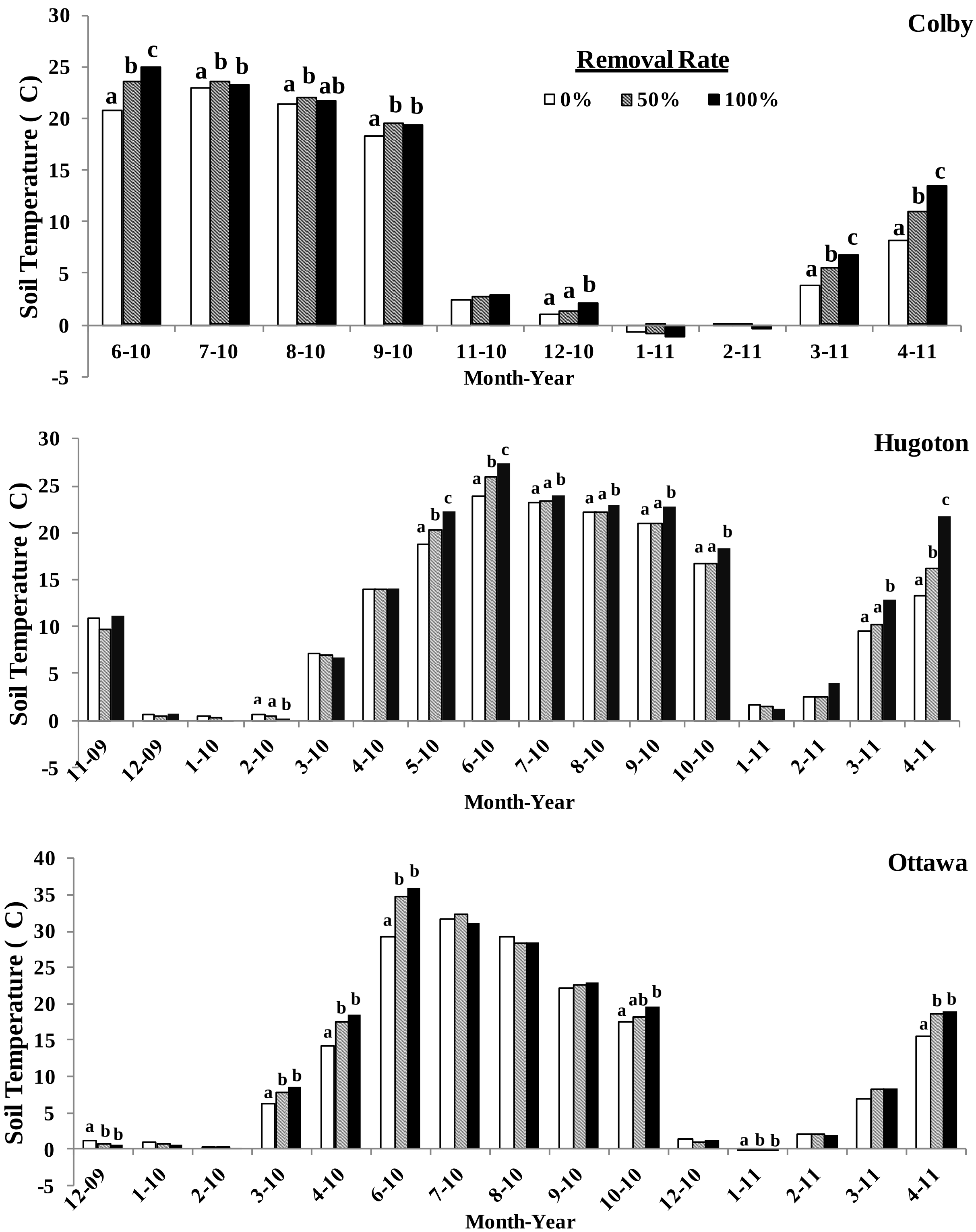


Figure 4.15 Impact of 0, 50, and 100% stover removal on soil freezing and thawing at Colby during the 2010/2011 winter season.

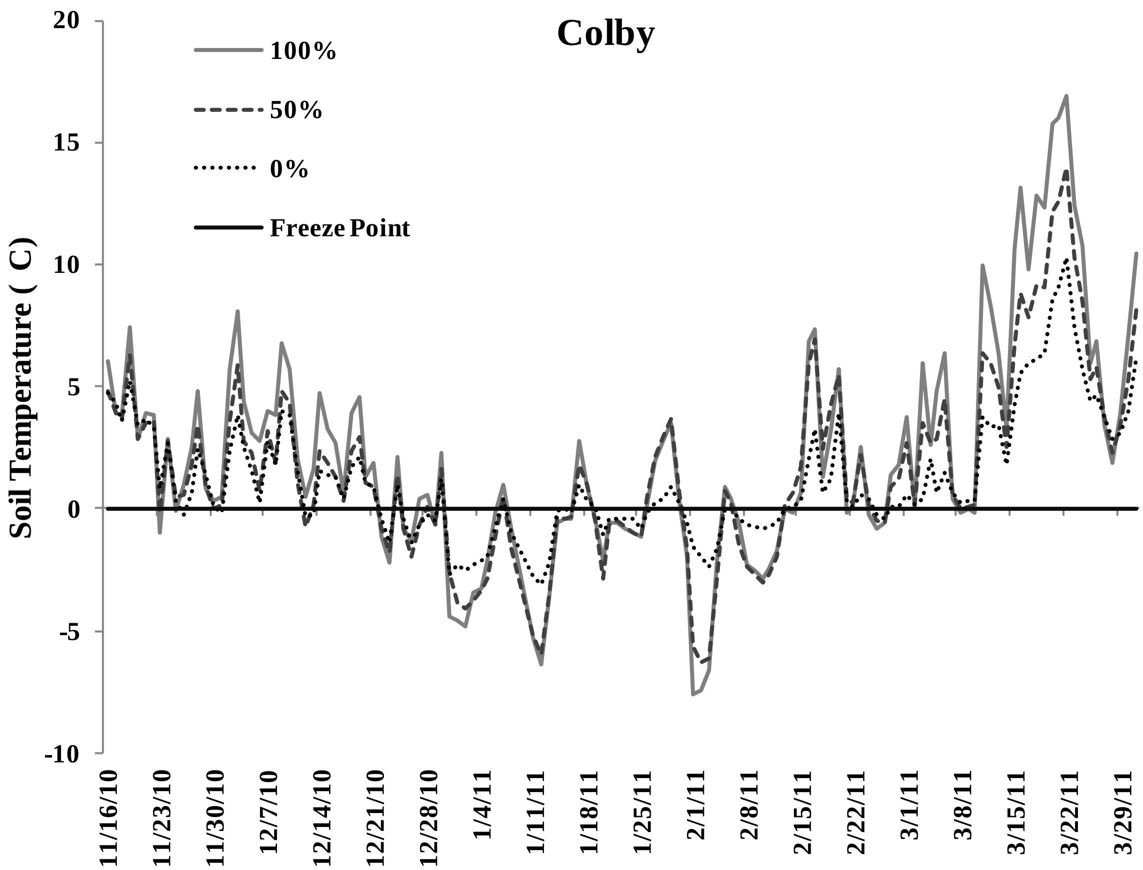
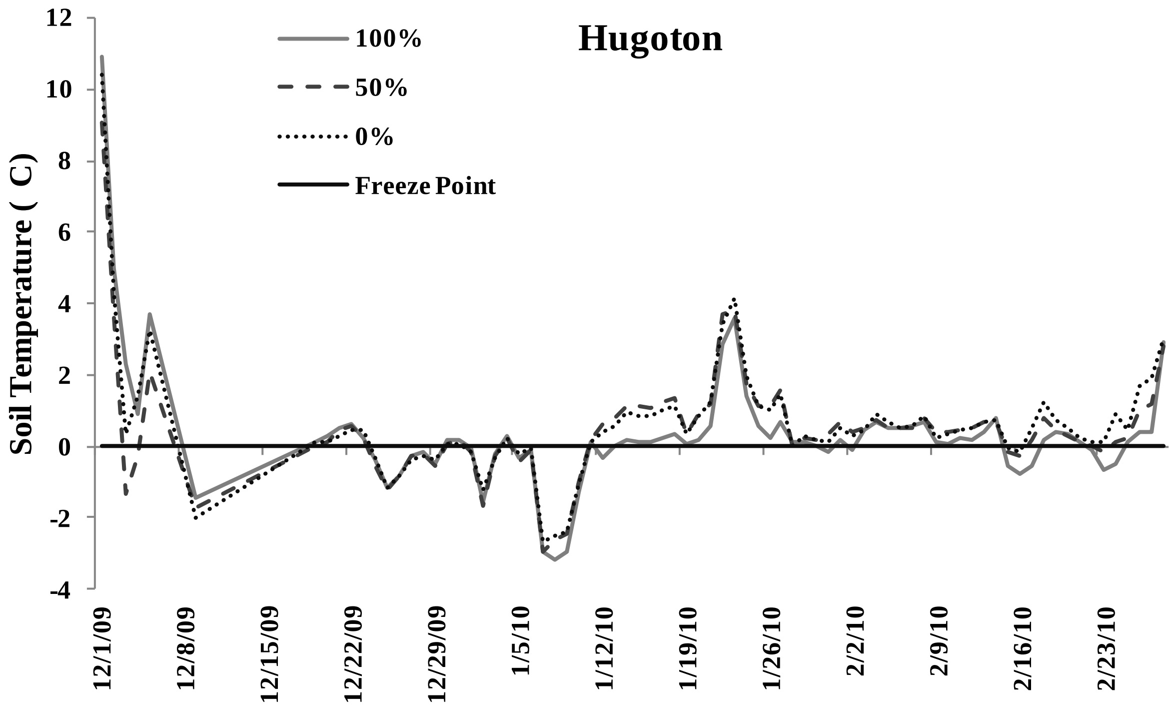


Figure 4.16 Impact of 0, 50, and 100% stover removal on soil freezing and thawing at Hugoton during the 2009/2010 and 2010/2011 winter seasons.



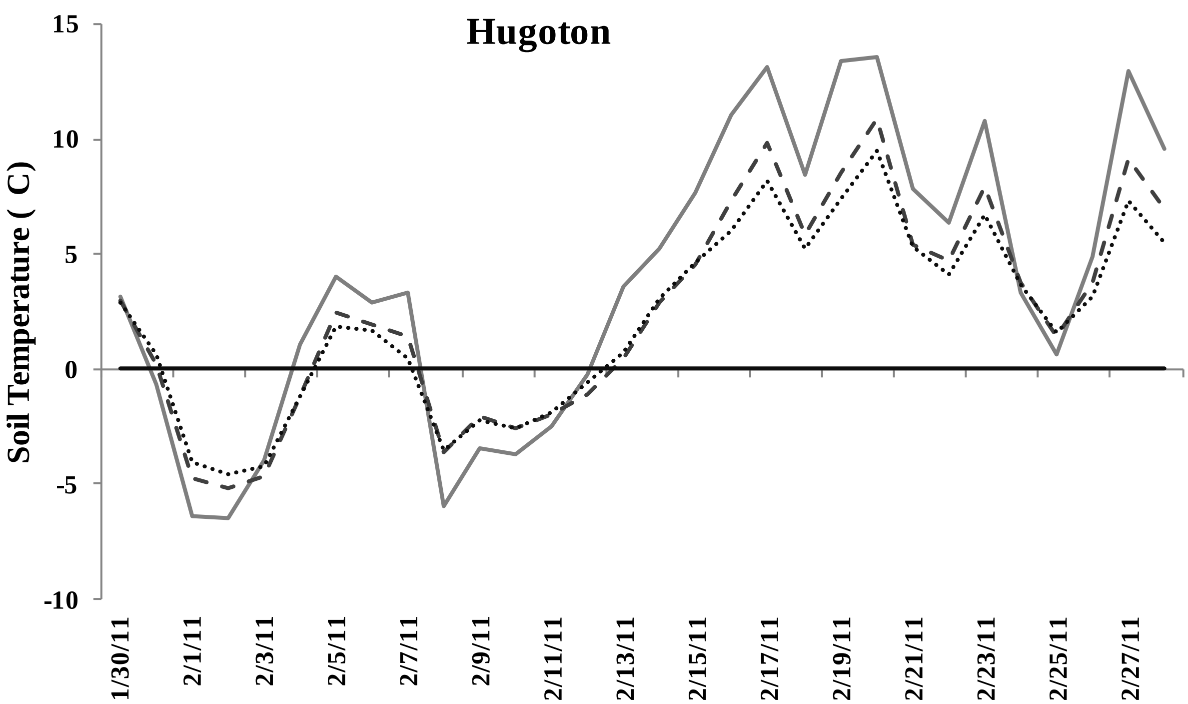


Figure 4.17 Impact of 0, 50, and 100% stover removal on soil freezing and thawing at Ottawa during the 2009/2010 and 2010/2011 winter seasons.

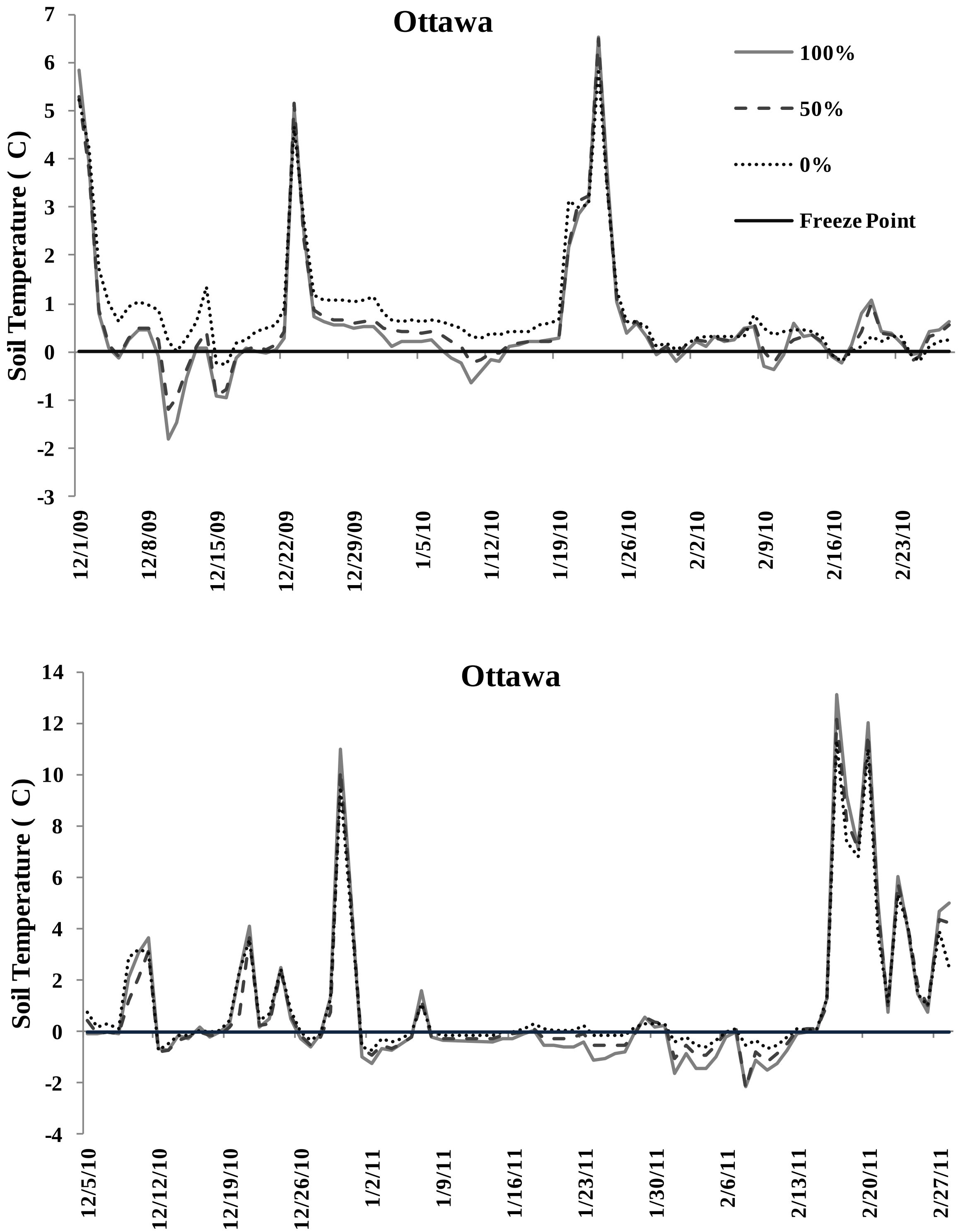


Figure 4.18 Impact of 0, 50, and 100% stover removal on mean noontime soil moisture at each site. Treatments within the same month with different letters are significantly different.

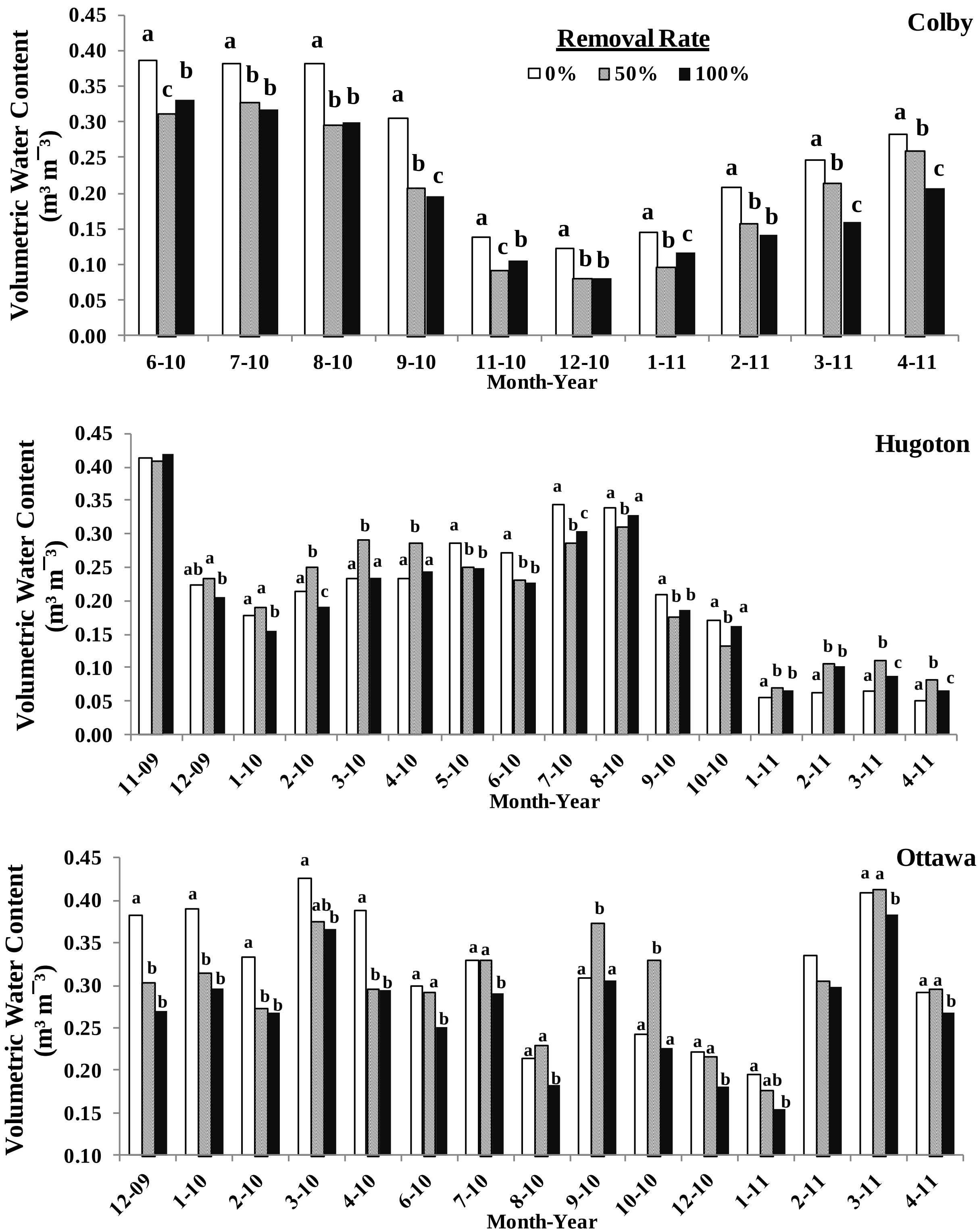


Figure 4.19 Impact of stover removal on early-season plant height. Treatments within the same year with different letters are significantly different.

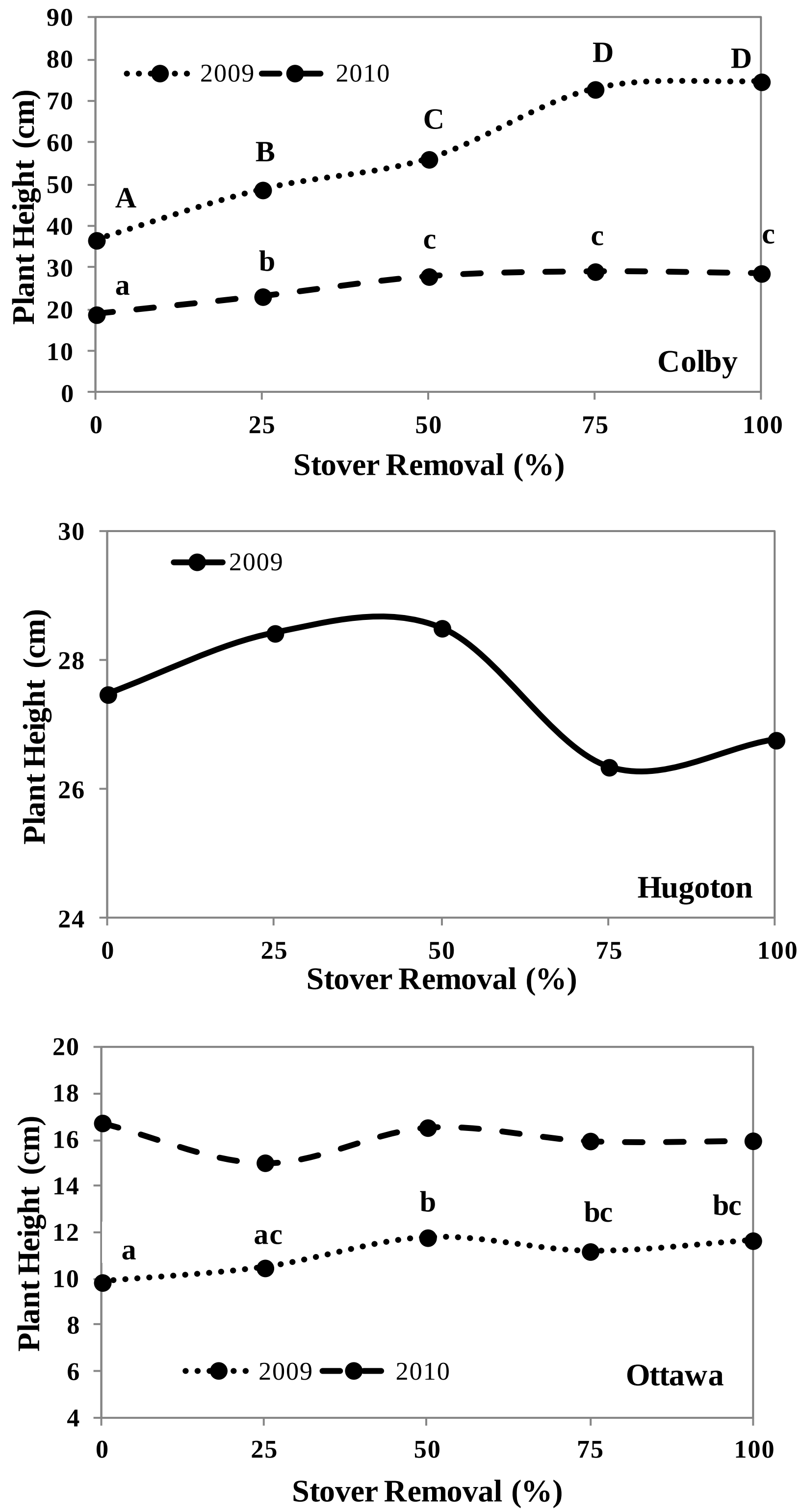


Table 4.1 Management, climate, and soil characteristics of the three study sites.

Study Site	Management	Avg. daily min. and max. temp. (°C)	Avg. annual precipitation (mm)	Soil series	Taxonomic classification
Colby	No-till continuous corn Irrigated	3.00 17.7	470	Ulysses silt loam	Fine-silty, mixed, superactive, mesic Aridic Haplustolls
Hugoton	Strip-till continuous corn Irrigated	5.94 19.8	457	Hugoton loam	Fine-silty, mixed, superactive, mesic Aridic Argiustolls
Ottawa	No-till continuous corn Rain-fed	6.28 18.4	953	Woodson silt loam	Fine, smectitic, thermic Abruptic Argiaquolls

† Soil slope was ≤ 1% at all sites.

Table 4.2 Soil particle size analysis of the three study sites to a depth of 20 cm.

Study Site	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture
Colby	0-5	24.2	59.6	16.2	Silt Loam
	5-10	24.8	56.5	18.7	Silt Loam
	10-20	20.0	59.6	20.4	Silt Loam
Hugoton	0-5	30.6	47.3	22.1	Loam
	5-10	25.9	50.2	23.9	Silt Loam
	10-20	32.4	40.3	27.3	Clay Loam
Ottawa	0-5	6.6	71.8	21.6	Silt Loam
	5-10	5.6	86.9	7.5	Silt
	10-20	4.1	72.7	23.2	Silt Loam

Table 4.3 Mass of stover removed after grain harvest in 2009 and 2010.

Study Site	Year	% Stover Removal 0	25	50	75	100
		--- Stover Dry Matter Removed (Mg ha^{-1})---				
Colby	2009	0.00	1.35	3.33	4.22	5.27
Hugoton		0.00	1.98	3.04	4.96	5.74
Ottawa		0.00	0.92	2.17	3.26	4.99
Colby	2010	0.00	1.88	3.15	4.71	5.86
Hugoton		0.00	1.08	2.81	4.85	4.87
Ottawa		0.00	1.02	1.50	2.24	6.10

Table 4.4 Mass of stover existing on-field in spring 2011.

Study Site	% Stover Removal 0	25	50	75	100
	---On-Field Stover Dry Matter (Mg ha^{-1})---				
Colby	20.7	8.10	6.70	3.40	0.00
Hugoton	15.3	8.60	5.00	2.80	0.00
Ottawa	5.86	3.90	3.35	1.96	0.00

Table 4.5 Soil bulk density values as impacted by stover removal at Colby, KS. Treatments with different letters within the same depth are significantly different.

			% Stover Removal				
Study Site	**Date**	**Depth (cm)**	**0**	**25**	**50**	**75**	**100**
Colby					---(Mg m⁻³)---		
	4-7-09	0-5	1.37	1.41	1.31	1.35	1.30
		5-10	1.42 a	1.60 b	1.46 ac	1.54 bc	1.57 b
	6-23-09	0-5	0.987	1.21	1.21	1.32	1.10
		5-10	1.37 a	1.31 ab	1.23 bc	1.25 ac	1.16 c
	7-15-09	0-5	1.33	1.36	1.31	1.28	1.33
		5-10	1.51	1.52	1.41	1.46	1.52
	8-21-09	0-5	1.27	1.33	1.00	1.20	1.21
		5-10	1.41	1.39	1.34	1.38	1.34
	6-9-10	0-5	1.31	1.26	1.27	1.25	1.30
		5-10	1.39	1.37	1.34	1.36	1.41
	11-15-10	0-5	1.23	1.19	1.32	1.29	1.27
		5-10	1.36	1.32	1.34	1.33	1.35
	6-3-11	0-5	1.36	1.39	1.26	1.31	1.38
		5-10	1.42	1.46	1.43	1.43	1.47

Table 4.6 Soil bulk density values as impacted by stover removal at Hugoton, KS. Treatments with different letters within the same depth are significantly different.

			% Stover Removal				
Study Site	**Date**	**Depth (cm)**	**0**	**25**	**50**	**75**	**100**
Hugoton					---(Mg m^{-3})---		
	6-16-09	0-5	1.18	0.97	1.16	1.04	1.17
		5-10	1.26	1.13	1.24	1.30	1.23
	8-10-09	0-5	1.09	1.05	1.08	1.07	1.15
		5-10	1.42	1.40	1.35	1.42	1.42
	11-18-09	0-5	0.96	1.00	0.99	1.01	0.99
		5-10	1.40	1.39	1.39	1.39	1.43
	5-12-10	0-5	1.22	1.31	1.23	1.34	1.25
		5-10	1.59 ac	1.49 bd	1.56 ab	1.65 c	1.55 ad
	11-22-10	0-5	1.16	1.28	1.25	1.18	1.36
		5-10	1.50 a	1.45 ab	1.47 a	1.29 b	1.47 a
	4-19-11	0-5	1.27	1.36	1.28	1.32	1.36
		5-10	1.35 a	1.50 ab	1.41 ab	1.42 ab	1.54 b

Table 4.7 Soil bulk density values as impacted by stover removal at Ottawa, KS. Treatments with different letters within the same depth are significantly different.

			% Stover Removal				
Study Site	**Date**	**Depth (cm)**	**0**	**25**	**50**	**75**	**100**
Ottawa					---(Mg m^{-3})---		
	7-31-09	0-5	1.19	1.15	1.18	1.27	1.17
		5-10	1.31	1.29	1.26	1.28	1.28
	11-30-09	0-5	1.20	1.16	1.23	1.26	1.18
		5-10	1.34	1.36	1.40	1.34	1.35
	6-24-10	0-5	1.17	1.23	1.20	1.16	1.24
		5-10	1.37	1.39	1.37	1.40	1.45
	11-28-10	0-5	1.20	1.05	1.04	0.96	0.99
		5-10	1.37	1.36	1.39	1.37	1.32
	6-7-11	0-5	1.32	1.31	1.29	1.32	1.31
		5-10	1.38	1.36	1.41	1.38	1.39

Table 4.8 Soil water retention as impacted by stover removal at Colby in spring of 2011. Treatments within the same pressure step with different letters are significantly different.

Removal Rate (%)	Pressure (-kPa)								
	0	**1.4**	**3.0**	**6.0**	**9.2**	**18.4**	**36.8**	**500**	**1500**
0	0.452 a	0.416 a	0.414 a	0.399 ab	0.388 ab	0.360	0.334	0.180	0.169
25	0.470 ab	0.424 a	0.414 a	0.389 a	0.376 a	0.346	0.321	0.171	0.164
50	0.508 b	0.470 b	0.459 b	0.425 b	0.406 b	0.352	0.316	0.181	0.167
75	0.509 b	0.468 b	0.452 bc	0.409 ab	0.392 ab	0.342	0.311	0.172	0.166
100	0.446 a	0.432 a	0.425 ac	0.406 ab	0.389 ab	0.349	0.317	0.177	0.165

Table 4.9 Soil water retention as impacted by stover removal at Hugoton in spring of 2011. Differences in water content within pressure steps were not observed.

Removal Rate (%)	Pressure (-kPa)								
	0	**1.4**	**3.0**	**6.0**	**9.2**	**18.4**	**36.8**	**500**	**1500**
0	0.461	0.432	0.422	0.406	0.394	0.366	0.347	0.170	0.147
25	0.442	0.404	0.392	0.370	0.350	0.316	0.295	0.160	0.141
50	0.459	0.424	0.413	0.395	0.379	0.349	0.329	0.169	0.148
75	0.457	0.429	0.423	0.404	0.389	0.362	0.343	0.174	0.149
100	0.474	0.453	0.439	0.416	0.391	0.347	0.320	0.170	0.148

Table 4.10 Soil water retention as impacted by stover removal at Ottawa in spring of 2011. Treatments within the same pressure step with different letters are significantly different.

Removal Rate (%)	Pressure (-kPa)								
	0	**1.4**	**3.0**	**6.0**	**9.2**	**18.4**	**36.8**	**500**	**1500**
0	0.497	0.427 a	0.416 a	0.398 a	0.386	0.363	0.340	0.169 a	0.139 a
25	0.509	0.449 b	0.440 b	0.421 b	0.407	0.385	0.358	0.179 a	0.148 ab
50	0.475	0.444 b	0.436 b	0.420 ab	0.406	0.382	0.354	0.174 a	0.141 a
75	0.512	0.448 b	0.430 ab	0.407 ab	0.390	0.365	0.337	0.197 b	0.158 b
100	0.482	0.439 ab	0.427 ab	0.406 ab	0.389	0.364	0.334	0.182 a	0.148 ab

Table 4.11 Impact of stover removal on available water content. Treatments within the same site with different letters are significantly different.

Study Site	% Stover Removal 0	25	50	75	100
	---Available Water Content ($m^3\ m^{-3}$)---				
Colby	0.167	0.157	0.149	0.145	0.152
Hugoton	0.200	0.155	0.181	0.194	0.171
Ottawa	0.201 ab	0.210 ac	0.213 a	0.180 b	0.186 bc

Table 4.12 Fitted parameters of van Genuchten's model for water retention at Colby. Treatments with different letters for the same parameter are significantly different.

% Removal	θ_R	θ_S	α	N
0	0.038	0.420 a	0.0061	1.271
25	0.074	0.425 a	0.0095	1.391
50	0.111	0.481 b	0.0136	1.378
75	0.097	0.481 b	0.0167	1.339
100	0.109	0.436 a	0.0090	1.435

Table 4.13 Fitted parameters of van Genuchten's model for water retention at Hugoton. No differences in parameters between treatments were observed.

% Removal	θ_R	θ_S	α	N
0	0.045	0.433	0.0078	1.374
25	0.011	0.411	0.0167	1.195
50	0.036	0.425	0.0089	1.319
75	0.000	0.434	0.0091	1.250
100	0.050	0.466	0.0150	1.316

Table 4.14 Fitted parameters of van Genuchten's model for water retention at Ottawa. Treatments with different letters for the same parameter are significantly different.

% Removal	θ_R	θ_S	α	N
0	0.025	0.422 a	0.0050 a	1.305 a
25	0.000	0.447 b	0.0056 ab	1.263 ab
50	0.000	0.443 b	0.0053 ab	1.274 ab
75	0.000	0.450 b	0.0133 b	1.204 b
100	0.012	0.440 b	0.0087 ab	1.242 ab

Table 4.15 Impact of stover removal on grain yield for 2009 and 2010 growing seasons. Treatments within the same site and year with different letters are significantly different.

		% Stover Removal				
Study Site	**Year**	**0**	**25**	**50**	**75**	**100**
		---Grain Yield (Mg ha^{-1}) at 15.5% Moisture---				
Colby	2009	13.11 a	16.48 ab	17.86 b	18.14 b	17.32 b
Hugoton		11.10	11.94	11.87	12.54	10.50
Ottawa		7.49 ab	6.32 a	7.96 bc	8.08 bc	9.43 c
Colby	2010	14.07 ab	14.72 ab	16.42 a	14.36 ab	12.42 b
Hugoton		15.78	15.14	16.79	16.07	15.51
Ottawa		4.40 a	4.40 a	4.58 ac	5.55 b	5.33 bc

Table 4.16 Impact of stover removal on stover yield in 2009 and 2010. Treatments within the same site and year with different letters are significantly different.

		% Stover Removal				
Study Site	**Year**	**0**	**25**	**50**	**75**	**100**
		---Stover Dry Matter Yield (Mg ha^{-1})---				
Colby	2009	5.68	5.40	6.65	5.63	5.27
Hugoton		7.05	7.90	6.08	6.61	5.74
Ottawa		3.87 a	3.66 a	4.34 ab	4.35 ab	4.99 b
Colby	2010	6.24	7.53	6.30	6.28	5.86
Hugoton		6.58	4.33	5.61	6.47	4.87
Ottawa		2.68 a	4.07 ab	3.00 a	2.98 a	6.10 b

Table 4.17 Impact of stover removal on early-season plant populations.

		% Stover Removal				
Study Site	**Year**	**0**	**25**	**50**	**75**	**100**
		---Mean Stand Count (Plants ha^{-1})---				
Colby	2009	57,370	75,346	75,346	89,661	71,794
Hugoton		78,898	78,898	71,794	71,794	71,794
Ottawa		61,030	64,582	68,134	61,030	57,370
Colby	2010	82,557	93,321	89,661	89,661	86,109
Hugoton		68,134	82,557	68,134	82,557	78,898
Ottawa		61,030	53,818	57,370	64,582	61,030

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Chapter 5 - Synthesis

Large-scale harvesting of corn stover as feedstock for bioenergy production may soon occur in the United States. The abundance and perceived availability of corn stover has caused its consideration as a prime feedstock for cellulosic ethanol production in the Corn Belt region of the U.S. Furthermore, corn stover is produced domestically and, unlike grain-based bioenergy feedstock, does not compete with food production. However, the indiscriminate harvesting of corn stover for bioenergy production may come at the expense of agricultural sustainability and environmental quality in some regions.

The data obtained from this study show that high rates of corn stover removal from no-till and strip-till soils in Kansas can have significant effects on runoff and soil erosion, soil physical properties, and crop production in the short-term. Moreover, the effects of stover removal depended upon site and soil. At Colby, stover removal rates as low as 25% significantly reduced time to runoff initiation and increased sediment loss, while rates of 50% increased losses of runoff, sediment-C, and NH_4-N, and decreased mean-weight diameter, reduced the amount of large water stable aggregates, increased soil temperature fluctuation, reduced soil moisture, and increased early season plant height and grain yield. At Hugoton, significant increases in losses of runoff, sediment, sediment-C, total N and P, and soluble nutrients, increases in soil temperature fluctuation and reductions in MWD and percent water stable macroaggregates only occurred with stover removal rates ≥75%. At Ottawa, removal rates of 50% significantly increased losses of sediment and sediment-C, decreased losses of PO_4-P, and reduced soil water content, while rates ≥75% resulted in significant decreases in MWD, percent water stable macroaggregates, soil C, and increased soil temperature fluctuation, early season plant height and grain yield.

Data from the first 2 yr of this study show that stover removal in Kansas can have negative effects in terms of soil and water conservation, and positive effects in terms of crop production. While corn stover has clear benefits for reducing erosion and maintaining soil quality, it may also result in decreased seed germination and plant growth in some years. It is difficult, therefore, to determine acceptable levels of stover removal because it depends upon whether the goal is to conserve soil and water resources, or to avoid decreases in crop production. From the conservation standpoint, it appears that no stover is available for harvest at

Colby, 50% may be available at Hugoton, and 25% may be available at Ottawa. If the goal is to avoid decreased yield while keeping as much stover as possible, then 50% may be available at Colby, 50% may still be available at Hugoton because stover removal did not affect crop yield, and 75% may be available for harvest at Ottawa.

The impact of stover removal on soil moisture is particularly important in regions that depend upon irrigation for crop production. Much of the irrigation water used in the western region of the Corn Belt comes from the Ogallala Aquifer, which is quickly diminishing in volume because pumping rates are greater than natural recharge rates. Therefore, management practices that conserve soil moisture and reduce irrigation rates are tremendously beneficial in terms of agricultural sustainability. Crop producers in arid and semiarid regions will need to decide if short-term decreases in productivity outweigh the long-term viability of aquifers used for irrigation. In addition, long-term agricultural productivity may be jeopardized due to soil degradation for short-term gains. Although crop yields may be impacted in the short-term, long-term studies are needed in order to ascertain the impacts of a changing global climate on crop yields in the future.

Appendix A - Effects of Corn Stover Removal on Soil Erosion by Water

Raw Data

Table A.1 Time to runoff initiation at Colby

% Stover Removal	Rep	Colby Dry	Colby Wet
		---Time to Runoff Initiation (min)---	
0	1	>30	17.5
0	2	>30	>30
0	3	>30	15.25
25	1	6.75	3.75
25	2	26.17	10
25	3	14.13	20
50	1	12.43	8.55
50	2	5.82	6.83
50	3	13.57	9.1
75	1	14.5	9.55
75	2	8.18	8.87
75	3	16.92	3.88
100	1	8.83	5.12
100	2	6.83	3.47
100	3	12.57	4.7

Table A.2 Time to runoff initiation at Hugoton

% Stover Removal	Rep	Hugoton Dry	Hugoton Wet
		Time to Runoff Initiation (min)	
0	1	>30	14.45
0	2	26.67	9.67
0	3	>30	16
25	1	21.5	11.5
25	2	>30	21.67
25	3	>30	>30
50	1	27	13.17
50	2	25.33	14.35
50	3	24.65	7
75	1	17.83	4.17
75	2	26.72	7.75
75	3	>30	20
100	1	14.05	7.5
100	2	18.33	6
100	3	13	6

Table A.3 Time to runoff initiation at Ottawa

% Stover Removal	Rep	Ottawa Dry	Ottawa Wet
		---Time to Runoff Initiation (min)---	
0	1	13.75	5.17
0	2	16.5	7.5
0	3	16.67	7.25
25	1	16.33	5.5
25	2	13	3.5
25	3	20	7.83
50	1	15	5.75
50	2	17.25	4.5
50	3	17	5.05
75	1	18.25	3.33
75	2	15	3.67
75	3	13	4.5
100	1	16	3.83
100	2	13.75	3.33
100	3	11.5	4.07

Table A.4 Runoff depth at Colby

% Stover Removal	Rep	Sampling Period	Colby Dry	Colby Wet
			--Runoff Depth (cm)---	
0	1	1	0	0
0	1	2	0	0.032
0	1	3	0	0.184
0	2	1	0	0
0	2	2	0	0
0	2	3	0	0
0	3	1	0	0
0	3	2	0	0.056
0	3	3	0	0.150
25	1	1	0.022	0.072
25	1	2	0.268	0.404
25	1	3	0.416	0.572
25	2	1	0	0
25	2	2	0	0.282
25	2	3	0.090	0.382
25	3	1	0	0
25	3	2	0.030	0
25	3	3	0.080	0.112
50	1	1	0	0.022
50	1	2	0.060	0.370
50	1	3	0.430	0.744
50	2	1	0.036	0.064
50	2	2	0.290	0.486
50	2	3	0.330	0.510
50	3	1	0	0.068
50	3	2	0.040	0.640
50	3	3	0.260	0.805
75	1	1	0	0.030
75	1	2	0.090	0.308
75	1	3	0.320	0.592
75	2	1	0.007	0.005
75	2	2	0.160	0.150
75	2	3	0.176	0.430
75	3	1	0	0.202
75	3	2	0.070	0.726
75	3	3	0.300	0.802
100	1	1	0.002	0.224
100	1	2	0.146	0.852
100	1	3	0.688	0.740
100	2	1	0.130	0.456
100	2	2	0.794	0.784
100	2	3	0.804	0.896

100	3	1	0	0.190
100	3	2	0.144	0.696
100	3	3	0.380	0.804

Table A.5 Runoff depth at Hugoton

% Stover Removal	Rep	Sampling Period	Hugoton Dry	Hugoton Wet
			--Runoff Depth (cm)---	
0	1	1	0	0.000
0	1	2	0	0.150
0	1	3	0	0.700
0	2	1	0	0.006
0	2	2	0	0.306
0	2	3	0.020	0.390
0	3	1	0	0.000
0	3	2	0	0.190
0	3	3	0	0.646
25	1	1	0	0.000
25	1	2	0	0.290
25	1	3	0.066	0.766
25	2	1	0	0.000
25	2	2	0	0.000
25	2	3	0	0.152
25	3	1	0	0.000
25	3	2	0	0.000
25	3	3	0	0.000
50	1	1	0	0.000
50	1	2	0	0.080
50	1	3	0.040	0.250
50	2	1	0	0.000
50	2	2	0	0.128
50	2	3	0.064	0.270
50	3	1	0	0.120
50	3	2	0	0.930
50	3	3	0.208	1.056
75	1	1	0	0.142
75	1	2	0.038	0.622
75	1	3	0.436	1.1
75	2	1	0	0.144
75	2	2	0	0.664
75	2	3	0.023	0.92
75	3	1	0	0.000
75	3	2	0	0.000
75	3	3	0	0.034
100	1	1	0	0.054
100	1	2	0.076	0.226
100	1	3	0.288	0.524
100	2	1	0	0.166
100	2	2	0.040	0.65
100	2	3	0.162	0.746

100	3	1	0	0.25
100	3	2	0.060	0.896
100	3	3	0.418	1.026

Table A.6 Runoff depth at Ottawa

% Stover Removal	Rep	Sampling Period	Ottawa Dry	Ottawa Wet
			--Runoff Depth (cm)---	
0	1	1	0	0.576
0	1	2	0.416	1.596
0	1	3	0.980	1.568
0	2	1	0	0.110
0	2	2	0.070	0.646
0	2	3	0.522	0.856
0	3	1	0	0.088
0	3	2	0.168	0.834
0	3	3	0.748	1.094
25	1	1	0	0.340
25	1	2	0.270	1.760
25	1	3	1.166	1.646
25	2	1	0	0.478
25	2	2	0.168	1.216
25	2	3	0.632	1.240
25	3	1	0	0.090
25	3	2	0	0.628
25	3	3	0.314	0.640
50	1	1	0	0.340
50	1	2	0.034	1.172
50	1	3	0.500	1.376
50	2	1	0	0.508
50	2	2	0.128	1.478
50	2	3	0.772	1.524
50	3	1	0	0.120
50	3	2	0.072	1.240
50	3	3	0.672	1.064
75	1	1	0	0.706
75	1	2	0.042	1.652
75	1	3	1.048	1.736
75	2	1	0	0.286
75	2	2	0.128	0.934
75	2	3	0.528	1.058
75	3	1	0	0.262
75	3	2	0.100	1.058
75	3	3	0.460	1.286
100	1	1	0	0.658
100	1	2	0.066	1.346
100	1	3	0.768	1.364
100	2	1	0	0.536
100	2	2	0.320	0.904
100	2	3	1.036	0.884

100	3	1	0	0.326
100	3	2	0.236	0.918
100	3	3	0.680	0.972

Table A.7 Sediment loss at Colby

% Stover Removal	Rep	Sampling Period	Colby Dry	Colby Wet
			---Sediment Loss (kg ha^{-1})---	
0	1	1	0	0
0	1	2	0	3.40
0	1	3	0	15.87
0	2	1	0	0
0	2	2	0	0
0	2	3	0	0
0	3	1	0	0
0	3	2	0	3.51
0	3	3	0	8.51
25	1	1	9.82	47.56
25	1	2	217.00	269.57
25	1	3	339.99	346.32
25	2	1	0	0
25	2	2	0	26.41
25	2	3	5.91	25.23
25	3	1	0	0
25	3	2	3.60	0
25	3	3	11.18	8.60
50	1	1	0	4.57
50	1	2	16.74	73.26
50	1	3	226.51	213.99
50	2	1	12.31	14.76
50	2	2	100.93	86.94
50	2	3	83.56	70.18
50	3	1	0	9.28
50	3	2	4.71	48.87
50	3	3	25.88	49.90
75	1	1	0	9.79
75	1	2	16.53	47.18
75	1	3	53.83	73.79
75	2	1	1.02	0.80
75	2	2	17.01	16.81
75	2	3	14.35	32.01
75	3	1	0	77.45
75	3	2	30.23	183.18
75	3	3	289.33	87.49
100	1	1	0.76	73.95
100	1	2	69.13	226.17
100	1	3	214.73	243.38
100	2	1	43.06	187.37
100	2	2	229.64	199.31
100	2	3	140.61	254.86

100	3	1	0	36.88
100	3	2	15.66	71.52
100	3	3	30.57	67.55

Table A.8 Sediment loss at Hugoton

% Stover Removal	Rep	Sampling Period	Hugoton Dry	Hugoton Wet
			---Sediment Loss (kg ha^{-1})---	
0	1	1	0.000	0.000
0	1	2	0.000	14.927
0	1	3	0.000	73.073
0	2	1	0.000	0.000
0	2	2	0.000	35.145
0	2	3	1.371	34.456
0	3	1	0.000	0.000
0	3	2	0.000	17.465
0	3	3	0.000	54.964
25	1	1	0.000	0.000
25	1	2	0.000	43.572
25	1	3	9.867	107.779
25	2	1	0.000	0.000
25	2	2	0.000	0.000
25	2	3	0.000	20.267
25	3	1	0.000	0.000
25	3	2	0.000	0.000
25	3	3	0.000	0.000
50	1	1	0.000	0.000
50	1	2	0.000	10.376
50	1	3	7.404	129.639
50	2	1	0.000	0.000
50	2	2	0.000	15.764
50	2	3	9.179	34.875
50	3	1	0.000	24.995
50	3	2	0.000	104.747
50	3	3	33.280	111.266
75	1	1	0.000	21.846
75	1	2	3.909	91.973
75	1	3	121.655	159.238
75	2	1	0.000	19.092
75	2	2	0.000	76.344
75	2	3	6.840	103.443
75	3	1	0.000	0.000
75	3	2	0.000	0.000
75	3	3	0.000	12.643
100	1	1	0.000	15.369
100	1	2	21.971	31.960
100	1	3	127.844	148.716
100	2	1	0.000	26.876
100	2	2	10.378	93.476
100	2	3	30.404	145.648

100	3	1	0.000	60.591
100	3	2	34.860	590.154
100	3	3	213.644	255.621

Table A.9 Sediment loss at Ottawa

% Stover Removal	Rep	Sampling Period	Ottawa Dry	Ottawa Wet
			---Sediment Loss (kg ha^{-1})---	
0	1	1	0.00	37.66
0	1	2	26.53	88.51
0	1	3	55.07	63.61
0	2	1	0.00	10.44
0	2	2	3.65	45.46
0	2	3	33.13	55.95
0	3	1	0.00	19.51
0	3	2	12.89	121.23
0	3	3	49.87	133.77
25	1	1	0.00	23.11
25	1	2	26.23	86.75
25	1	3	139.69	118.02
25	2	1	0.00	51.86
25	2	2	61.39	106.36
25	2	3	82.88	111.89
25	3	1	0.00	25.91
25	3	2	0.00	110.14
25	3	3	126.22	80.78
50	1	1	0.00	24.63
50	1	2	28.07	59.16
50	1	3	78.70	81.25
50	2	1	0.00	125.70
50	2	2	37.17	228.08
50	2	3	115.98	230.74
50	3	1	0.00	62.26
50	3	2	16.40	497.15
50	3	3	162.83	176.19
75	1	1	0.00	129.93
75	1	2	21.81	148.76
75	1	3	300.43	175.22
75	2	1	0.00	90.50
75	2	2	104.06	186.80
75	2	3	176.88	187.53
75	3	1	0.00	163.69
75	3	2	109.55	349.95
75	3	3	345.21	360.08
100	1	1	0.00	106.29
100	1	2	41.20	166.65
100	1	3	235.52	207.17
100	2	1	0.00	165.95
100	2	2	132.83	208.89
100	2	3	238.33	258.21

100	3	1	0.00	132.86
100	3	2	243.72	468.62
100	3	3	363.72	300.52

Table A.10 Sediment-C loss at Colby

% Stover Removal	Rep	Colby Dry	Colby Wet
		---Sediment-C Loss (kg ha^{-1})---	
0	1	0	0.364
0	2	0	0.000
0	3	0	0.288
25	1	2.467	3.554
25	2	0.132	0.346
25	3	0.394	0.139
50	1	1.251	0.958
50	2	1.401	1.131
50	3	0.391	0.586
75	1	0.680	0.923
75	2	0.422	0.370
75	3	1.973	1.198
100	1	1.121	1.351
100	2	1.071	1.719
100	3	0.358	0.669

Table A.11 Sediment-C loss at Hugoton

% Stover Removal	Rep	Hugoton Dry	Hugoton Wet
		---Sediment-C Loss (kg ha^{-1})---	
0	1	0.0000	0.3463
0	2	0.0289	0.3227
0	3	0.0000	0.2828
25	1	0.1521	0.3255
25	2	0.0000	0.1765
25	3	0.0000	0.0000
50	1	0.2370	0.6206
50	2	0.1819	0.3451
50	3	0.1842	0.4283
75	1	0.4368	0.5927
75	2	0.1701	0.4911
75	3	0.0000	0.5978
100	1	0.8661	0.8039
100	2	0.5089	0.7579
100	3	1.4430	1.1541

Table A.12 Sediment-C loss at Ottawa

% Stover Removal	Rep	Ottawa Dry	Ottawa Wet
		---Sediment-C Loss (kg ha^{-1})---	
0	1	0.2605	0.3728
0	2	0.2434	0.3276
0	3	0.2743	0.8250
25	1	0.3680	0.3678
25	2	0.7312	0.5399
25	3	0.4351	0.7469
50	1	1.2332	0.3716
50	2	0.6422	0.6438
50	3	0.6096	1.4973
75	1	1.2121	0.6095
75	2	1.2239	0.9647
75	3	2.1470	1.5324
100	1	1.3346	0.6889
100	2	0.9121	0.9670
100	3	2.2037	1.7867

Table A.13 Total N and P loss at Colby during dry runs

Colby Dry % Stover Removal	Rep	Total N Loss	Total P Loss
		---kg ha^{-1}---	
0	1	0.000	0.000
0	2	0.000	0.000
0	3	0.000	0.000
25	1	0.507	0.461
25	2	0.000	0.003
25	3	0.015	0.011
50	1	0.197	0.250
50	2	0.239	0.222
50	3	0.075	0.022
75	1	0.113	0.099
75	2	0.027	0.024
75	3	0.521	0.363
100	1	0.141	0.286
100	2	0.850	0.624
100	3	0.000	0.028

Table A.14 Total N and P loss at Hugoton during dry runs

Hugoton Dry % Stover Removal	Rep	Total N Loss	Total P Loss
		---kg ha^{-1}---	
0	1	0	0
0	2	0.008	0.001
0	3	0.000	0.000
25	1	0.072	0.008
25	2	0.000	0.000
25	3	0.00	0.000
50	1	0.044	0.007
50	2	0.034	0.008
50	3	0.079	0.017
75	1	0.450	0.040
75	2	0.031	0.003
75	3	0.000	0.000
100	1	0.455	0.052
100	2	0.150	0.042
100	3	0.463	0.105

Table A.15 Total N and P loss at Ottawa during dry runs

Ottawa Dry % Stover Removal	Rep	Total N Loss	Total P Loss
		---kg ha^{-1}---	
0	1	0.544	0.043
0	2	0.209	0.020
0	3	0.369	0.026
25	1	0.711	0.043
25	2	0.356	0.027
25	3	0.251	0.021
50	1	0.511	0.044
50	2	0.497	0.035
50	3	4.407	0.025
75	1	0.843	0.069
75	2	0.552	0.049
75	3	0.585	0.054
100	1	1.022	0.078
100	2	1.074	0.084
100	3	1.255	0.122

Table A.16 Total N and P loss at Colby during wet runs

Colby Wet % Stover Removal	Rep	Sampling Period	Total N	Total P
			---kg ha^{-1}---	
0	1	1	0.000	0.000
0	1	2	0.008	0.003
0	1	3	0.011	0.012
0	2	1	0.000	0.000
0	2	2	0.000	0.000
0	2	3	0.000	0.000
0	3	1	0.000	0.000
0	3	2	0.000	0.001
0	3	3	0.000	0.002
25	1	1	0.165	0.111
25	1	2	0.709	0.596
25	1	3	0.594	0.437
25	2	1	0.000	0.000
25	2	2	0.000	0.015
25	2	3	0.000	0.014
25	3	1	0.000	0.000
25	3	2	0.000	0.000
25	3	3	0.002	0.007
50	1	1	0.008	0.008
50	1	2	0.084	0.079
50	1	3	1.884	2.425
50	2	1	0.033	0.022
50	2	2	0.148	0.119
50	2	3	0.043	0.068
50	3	1	0.027	0.016
50	3	2	0.031	0.029
50	3	3	0.000	0.024
75	1	1	0.028	0.021
75	1	2	0.064	0.056
75	1	3	0.175	0.149
75	2	1	0.002	0.001
75	2	2	0.024	0.010
75	2	3	0.021	0.019
75	3	1	0.132	0.107
75	3	2	0.277	0.227
75	3	3	0.093	0.107
100	1	1	0.258	0.156
100	1	2	0.412	0.360
100	1	3	0.335	0.401
100	2	1	0.462	0.390

100	2	2	0.265	0.305
100	2	3	0.549	0.502
100	3	1	0.061	0.040
100	3	2	0.065	0.065
100	3	3	0.012	0.040

Table A.17 Total N and P loss at Hugoton during wet runs

Hugoton Wet % Stover Removal	Rep	Sampling Period	Total N	Total P
			---kg ha^{-1}---	
0	1	1	0.000	0.000
0	1	2	0.003	0.020
0	1	3	0.035	0.190
0	2	1	0.303	0.001
0	2	2	2.278	0.037
0	2	3	3.350	0.043
0	3	1	0.000	0.000
0	3	2	1.631	0.017
0	3	3	5.325	0.051
25	1	1	0.000	0.000
25	1	2	0.002	0.029
25	1	3	0.000	0.074
25	2	1	0.000	0.000
25	2	2	0.000	0.000
25	2	3	1.235	0.020
25	3	1	0.000	0.000
25	3	2	0.000	0.000
25	3	3	0.000	0.000
50	1	1	0.000	0.000
50	1	2	0.000	0.007
50	1	3	0.013	0.048
50	2	1	0.000	0.000
50	2	2	1.040	0.016
50	2	3	2.310	0.030
50	3	1	0.996	0.012
50	3	2	7.735	0.061
50	3	3	8.902	0.072
75	1	1	0.000	0.010
75	1	2	0.000	0.045
75	1	3	0	0.127
75	2	1	0	0.013
75	2	2	0	0.042
75	2	3	0	0.045
75	3	1	0	0.000
75	3	2	0	0.000
75	3	3	0.297	0.006
100	1	1	0.001	0.008
100	1	2	0.000	0.020
100	1	3	0.000	0.070
100	2	1	1.370	0.018

100	2	2	5.290	0.064
100	2	3	6.353	0.102
100	3	1	2.054	0.027
100	3	2	8.002	0.216
100	3	3	9.002	0.142

Table A.18 Total N and P loss at Ottawa during wet runs

Ottawa Wet % Stover Removal	Rep	Sampling Period	Total N	Total P
			---kg ha⁻¹---	
0	1	1	0.1532	0.0115
0	1	2	0.3000	0.0271
0	1	3	0.2587	0.0220
0	2	1	0.0646	0.0040
0	2	2	0.2778	0.0181
0	2	3	0.2448	0.0171
0	3	1	0.0617	0.0045
0	3	2	0.3478	0.0225
0	3	3	0.3348	0.0219
25	1	1	0.3084	0.0088
25	1	2	0.6125	0.0229
25	1	3	0.4016	0.0198
25	2	1	0.2328	0.0172
25	2	2	0.4221	0.0414
25	2	3	0.3608	0.0248
25	3	1	0.0880	0.0038
25	3	2	0.2795	0.0226
25	3	3	0.1997	0.0160
50	1	1	0.0969	0.0065
50	1	2	0.2332	0.0211
50	1	3	0.3068	0.0261
50	2	1	2.7854	0.0173
50	2	2	9.1828	0.0414
50	2	3	10.0416	0.0335
50	3	1	0.1798	0.0095
50	3	2	1.6318	0.1079
50	3	3	0.6661	0.0351
75	1	1	0.6022	0.0537
75	1	2	0.4873	0.0446
75	1	3	0.4357	0.0365
75	2	1	0.2288	0.0166
75	2	2	0.5473	0.0430
75	2	3	0.4740	0.0423
75	3	1	0.2243	0.0173
75	3	2	0.5428	0.0402
75	3	3	0.5736	0.0463
100	1	1	0.3027	0.0138
100	1	2	0.4617	0.0229
100	1	3	0.4760	0.0286
100	2	1	3.1903	0.0273
100	2	2	5.9872	0.0452

100	2	3	5.9493	0.0469
100	3	1	0.2455	0.0189
100	3	2	0.7647	0.0679
100	3	3	6.5717	0.4773

Table A.19 Soluble nutrient loss at Colby during dry runs

Colby Dry % Stover Removal	Rep	Sampling Period	Phosphate	Ammonium	Nitrate
				---kg ha^{-1}---	
0	1	1	0.00000	0.00000	0.00000
0	1	2	0.00000	0.00000	0.00000
0	1	3	0.00000	0.00000	0.00000
0	2	1	0.00000	0.00000	0.00000
0	2	2	0.00000	0.00000	0.00000
0	2	3	0.00000	0.00000	0.00000
0	3	1	0.00000	0.00000	0.00000
0	3	2	0.00000	0.00000	0.00000
0	3	3	0.00000	0.00000	0.00000
25	1	1	0.00000	0.00018	0.00000
25	1	2	0.00000	0.00080	0.00000
25	1	3	0.00000	0.00104	0.00000
25	2	1	0.00000	0.00000	0.00000
25	2	2	0.00000	0.00000	0.00000
25	2	3	0.00000	0.00028	0.00000
25	3	1	0.00000	0.00000	0.00000
25	3	2	0.00000	0.00071	0.00003
25	3	3	0.00000	0.00061	0.00000
50	1	1	0.00000	0.00000	0.00000
50	1	2	0.00000	0.00027	0.00000
50	1	3	0.00000	0.00198	0.00000
50	2	1	0.00000	0.00036	0.00000
50	2	2	0.00000	0.00113	0.00000
50	2	3	0.00000	0.00046	0.00000
50	3	1	0.00000	0.00000	0.00000
50	3	2	0.00000	0.00103	0.00672
50	3	3	0.00000	0.00406	0.04810
75	1	1	0.00000	0.00000	0.00000
75	1	2	0.00000	0.00035	0.00000
75	1	3	0.00000	0.00154	0.00000
75	2	1	0.00000	0.00005	0.00000
75	2	2	0.00000	0.00125	0.00000
75	2	3	0.00000	0.00088	0.00000
75	3	1	0.00000	0.00000	0.00000
75	3	2	0.00000	0.00152	0.01001
75	3	3	0.00000	0.00447	0.04500
100	1	1	0.00000	0.00001	0.00000
100	1	2	0.00000	0.00042	0.00000
100	1	3	0.00000	0.00151	0.00000
100	2	1	0.00000	0.00070	0.00000

100	2	2	0.00000	0.00238	0.00000
100	2	3	0.00000	0.00048	0.00000
100	3	1	0.00000	0.00000	0.00000
100	3	2	0.00000	0.00082	0.00000
100	3	3	0.00000	0.00110	0.00000

Table A.20 Soluble nutrient loss at Hugoton during dry runs

Hugoton Dry % Stover Removal	Rep	Sampling Period	Phosphate	Ammonium	Nitrate
				---kg ha^{-1}---	
0	1	1	0.00000	0.00000	0.00000
0	1	2	0.00000	0.00000	0.00000
0	1	3	0.00000	0.00000	0.00000
0	2	1	0.00000	0.00000	0.00000
0	2	2	0.00000	0.00000	0.00000
0	2	3	0.00132	0.00044	0.00240
0	3	1	0.00000	0.00000	0.00000
0	3	2	0.00000	0.00000	0.00000
0	3	3	0.00000	0.00000	0.00000
25	1	1	0.00000	0.00000	0.00000
25	1	2	0.00000	0.00000	0.00000
25	1	3	0.00593	0.01604	0.01881
25	2	1	0.00000	0.00000	0.00000
25	2	2	0.00000	0.00000	0.00000
25	2	3	0.00000	0.00000	0.00000
25	3	1	0.00000	0.00000	0.00000
25	3	2	0.00000	0.00000	0.00000
25	3	3	0.00000	0.00000	0.00000
50	1	1	0.00000	0.00000	0.00000
50	1	2	0.00000	0.00000	0.00000
50	1	3	0.00409	0.01004	0.00976
50	2	1	0.00000	0.00000	0.00000
50	2	2	0.00000	0.00000	0.00000
50	2	3	0.00751	0.00000	0.01869
50	3	1	0.00000	0.00000	0.00000
50	3	2	0.00000	0.00000	0.00000
50	3	3	0.01187	0.00000	0.02683
75	1	1	0.00000	0.00000	0.00000
75	1	2	0.00114	0.00851	0.00699
75	1	3	0.010889	0.099408	0.047088
75	2	1	0.000000	0.000000	0.000000
75	2	2	0.000000	0.000000	0.000000
75	2	3	0.000708	0.004469	0.003488
75	3	1	0.000000	0.000000	0.000000
75	3	2	0.000000	0.000000	0.000000
75	3	3	0.000000	0.000000	0.000000
100	1	1	0.000000	0.000000	0.000000
100	1	2	0.003220	0.013908	0.013680
100	1	3	0.008604	0.059040	0.047232
100	2	1	0.000000	0.000000	0.000000
100	2	2	0.004891	0.000480	0.006440

100	2	3	0.013458	0.000972	0.017982
100	3	1	0.000000	0.000000	0.000000
100	3	2	0.000220	0.000000	0.001860
100	3	3	0.001034	0.000000	0.010868

Table A.21 Soluble nutrient loss at Ottawa during dry runs

Ottawa Dry % Stover Removal	Rep	Sampling Period	Phosphate	Ammonium	Nitrate
				---kg ha⁻¹---	
0	1	1	0.00000	0.00000	0.00000
0	1	2	0.00240	0.00528	0.00275
0	1	3	0.00450	0.00333	0.00000
0	2	1	0.00000	0.00000	0.00000
0	2	2	0.00053	0.00000	0.00006
0	2	3	0.00562	0.00256	0.00000
0	3	1	0.00000	0.00000	0.00000
0	3	2	0.00126	0.00373	0.00081
0	3	3	0.00432	0.00898	0.00000
25	1	1	0.00000	0.00000	0.00000
25	1	2	0.00018	0.00891	0.00594
25	1	3	0.00232	0.03498	0.00641
25	2	1	0.00000	0.00000	0.00000
25	2	2	0.00072	0.00262	0.00000
25	2	3	0.00504	0.00379	0.00000
25	3	1	0.00000	0.00000	0.00000
25	3	2	0.00000	0.00000	0.00000
25	3	3	0.00141	0.00427	0.00000
50	1	1	0.00000	0.00000	0.00000
50	1	2	0.00000	0.00015	0.00000
50	1	3	0.00096	0.00365	0.00000
50	2	1	0.00000	0.00000	0.00000
50	2	2	0.00028	0.00035	0.00000
50	2	3	0.00217	0.00293	0.00000
50	3	1	0.00000	0.00000	0.00000
50	3	2	0.00062	0.42538	0.00000
50	3	3	0.00375	4.12474	0.00000
75	1	1	0.00000	0.00000	0.00000
75	1	2	0.00000	0.00095	0.00000
75	1	3	0.00000	0.00681	0.00000
75	2	1	0.00000	0.00000	0.00000
75	2	2	0.00000	0.00000	0.00000
75	2	3	0.00049	0.00158	0.00000
75	3	1	0.00000	0.00000	0.00000
75	3	2	0.00000	0.00093	0.00000
75	3	3	0.00000	0.00281	0.00000
100	1	1	0.00000	0.00000	0.00000
100	1	2	0.00002	0.00244	0.00065
100	1	3	0.00000	0.02381	0.00100
100	2	1	0.00000	0.00000	0.00000
100	2	2	0.00000	0.00355	0.00000

100	2	3	0.00000	0.00663	0.00000
100	3	1	0.00000	0.00000	0.00000
100	3	2	0.00000	0.00491	0.00000
100	3	3	0.00000	0.00816	0.00000

Table A.22 Soluble nutrient loss at Colby during wet runs

Colby Wet % Stover Removal	Rep	Sampling Period	Phosphate	Ammonium	Nitrate
				---kg ha^{-1}---	
0	1	1	0.00000	0.00000	0.00000
0	1	2	0.00000	0.00012	0.00058
0	1	3	0.00000	0.00035	0.00000
0	2	1	0.00000	0.00000	0.00000
0	2	2	0.00000	0.00000	0.00000
0	2	3	0.00000	0.00000	0.00000
0	3	1	0.00000	0.00000	0.00000
0	3	2	0.00000	0.00056	0.00000
0	3	3	0.00000	0.00099	0.00000
25	1	1	0.00000	0.00032	0.00000
25	1	2	0.00000	0.00105	0.00242
25	1	3	0.00000	0.00057	0.00114
25	2	1	0.00000	0.00000	0.00000
25	2	2	0.00000	0.00025	0.00000
25	2	3	0.00000	0.00130	0.00000
25	3	1	0.00000	0.00000	0.00000
25	3	2	0.00000	0.00000	0.00000
25	3	3	0.00000	0.00074	0.00000
50	1	1	0.00000	0.00009	0.00036
50	1	2	0.00000	0.00044	0.00666
50	1	3	0.00000	0.00030	0.00967
50	2	1	0.00000	0.00021	0.00000
50	2	2	0.00000	0.00117	0.00000
50	2	3	0.00000	0.00000	0.00000
50	3	1	0.00000	0.00056	0.00000
50	3	2	0.00000	0.00352	0.00000
50	3	3	0.00000	0.00290	0.00000
75	1	1	0.00000	0.00026	0.00069
75	1	2	0.00000	0.00197	0.00000
75	1	3	0.00000	0.00130	0.00474
75	2	1	0.00000	0.00005	0.00032
75	2	2	0.00000	0.00102	0.00150
75	2	3	0.00000	0.00095	0.00000
75	3	1	0.00000	0.00180	0.00000
75	3	2	0.00000	0.00595	0.00000
75	3	3	0.00000	0.00329	0.00000
100	1	1	0.00000	0.00105	0.00493
100	1	2	0.00000	0.00187	0.00256
100	1	3	0.00000	0.00074	0.00148
100	2	1	0.00000	0.00155	0.00000
100	2	2	0.00000	0.00039	0.00000

100	2	3	0.00000	0.00134	0.00000
100	3	1	0.00000	0.00086	0.00000
100	3	2	0.00000	0.00223	0.00000
100	3	3	0.00000	0.00169	0.00000

Table A.23 Soluble nutrient loss at Hugoton during wet runs

Hugoton Wet % Stover Removal	Rep	Sampling Period	Phosphate	Ammonium	Nitrate
				---kg ha^{-1}---	
0	1	1	0.00000	0.00000	0.00000
0	1	2	0.01714	0.00000	0.03585
0	1	3	0.07019	0.00000	0.11620
0	2	1	0.00043	0.04801	0.02656
0	2	2	0.02799	0.33262	0.49847
0	2	3	0.03400	0.45513	0.63921
0	3	1	0.00000	0.00000	0.00000
0	3	2	0.01195	0.21793	0.30951
0	3	3	0.03609	0.80556	1.00711
25	1	1	0.00000	0.00000	0.00000
25	1	2	0.01504	0.00000	0.02175
25	1	3	0.02756	0.00000	0.00536
25	2	1	0.00000	0.00000	0.00000
25	2	2	0.00000	0.00000	0.00000
25	2	3	0.01509	0.16066	0.25217
25	3	1	0.00000	0.00000	0.00000
25	3	2	0.00000	0.00000	0.00000
25	3	3	0.00000	0.00000	0.00000
50	1	1	0.00000	0.00000	0.00000
50	1	2	0.00283	0.00000	0.00000
50	1	3	0.01517	0.00000	0.00350
50	2	1	0.00000	0.00000	0.00000
50	2	2	0.01172	0.14938	0.22259
50	2	3	0.02024	0.37179	0.45873
50	3	1	0.00536	0.14004	0.19548
50	3	2	0.03029	1.28991	1.45917
50	3	3	0.02849	1.51747	1.67798
75	1	1	0.00333	0.00000	0.00895
75	1	2	0.01211	0.00000	0.00000
75	1	3	0.02120	0.00000	0.00000
75	2	1	0.00551	0.00000	0.01224
75	2	2	0.01618	0.00000	0.00730
75	2	3	0.01451	0.00000	0.00000
75	3	1	0.00000	0.00000	0.00000
75	3	2	0.00000	0.00000	0.00000
75	3	3	0.00004	0.05226	0.05369
100	1	1	0.00154	0.00000	0.00113
100	1	2	0.00594	0.00000	0.00000
100	1	3	0.01131	0.00000	0.00000
100	2	1	0.00679	0.21530	0.26875
100	2	2	0.02481	0.89505	1.06535

100	2	3	0.02542	1.03470	1.18539
100	3	1	0.00207	0.34175	0.37975
100	3	2	0.00455	1.34131	1.36102
100	3	3	0.00572	1.51540	1.56875

Table A.24 Soluble nutrient loss at Ottawa during wet runs

Ottawa Wet % Stover Removal	Rep	Sampling Period	Phosphate	Ammonium	Nitrate
				---kg ha^{-1}---	
0	1	1	0.00156	0.00000	0.00000
0	1	2	0.00331	0.00000	0.00000
0	1	3	0.00052	0.00000	0.00000
0	2	1	0.00032	0.02365	0.00018
0	2	2	0.00347	0.09367	0.00000
0	2	3	0.00368	0.04280	0.00000
0	3	1	0.00016	0.00121	0.00276
0	3	2	0.00067	0.00000	0.00926
0	3	3	0.00155	0.00186	0.00000
25	1	1	0.00024	0.05474	0.00456
25	1	2	0.00000	0.11440	0.00000
25	1	3	0.00000	0.04773	0.00000
25	2	1	0.00238	0.00186	0.00000
25	2	2	0.00234	0.00268	0.00000
25	2	3	0.00219	0.00484	0.00000
25	3	1	0.00046	0.00248	0.00036
25	3	2	0.00153	0.00848	0.00000
25	3	3	0.00076	0.00550	0.00000
50	1	1	0.00016	0.00000	0.00000
50	1	2	0.00330	0.00000	0.00000
50	1	3	0.00000	0.00206	0.00000
50	2	1	0.00067	2.58470	0.00000
50	2	2	0.00074	8.51032	0.00000
50	2	3	0.00077	9.00379	0.00000
50	3	1	0.00049	0.06936	0.00065
50	3	2	0.00150	0.40300	0.00000
50	3	3	0.00000	0.21599	0.00000
75	1	1	0.00000	0.00275	0.00000
75	1	2	0.00000	0.00463	0.00000
75	1	3	0.00000	0.00833	0.00000
75	2	1	0.00063	0.06864	0.00000
75	2	2	0.00041	0.07285	0.00000
75	2	3	0.00049	0.04338	0.00000
75	3	1	0.00000	0.00210	0.00000
75	3	2	0.00000	0.00635	0.00000
75	3	3	0.00000	0.00566	0.00000
100	1	1	0.00000	0.07567	0.00000
100	1	2	0.00000	0.05922	0.00000
100	1	3	0.00082	0.03451	0.00000
100	2	1	0.00000	2.64677	0.00000
100	2	2	0.00187	5.07867	0.00000

100	2	3	0.00000	5.29339	0.00000
100	3	1	0.00020	0.00665	0.00000
100	3	2	0.00060	0.01267	0.00000
100	3	3	0.00000	0.00437	0.00000

Table A.25 Antecedent soil moisture before dry runs

% Stover Removal	Rep	Colby	Hugoton	Ottawa
		---Antecedent Soil Moisture (kg kg^{-1})---		
0	1	0.306	0.279	0.236
0	2	0.323	0.082	0.226
0	3	0.297	0.193	0.220
25	1	0.190	0.117	0.226
25	2	0.294	0.208	0.175
25	3	0.237	0.191	0.230
50	1	0.190	0.200	0.211
50	2	0.235	0.178	0.240
50	3	0.254	0.083	0.184
75	1	0.186	0.077	0.159
75	2	0.236	0.134	0.230
75	3	0.253	0.061	0.178
100	1	0.205	0.087	0.206
100	2	0.216	0.145	0.188
100	3	0.234	0.080	0.179

Appendix B - Effects of Corn Stover Removal on Soil Properties and Crop Production

Raw Data

Table B.1 Soil bulk density at 0-5 cm at Colby

% Stover Removal	Rep	04/07/09	06/23/09	07/15/09	8/21/2009	6/9/2010	11/15/2010	6/3/2011
					---(Mg m^{-3})---			
0	1	1.37	1.28	1.30	1.26	1.29	1.35	1.30
0	2	1.36	0.76	1.36	1.28	1.31	1.23	1.41
0	3	1.38	0.92	1.32	1.26	1.34	1.11	1.36
25	1	1.41	1.07	1.39	1.23	1.21	1.28	1.39
25	2	1.40	1.31	1.37	1.41	1.31	1.31	1.38
25	3	1.41	1.25	1.33	1.36	1.25	0.99	1.39
50	1	1.30	1.10	1.31	1.23	1.31	1.28	1.14
50	2	1.25	1.02	1.31	0.90	1.20	1.28	1.36
50	3	1.39	1.50	1.30	0.87	1.30	1.39	1.28
75	1	1.48	1.24	1.17	1.35	1.27	1.36	1.37
75	2	1.26	1.14	1.39	1.34	1.28	1.28	1.36
75	3	1.30	1.57	1.28	0.90	1.19	1.22	1.21
100	1	1.36	0.80	1.35	1.32	1.37	1.29	1.42
100	2	1.30	1.18	1.45	0.94	1.20	1.30	1.33
100	3	1.25	1.31	1.19	1.36	1.33	1.22	1.40

Table B.2 Soil bulk density at 5-10 cm at Colby

% Stover Removal	Rep	04/07/09	06/23/09	07/15/09	8/21/2009	6/9/2010	11/15/2010	6/3/2011
					---(Mg m^{-3})---			
0	1	1.48	1.35	1.48	1.40	1.41	1.36	1.39
0	2	1.35	1.31	1.55	1.39	1.37	1.37	1.45
0	3	1.43	1.44	1.49	1.44	1.40	1.34	1.43
25	1	1.62	1.27	1.51	1.42	1.32	1.24	1.45
25	2	1.57	1.31	1.46	1.41	1.38	1.27	1.45
25	3	1.60	1.36	1.59	1.35	1.41	1.45	1.47
50	1	1.56	1.26	1.38	1.34	1.32	1.30	1.44
50	2	1.34	1.17	1.49	1.37	1.29	1.44	1.42
50	3	1.49	1.27	1.35	1.30	1.41	1.28	1.42
75	1	1.55	1.29	1.44	1.40	1.33	1.28	1.43
75	2	1.53	1.16	1.54	1.30	1.38	1.37	1.45
75	3	1.54	1.31	1.40	1.44	1.38	1.34	1.41
100	1	1.60	1.04	1.59	1.31	1.43	1.29	1.46
100	2	1.50	1.23	1.55	1.29	1.38	1.37	1.41
100	3	1.62	1.22	1.41	1.41	1.41	1.39	1.54

Table B.3 Soil bulk density at 0-5 cm at Hugoton

% Stover Removal	Rep	06/16/09	08/10/09	11/18/09	5/12/2010	11/22/2010	4/19/2011
				---(Mg m^{-3})---			
0	1	1.41	1.17	0.98	1.42	1.32	1.37
0	2	1.34	0.93	1.06	1.10	1.31	1.17
0	3	0.78	1.16	0.84	1.13	0.84	1.26
25	1	1.17	0.93	0.87	1.37	1.32	1.36
25	2	1.01	1.11	1.09	1.40	1.36	1.49
25	3	0.73	1.11	1.05	1.17	1.15	1.24
50	1	1.31	1.02	1.09	1.07	1.26	1.27
50	2	0.82	1.03	0.90	1.32	1.19	1.25
50	3	1.35	1.19	0.99	1.31	1.31	1.31
75	1	1.16	1.19	0.98	1.43	1.32	1.45
75	2	1.01	1.20	1.18	1.34	1.18	1.24
75	3	0.96	0.82	0.86	1.25	1.04	1.27
100	1	1.12	0.87	1.09	1.18	1.42	1.40
100	2	1.34	1.20	0.90	1.20	1.35	1.45
100	3	1.05	1.39	1.00	1.36	1.30	1.22

Table B.4 Soil bulk density at 5-10 cm at Hugoton

% Stover Removal	Rep	06/16/09	08/10/09	11/18/09	5/12/2010	11/22/2010	4/19/2011
				---(Mg m^{-3})---			
0	1	1.61	1.28	1.35	1.60	1.55	1.44
0	2	0.99	1.44	1.47	1.55	1.52	1.26
0	3	1.19	1.54	1.38	1.62	1.43	1.34
25	1	1.18	1.36	1.33	1.54	1.38	1.49
25	2	1.12	1.49	1.48	1.51	1.51	1.59
25	3	1.08	1.34	1.37	1.42	1.47	1.43
50	1	1.43	1.52	1.32	1.52	1.50	1.40
50	2	1.25	1.16	1.44	1.58	1.36	1.37
50	3	1.05	1.36	1.41	1.59	1.55	1.46
75	1	1.47	1.41	1.41	1.62	1.37	1.54
75	2	1.10	1.49	1.42	1.64	1.26	1.32
75	3	1.33	1.35	1.33	1.69	1.23	1.40
100	1	1.20	1.23	1.39	1.55	1.43	1.58
100	2	1.34	1.44	1.41	1.52	1.62	1.65
100	3	1.15	1.58	1.48	1.57	1.36	1.39

Table B.5 Soil bulk density at 0-5 cm at Ottawa

% Stover Removal	Rep	07/31/09	11/30/09	06/24/10	11/28/10	06/07/11
				---(Mg m^{-3})---		
0	1	1.23	1.08	1.03	1.22	1.26
0	2	1.20	1.29	1.24	1.28	1.33
0	3	1.15	1.22	1.24	1.10	1.38
25	1	1.16	1.10	1.05	1.22	1.28
25	2	1.19	1.17	1.35	1.15	1.34
25	3	1.09	1.21	1.30	0.77	1.30
50	1	1.15	1.23	1.20	0.81	1.30
50	2	1.33	1.26	1.29	1.26	1.32
50	3	1.05	1.21	1.10	1.05	1.26
75	1	1.21	1.31	1.18	1.07	1.27
75	2	1.25	1.22	0.92	0.95	1.34
75	3	1.35	1.24	1.39	0.86	1.34
100	1	1.09	1.16	1.10	1.17	1.27
100	2	1.10	1.29	1.20	0.93	1.34
100	3	1.32	1.09	1.43	0.86	1.32

Table B.6 Soil bulk density at 5-10 cm at Ottawa

% Stover Removal	Rep	07/31/09	11/30/09	06/24/10	11/28/10	06/07/11
				---(Mg m^{-3})---		
0	1	1.18	1.30	1.34	1.28	1.32
0	2	1.39	1.41	1.33	1.43	1.46
0	3	1.36	1.30	1.44	1.40	1.35
25	1	1.28	1.34	1.38	1.37	1.32
25	2	1.33	1.39	1.44	1.34	1.40
25	3	1.26	1.36	1.36	1.36	1.37
50	1	1.21	1.49	1.39	1.37	1.43
50	2	1.30	1.34	1.34	1.36	1.40
50	3	1.28	1.37	1.39	1.43	1.41
75	1	1.33	1.23	1.35	1.31	1.37
75	2	1.25	1.28	1.38	1.38	1.32
75	3	1.26	1.50	1.47	1.41	1.46
100	1	1.25	1.25	1.41	1.33	1.34
100	2	1.37	1.44	1.46	1.37	1.48
100	3	1.21	1.36	1.47	1.26	1.36

Table B.7 Mean weight diameter of water stable aggregates at Colby

% Stover Removal	Rep	Spring 2010	Fall 2010	Spring 2011
			---(mm)---	
0	1	2.15	3.74	2.42
0	2	2.21	2.41	1.96
0	3	2.15	2.61	2.03
25	1	2.47	2.98	1.11
25	2	2.28	4.24	2.60
25	3	2.26	3.23	1.24
50	1	1.85	2.27	2.65
50	2	1.65	1.89	1.95
50	3	1.33	2.69	2.26
75	1	1.94	2.32	1.08
75	2	1.71	1.88	1.58
75	3	1.67	2.96	2.44
100	1	1.52	2.12	0.80
100	2	1.37	2.64	1.93
100	3	1.05	1.98	1.20

Table B.8 Mean weight diameter of water stable aggregates at Hugoton

% Stover Removal	Rep	Spring 2010	Fall 2010	Spring 2011
			---(mm)---	
0	1	1.56	2.05	2.89
0	2	1.69	2.09	2.27
0	3	2.63	2.34	2.54
25	1	1.94	2.19	2.21
25	2	0.950	2.39	1.79
25	3	1.55	2.58	2.77
50	1	1.46	1.88	1.52
50	2	1.85	1.19	2.79
50	3	1.40	2.30	2.42
75	1	1.69	1.74	3.24
75	2	0.818	1.28	2.09
75	3	1.84	1.56	1.78
100	1	1.00	1.37	1.79
100	2	0.537	1.26	1.79
100	3	0.956	2.00	1.31

Table B.9 Mean weight diameter of water stable aggregates at Ottawa

% Stover Removal	Rep	Spring 2010	Fall 2010	Spring 2011
			---(mm)---	
0	1	1.95	2.29	2.13
0	2	1.57	2.37	2.36
0	3	2.15	2.00	1.69
25	1	2.06	2.18	2.36
25	2	1.67	2.06	2.18
25	3	1.35	2.56	2.10
50	1	1.25	2.17	2.03
50	2	1.55	2.31	2.04
50	3	1.39	2.42	1.71
75	1	1.45	1.94	1.45
75	2	1.02	2.02	1.32
75	3	1.17	1.80	1.09
100	1	1.34	1.45	1.59
100	2	1.52	1.28	1.44
100	3	0.96	1.65	1.79

Table B.10 Percent water stable aggregates in spring 2010 at Colby

% Stover Removal	Rep	>4.75	2-4.75	1-2	.5-1	.25-5	<.25
			---Water Stable Aggregates (%)---				
0	1	25.26	8.24	5.22	9.08	18.55	33.65
0	2	25.77	8.97	6.34	8.77	17.93	32.22
0	3	23.60	10.89	6.95	9.13	17.81	31.62
25	1	28.35	11.63	6.84	9.65	16.01	27.53
25	2	26.14	10.83	5.54	7.16	17.30	33.02
25	3	24.85	11.18	7.96	10.12	17.21	28.69
50	1	19.87	9.64	5.61	7.92	18.00	38.95
50	2	15.75	9.41	7.68	12.43	21.82	32.91
50	3	12.24	7.05	6.66	10.04	21.61	42.41
75	1	19.31	11.76	7.78	11.26	19.69	30.21
75	2	17.94	7.74	6.33	10.92	22.15	34.91
75	3	16.68	8.62	7.06	11.38	23.10	33.17
100	1	15.40	7.60	5.50	9.88	20.66	40.96
100	2	11.87	9.38	6.08	10.87	20.73	41.08
100	3	7.72	7.19	6.24	10.63	21.43	46.79

Table B.11 Percent water stable aggregates in fall 2010 at Colby

% Stover Removal	Rep	>4.75	2-4.75	1-2	.5-1	.25-5	<.25
				---Water Stable Aggregates (%)---			
0	1	47.21	15.87	5.50	7.26	10.23	13.93
0	2	27.97	11.41	5.88	7.97	14.51	32.27
0	3	30.06	12.44	6.99	10.02	16.60	23.89
25	1	35.14	14.48	6.84	10.11	14.00	19.43
25	2	56.69	14.68	3.59	4.62	8.19	12.23
25	3	39.42	13.02	8.83	10.50	13.21	15.03
50	1	25.71	11.53	5.49	7.16	16.78	33.33
50	2	19.61	10.51	6.58	10.61	17.90	34.78
50	3	30.62	14.54	6.39	8.58	14.12	25.75
75	1	26.28	11.09	6.16	10.01	17.99	28.47
75	2	18.98	10.64	7.36	12.09	17.71	33.24
75	3	33.83	16.53	6.99	8.13	12.89	21.62
100	1	24.17	9.15	5.73	10.48	17.69	32.78
100	2	31.66	11.23	5.78	9.34	15.16	26.83
100	3	21.34	9.98	6.01	10.45	18.33	33.89

Table B.12 Percent water stable aggregates in spring 2011 at Colby

% Stover Removal	Rep	>4.75	2-4.75	1-2	.5-1	.25-5	<.25
				---Water Stable Aggregates (%)---			
0	1	27.11	12.31	7.27	9.47	16.85	26.98
0	2	21.62	9.37	6.43	7.77	16.29	38.51
0	3	20.57	11.89	8.23	11.58	19.75	27.98
25	1	7.79	8.43	7.38	11.00	22.29	43.12
25	2	29.75	13.47	6.64	7.96	16.41	25.78
25	3	8.23	10.26	9.32	12.94	22.78	36.46
50	1	34.03	7.04	5.22	7.67	18.54	27.50
50	2	19.48	10.86	8.84	13.24	19.93	27.66
50	3	22.15	15.84	9.49	10.48	17.82	24.20
75	1	8.43	6.94	6.19	9.68	21.44	47.31
75	2	13.73	10.54	7.79	13.29	23.73	30.91
75	3	24.88	16.03	9.21	10.67	16.96	22.25
100	1	4.83	5.48	5.56	8.99	23.03	52.11
100	2	20.00	10.14	7.28	11.07	21.88	29.63
100	3	9.89	6.81	5.96	12.91	28.10	36.34

Table B.13 Percent water stable aggregates in spring 2010 at Hugoton

% Stover Removal	Rep	>4.75	2-4.75	1-2	.5-1	.25-5	<.25
			---Water Stable Aggregates (%)---				
0	1	16.35	6.70	6.22	10.36	17.40	42.97
0	2	18.07	7.52	6.46	9.51	16.59	41.85
0	3	31.43	9.38	5.59	20.10	12.65	20.85
25	1	21.06	9.01	6.93	10.43	17.67	34.91
25	2	6.78	7.18	5.36	8.33	16.88	55.47
25	3	16.26	7.49	5.88	7.21	14.70	48.45
50	1	15.13	7.14	5.43	7.51	16.21	48.58
50	2	20.34	8.29	6.42	9.11	15.55	40.30
50	3	12.92	7.31	6.88	12.86	21.35	38.68
75	1	18.35	7.53	5.81	8.77	16.55	42.99
75	2	6.25	3.70	5.38	9.44	19.81	55.42
75	3	19.74	9.14	5.62	8.78	18.87	37.84
100	1	6.42	6.96	8.00	11.80	24.54	42.28
100	2	2.43	3.73	3.54	7.11	18.25	64.93
100	3	7.60	5.38	5.64	8.55	19.84	52.99

Table B.14 Percent water stable aggregates in fall 2010 at Hugoton

% Stover Removal	Rep	>4.75	2-4.75	1-2	.5-1	.25-5	<.25
			---Water Stable Aggregates (%)---				
0	1	22.77	10.97	5.29	7.05	12.22	41.70
0	2	23.06	11.77	4.99	6.51	12.47	41.20
0	3	27.98	10.71	4.95	5.60	6.90	43.86
25	1	25.40	10.07	4.95	7.42	13.40	38.76
25	2	28.67	11.07	4.34	5.44	9.78	40.70
25	3	31.61	10.29	4.82	6.87	13.81	32.61
50	1	19.88	11.67	4.85	6.25	11.22	46.12
50	2	9.39	9.88	5.69	7.76	13.70	53.59
50	3	27.82	9.64	4.42	6.09	11.16	40.87
75	1	17.74	11.34	5.14	6.81	11.05	47.92
75	2	12.46	7.38	4.49	6.47	13.55	55.65
75	3	16.64	8.50	4.13	5.42	10.00	55.30
100	1	13.88	7.76	4.34	5.56	12.15	56.32
100	2	11.94	8.74	4.18	4.83	8.36	61.95
100	3	24.05	7.64	4.02	6.02	12.65	45.62

Table B.15 Percent water stable aggregates in spring 2011 at Hugoton

% Stover Removal	Rep	>4.75	2-4.75	1-2	.5-1	.25-5	<.25
				---Water Stable Aggregates (%)---			
0	1	36.60	10.47	4.63	6.59	13.36	28.36
0	2	26.92	8.87	5.58	9.18	17.62	31.83
0	3	30.53	10.59	5.52	7.83	15.76	29.78
25	1	26.15	8.78	5.11	8.11	16.46	35.39
25	2	19.23	8.95	5.47	8.38	16.56	41.40
25	3	32.92	12.37	6.01	9.36	16.74	22.59
50	1	15.03	8.45	6.27	8.64	17.65	43.96
50	2	33.49	12.41	5.89	8.56	15.33	24.32
50	3	27.83	11.55	6.40	8.98	15.81	29.43
75	1	41.22	10.10	7.70	10.85	13.81	16.32
75	2	23.10	9.78	6.98	10.60	18.28	31.26
75	3	17.19	10.99	7.19	11.57	19.86	33.20
100	1	20.20	7.58	4.80	7.74	16.94	42.75
100	2	19.33	8.68	5.95	8.16	17.54	40.35
100	3	10.68	9.17	6.78	10.87	21.83	40.66

Table B.16 Percent water stable aggregates in spring 2010 at Ottawa

% Stover Removal	Rep	>4.75	2-4.75	1-2	.5-1	.25-5	<.25
				---Water Stable Aggregates (%)---			
0	1	21.42	7.92	7.06	11.67	22.90	29.04
0	2	15.09	7.70	7.87	12.95	23.99	32.41
0	3	23.77	10.33	6.81	9.44	18.97	30.69
25	1	21.88	11.82	6.74	8.75	16.15	34.66
25	2	16.34	8.46	8.23	14.63	18.43	33.90
25	3	12.44	7.06	6.50	11.04	24.09	38.87
50	1	10.10	7.69	7.82	12.58	24.77	37.03
50	2	15.31	7.29	7.17	11.91	23.93	34.39
50	3	13.37	6.83	5.95	10.61	24.25	38.98
75	1	13.57	8.47	7.37	9.27	18.49	42.83
75	2	7.71	6.07	7.04	10.91	22.02	46.25
75	3	9.12	7.60	7.05	11.58	23.96	40.68
100	1	11.81	7.36	7.57	12.07	22.50	38.69
100	2	15.83	6.91	5.80	9.16	18.06	44.25
100	3	6.93	6.04	6.17	9.93	24.00	46.93

Table B.17 Percent water stable aggregates in fall 2010 at Ottawa

% Stover Removal	Rep	>4.75	2-4.75	1-2	.5-1	.25-5	<.25
				---Water Stable Aggregates (%)---			
0	1	23.85	13.98	8.09	9.73	17.58	26.76
0	2	25.78	13.34	7.84	9.08	16.17	27.78
0	3	19.59	13.80	7.43	9.50	17.14	32.54
25	1	24.29	10.41	7.11	9.69	17.84	30.67
25	2	20.15	14.65	8.10	8.85	14.69	33.56
25	3	29.10	13.26	7.06	8.52	15.39	26.66
50	1	24.54	9.91	6.81	8.82	15.19	34.74
50	2	24.32	14.69	7.53	8.54	13.94	30.98
50	3	27.45	12.29	6.62	8.13	16.48	29.04
75	1	20.36	11.24	6.66	7.82	14.68	39.24
75	2	22.59	8.90	7.46	9.00	15.56	36.48
75	3	17.40	11.49	7.91	10.08	17.20	35.91
100	1	13.76	8.78	6.45	8.45	16.25	46.30
100	2	11.44	7.27	7.29	9.45	17.48	47.07
100	3	16.01	9.87	6.91	9.55	19.01	38.66

Table B.18 Percent water stable aggregates in spring 2011 at Ottawa

% Stover Removal	Rep	>4.75	2-4.75	1-2	.5-1	.25-5	<.25
				---Water Stable Aggregates (%)---			
0	1	21.74	13.34	8.29	9.73	16.41	30.49
0	2	26.84	12.01	6.29	7.54	14.40	32.92
0	3	16.24	10.03	7.57	12.01	18.70	35.45
25	1	24.99	14.45	8.13	9.53	14.68	28.21
25	2	24.30	10.97	6.57	8.31	14.46	35.40
25	3	21.87	12.90	7.23	7.67	15.08	35.25
50	1	21.08	11.74	7.75	9.26	14.88	35.30
50	2	22.46	10.29	7.00	7.25	13.85	39.16
50	3	16.23	10.21	9.44	9.94	17.65	36.54
75	1	11.15	12.08	9.23	9.92	17.35	40.28
75	2	10.57	9.54	8.15	10.87	18.43	42.43
75	3	8.99	6.02	7.18	10.23	19.64	47.95
100	1	16.10	8.60	6.49	8.24	15.27	45.30
100	2	13.62	8.48	6.57	8.73	17.76	44.84
100	3	16.16	11.25	12.37	11.81	16.68	31.73

Table B.19 Water retention values at Colby

% Stover Removal	Rep	**1**	**1.4**	**3**	**6**	**9.2**	**18.4**	**36.8**	**500**	**1500**
					---Water Content ($m^3\ m^{-3}$)---					
0	1	0.461	0.410	0.406	0.383	0.371	0.341	0.316	0.171	0.160
0	2	0.442	0.422	0.420	0.414	0.404	0.378	0.350	0.188	0.178
0	3	-	-	-	-	-	-	-	-	-
25	1	0.459	0.415	0.411	0.396	0.387	0.359	0.331	0.171	0.173
25	2	0.468	0.426	0.415	0.380	0.361	0.321	0.292	0.160	0.153
25	3	0.484	0.432	0.416	0.392	0.381	0.357	0.341	0.182	0.165
50	1	0.486	0.468	0.459	0.432	0.415	0.357	0.313	0.179	0.158
50	2	0.524	0.471	0.459	0.419	0.401	0.350	0.318	0.188	0.184
50	3	0.514	0.471	0.460	0.423	0.403	0.350	0.317	0.176	0.160
75	1	0.539	0.472	0.447	0.402	0.381	0.319	0.284	0.158	0.152
75	2	0.487	0.446	0.430	0.404	0.393	0.362	0.340	0.186	0.186
75	3	0.501	0.487	0.479	0.422	0.401	0.346	0.310	0.173	0.160
100	1	0.407	0.406	0.402	0.387	0.371	0.328	0.295	0.174	0.167
100	2	0.471	0.457	0.443	0.417	0.393	0.353	0.323	0.183	0.165
100	3	0.459	0.432	0.429	0.413	0.404	0.365	0.332	0.173	0.162

Table B.20 Water retention values at Hugoton

% Stover Removal	Rep	**1**	**1.4**	**3**	**6**	**9.2**	**18.4**	**36.8**	**500**	**1500**
					---Water Content ($m^3\ m^{-3}$)---					
0	1	0.484	0.421	0.405	0.374	0.351	0.308	0.281	0.144	0.129
0	2	0.447	0.435	0.428	0.418	0.409	0.384	0.366	0.175	0.153
0	3	0.452	0.441	0.434	0.427	0.421	0.405	0.395	0.190	0.160
25	1	-	-	-	-	-	-	-	-	-
25	2	0.460	0.397	0.385	0.365	0.349	0.319	0.296	0.161	0.144
25	3	0.423	0.410	0.399	0.374	0.353	0.326	0.306	0.172	0.148
50	1	0.445	0.422	0.408	0.386	0.364	0.328	0.309	0.159	0.140
50	2	0.463	0.425	0.413	0.390	0.373	0.343	0.322	0.169	0.149
50	3	0.468	0.424	0.418	0.409	0.401	0.377	0.355	0.178	0.154
75	1	0.472	0.433	0.420	0.390	0.366	0.331	0.311	0.166	0.146
75	2	0.459	0.447	0.447	0.440	0.433	0.408	0.390	0.172	0.147
75	3	0.439	0.407	0.401	0.383	0.369	0.346	0.329	0.184	0.155
100	1	0.530	0.503	0.475	0.434	0.403	0.355	0.331	0.160	0.137
100	2	0.400	0.398	0.398	0.398	0.377	0.336	0.304	0.173	0.148
100	3	0.493	0.457	0.444	0.416	0.392	0.349	0.325	0.177	0.159

Table B.21 Water retention values at Ottawa

% Stover Removal	Rep	**1**	**1.4**	**3**	**6**	**9.2**	**18.4**	**36.8**	**500**	**1500**
					---Water Content ($m^3\ m^{-3}$)---					
0	1	0.488	0.418	0.412	0.397	0.386	0.366	0.340	0.177	0.151
0	2	0.509	0.427	0.416	0.397	0.383	0.361	0.338	0.164	0.133
0	3	0.495	0.435	0.421	0.401	0.388	0.363	0.342	0.166	0.132
25	1	0.524	0.437	0.423	0.401	0.387	0.364	0.338	0.187	0.152
25	2	0.500	0.457	0.452	0.435	0.421	0.401	0.378	0.186	0.157
25	3	0.502	0.453	0.444	0.428	0.413	0.389	0.358	0.165	0.134
50	1	0.445	0.438	0.437	0.432	0.423	0.401	0.370	0.182	0.149
50	2	0.469	0.444	0.435	0.416	0.401	0.377	0.348	0.179	0.140
50	3	0.510	0.451	0.436	0.411	0.394	0.369	0.343	0.160	0.135
75	1	0.536	0.449	0.426	0.402	0.383	0.356	0.327	0.211	0.175
75	2	0.502	0.448	0.435	0.413	0.397	0.374	0.350	0.205	0.159
75	3	0.499	0.446	0.430	0.407	0.390	0.364	0.335	0.174	0.140
100	1	0.447	0.421	0.414	0.398	0.383	0.359	0.331	0.199	0.152
100	2	0.500	0.444	0.424	0.398	0.380	0.353	0.322	0.176	0.144
100	3	0.498	0.452	0.442	0.422	0.405	0.379	0.348	0.172	0.148

Table B.22 Available water content values

% Stover Removal	Rep	Colby	Hugoton	Ottawa
			---($m^3\ m^{-3}$)---	
0	1	0.156	0.152	0.188
0	2	0.171	0.214	0.205
0	3	0.157	0.234	0.210
25	1	0.139	0.152	0.186
25	2	0.175	0.158	0.221
25	3	0.155	0.169	0.224
50	1	0.134	0.174	0.222
50	2	0.157	0.201	0.209
50	3	0.133	0.165	0.208
75	1	0.153	0.244	0.153
75	2	0.150	0.174	0.191
75	3	0.128	0.193	0.195
100	1	0.158	0.155	0.179
100	2	0.170	0.166	0.178
100	3	0.156	0.152	0.200

Table B.23 RETC model output at Colby

% Stover Removal	Rep	**θr**	**θs**	**α**	**n**	**m**	**R^2**
0	1	0.089	0.411	0.007	1.347	0.291	0.995
0	2	0.000	0.428	0.005	1.222	0.291	0.991
0	3	-	-	-	-	-	-
25	1	0.146	0.409	0.004	1.667	0.291	0.993
25	2	0.076	0.438	0.016	1.300	0.291	0.996
25	3	0.000	0.429	0.009	1.206	0.291	0.989
50	1	0.118	0.475	0.010	1.441	0.291	0.999
50	2	0.129	0.483	0.016	1.368	0.291	0.996
50	3	0.087	0.484	0.015	1.324	0.291	0.998
75	1	0.103	0.489	0.020	1.383	0.291	0.997
75	2	0.094	0.444	0.009	1.297	0.291	0.988
75	3	0.094	0.509	0.020	1.336	0.291	0.996
100	1	0.139	0.410	0.007	1.520	0.291	0.998
100	2	0.063	0.467	0.015	1.264	0.291	0.998
100	3	0.124	0.432	0.005	1.521	0.291	0.997

Table B.24 RETC model output at Hugoton

% Stover Removal	Rep	**θr**	**θs**	**α**	**n**	**m**	**R^2**
0	1	0.027	0.435	0.018	1.256	0.359	0.997
0	2	0.108	0.428	0.003	1.554	0.359	0.996
0	3	0.000	0.437	0.002	1.311	0.359	0.993
25	1	-	-	-	-	-	-
25	2	0.023	0.401	0.011	1.231	0.359	0.996
25	3	0.000	0.418	0.015	1.195	0.359	0.996
50	1	0.000	0.429	0.013	1.219	0.359	0.995
50	2	0.000	0.428	0.010	1.217	0.359	0.994
50	3	0.107	0.419	0.003	1.520	0.359	0.997
75	1	0.000	0.446	0.018	1.205	0.359	0.995
75	2	0.000	0.449	0.003	1.332	0.359	0.994
75	3	0.000	0.408	0.007	1.213	0.359	0.996
100	1	0.000	0.523	0.023	1.232	0.359	0.995
100	2	0.114	0.405	0.006	1.476	0.359	0.997
100	3	0.037	0.469	0.016	1.241	0.359	0.996

Table B.25 RETC model output at Ottawa

% Stover Removal	Rep	**θr**	**θs**	**α**	**n**	**m**	**R^2**
0	1	0.074	0.414	0.004	1.373	0.291	0.997
0	2	0.000	0.422	0.005	1.271	0.291	0.995
0	3	0.000	0.428	0.005	1.271	0.291	0.994
25	1	0.000	0.435	0.008	1.220	0.291	0.996
25	2	0.000	0.455	0.004	1.271	0.291	0.995
25	3	0.000	0.450	0.005	1.297	0.291	0.997
50	1	0.000	0.442	0.003	1.295	0.291	0.998
50	2	0.000	0.442	0.006	1.259	0.291	0.998
50	3	0.000	0.446	0.007	1.267	0.291	0.993
75	1	0.000	0.460	0.023	1.163	0.291	0.999
75	2	0.000	0.447	0.008	1.208	0.291	0.996
75	3	0.000	0.444	0.008	1.240	0.291	0.996
100	1	0.000	0.423	0.007	1.211	0.291	0.999
100	2	0.000	0.446	0.013	1.216	0.291	0.997
100	3	0.036	0.450	0.006	1.300	0.291	0.996

Table B.26 Soil C values at Colby

% Stover Removal	Rep	Spring 2010	Fall 2010	Spring 2011
			---(Mg ha^{-1})---	
0	1	15.75	18.46	17.01
0	2	14.23	12.64	16.34
0	3	16.09	12.31	13.83
25	1	14.17	14.73	15.42
25	2	15.26	18.05	17.46
25	3	14.43	10.69	13.11
50	1	14.93	15.12	13.34
50	2	14.68	15.36	16.80
50	3	14.74	15.97	15.41
75	1	16.11	17.47	16.52
75	2	14.10	12.91	15.01
75	3	14.62	17.60	14.21
100	1	13.82	13.10	13.37
100	2	14.80	15.78	16.54
100	3	13.09	11.32	13.09

Table B.27 Soil C values at Hugoton

% Stover Removal	Rep	Spring 2010	Fall 2010	Spring 2011
			---(Mg ha^{-1})---	
0	1	16.32	10.35	11.07
0	2	8.34	10.08	9.95
0	3	9.97	6.15	10.70
25	1	10.69	11.67	11.24
25	2	11.07	11.30	11.57
25	3	8.84	8.80	9.54
50	1	7.90	11.78	8.75
50	2	13.30	9.90	10.08
50	3	10.96	15.47	11.51
75	1	11.92	11.29	13.46
75	2	10.24	8.23	8.70
75	3	9.11	9.35	9.12
100	1	7.10	10.84	10.02
100	2	8.09	10.58	9.99
100	3	9.36	10.57	8.56

Table B.28 Soil C values at Ottawa

% Stover Removal	Rep	Spring 2010	Fall 2010	Spring 2011
			---(Mg ha^{-1})---	
0	1	15.02	18.31	19.15
0	2	20.66	18.84	18.49
0	3	19.56	15.54	17.62
25	1	16.65	19.90	19.02
25	2	20.83	17.42	17.95
25	3	19.22	10.90	17.01
50	1	17.44	11.49	18.19
50	2	19.59	21.31	18.93
50	3	16.18	15.11	17.25
75	1	16.80	16.29	16.46
75	2	13.74	14.11	18.08
75	3	19.62	10.95	16.02
100	1	14.54	16.11	16.44
100	2	16.61	12.38	16.43
100	3	18.79	11.23	16.58

Table B.29 Soil N values at Colby

% Stover Removal	Rep	Spring 2010	Fall 2010	Spring 2011
			---(Mg ha^{-1})---	
0	1	1.49	1.69	1.41
0	2	1.56	1.26	1.60
0	3	1.67	1.27	1.34
25	1	1.41	1.41	1.35
25	2	1.40	1.57	1.44
25	3	1.58	1.10	1.33
50	1	1.50	1.32	1.14
50	2	1.37	1.31	1.52
50	3	1.44	1.58	1.47
75	1	1.48	1.49	1.40
75	2	1.68	1.40	1.51
75	3	1.40	1.56	1.22
100	1	1.60	1.31	1.40
100	2	1.40	1.31	1.41
100	3	1.43	1.23	1.37

Table B.30 Soil N values at Hugoton

% Stover Removal	Rep	Spring 2010	Fall 2010	Spring 2011
			---(Mg ha^{-1})---	
0	1	1.65	0.98	1.16
0	2	0.87	1.08	1.00
0	3	1.04	0.63	1.10
25	1	1.22	1.24	1.08
25	2	1.30	1.17	1.20
25	3	1.05	0.86	0.963
50	1	0.89	1.19	0.946
50	2	1.32	0.98	0.985
50	3	1.28	1.24	1.10
75	1	1.33	1.18	1.32
75	2	1.07	0.86	0.949
75	3	1.00	0.86	0.905
100	1	0.81	1.16	1.05
100	2	0.87	1.06	1.11
100	3	1.08	1.02	0.882

Table B.31 Soil N values at Ottawa

% Stover Removal	Rep	Spring 2010	Fall 2010	Spring 2011
			---(Mg ha^{-1})---	
0	1	1.30	1.48	1.52
0	2	1.69	1.53	1.48
0	3	1.66	1.16	1.39
25	1	1.40	1.51	1.49
25	2	1.74	1.37	1.43
25	3	1.60	0.90	1.37
50	1	1.52	0.86	1.43
50	2	1.64	1.57	1.49
50	3	1.38	1.22	1.36
75	1	1.42	1.29	1.34
75	2	1.16	1.16	1.48
75	3	1.64	0.89	1.33
100	1	1.33	1.34	1.39
100	2	1.45	1.01	1.31
100	3	1.61	0.92	1.42

Table B.32 2009 grain yield

% Stover Removal	Rep	Colby	Hugoton	Ottawa
			---(Mg ha^{-1})---	
0	1	8.45	9.28	8.15
0	2	15.32	12.54	6.89
0	3	15.56	11.47	7.44
25	1	15.97	12.52	8.41
25	2	16.95	11.23	6.14
25	3	16.52	12.07	4.40
50	1	17.73	7.14	9.25
50	2	18.68	13.38	6.95
50	3	17.16	15.09	7.68
75	1	19.13	11.85	9.99
75	2	16.46	13.02	7.88
75	3	18.82	12.76	6.37
100	1	17.79	9.43	10.40
100	2	17.93	8.59	8.96
100	3	16.25	13.49	8.93

Table B.33 2009 stover yield

% Stover Removal	Rep	Colby	Hugoton	Ottawa
			---(Mg ha^{-1})---	
0	1	4.74	5.79	4.52
0	2	4.67	8.70	3.76
0	3	7.64	6.67	3.33
25	1	6.03	7.26	4.38
25	2	3.84	8.63	3.98
25	3	6.32	7.81	2.61
50	1	9.78	3.36	5.17
50	2	4.33	7.05	4.24
50	3	5.83	7.84	3.60
75	1	5.77	6.86	5.63
75	2	4.55	6.52	4.18
75	3	6.56	6.45	3.25
100	1	5.67	5.53	4.84
100	2	4.28	4.48	4.93
100	3	5.87	7.22	5.19

Table B.34 2010 grain yield

% Stover Removal	Rep	Colby	Hugoton	Ottawa
			---(Mg ha^{-1})---	
0	1	12.45	15.76	4.85
0	2	14.94	16.41	5.32
0	3	11.80	15.46	5.08
25	1	15.11	18.03	4.43
25	2	15.39	15.18	5.57
25	3	16.53	17.13	5.07
50	1	11.43	16.61	3.94
50	2	16.71	16.04	4.90
50	3	13.29	15.63	5.11
75	1	13.77	15.28	3.71
75	2	15.45	14.09	5.56
75	3	11.51	14.37	4.63
100	1	15.68	15.89	6.00
100	2	17.16	15.26	4.19
100	3	14.76	16.70	4.41

Table B.35 2010 stover yield

% Stover Removal	Rep	Colby	Hugoton	Ottawa
			---(Mg ha^{-1})---	
0	1	6.13	2.45	2.83
0	2	7.25	6.24	6.47
0	3	4.46	8.21	3.57
25	1	4.96	6.58	3.01
25	2	5.80	3.79	2.23
25	3	8.48	5.26	3.35
50	1	5.35	6.32	2.08
50	2	7.14	5.65	3.68
50	3	6.77	6.24	5.80
75	1	8.81	6.36	2.90
75	2	6.54	2.73	6.02
75	3	4.68	4.19	6.47
100	1	8.40	10.37	3.35
100	2	5.95	5.20	2.38
100	3	5.91	4.01	2.30

Appendix C - SAS Codes

Runoff and Erosion

```
dm 'log;clear;out;clear';
filename log    'My documents\my sas files\9.2\classdoc\704-1.log';
filename out    'My documents\my sas files\9.2\classdoc\704-1.out';
options ls = 80;
options nocenter;
data ColbyW;
input Trt       Rep     Time    Vol Depth       Sed     TotalN TotalP Phos      Ammon
Nit;
logvol = log10(vol + 1);
logdepth = log10(depth + 1);
logsed = log10(sed + 1);
datalines;
;
proc mixed data = ColbyW;
class rep trt time;
model logvol = trt|time;
random rep rep*trt;
lsmeans trt|time/pdiff;
run;
proc mixed data = ColbyW;
class rep trt time;
model logdepth = trt|time;
random rep rep*trt;
lsmeans trt|time/pdiff;
run;
```

```
proc mixed data = ColbyW;
class rep trt time;
model logsed = trt|time;
random rep rep*trt;
lsmeans trt|time/pdiff;
run;
quit;
proc sort;
by time;
proc mixed data = ColbyW;
by time;
class rep trt;
model logvol = trt;
random rep;
lsmeans trt/pdiff;
run;
proc mixed data = ColbyW;
by time;
class rep trt;
model logdepth = trt;
random rep;
lsmeans trt/pdiff;
run;
proc mixed data = ColbyW;
by time;
class rep trt;
model logsed = trt;
random rep;
lsmeans trt/pdiff;
run;
quit;
```

Time to Runoff Initiation

```
dm 'log;clear;out;clear';
options nocenter;
data ColbyTTR;
input Trt Rep  Time;
datalines;
;
proc sort data= ColbyTTR;
by trt;
proc univariate data = ColbyTTR normal plot;
        var Time;
        by trt;
proc mixed data= ColbyTTR;
class trt rep;
model Time =trt;
random rep;
lsmeans trt /diff;
run;
```

Soil Physical Properties and Crop Production

Wet Aggregate Stability

(A=>4.75 mm, B=2-4.75 mm, etc., etc.)

```
dm 'log;clear;out;clear';
options nocenter;
data ColbyS10WSA;
input Trt	Rep	A B C D E F;
datalines;
;
proc sort data=ColbyS10WSA;
by trt;
proc univariate data = ColbyS10WSA normal plot;
		var A;
		by trt;
proc mixed data=ColbyS10WSA;
class trt rep;
model A=trt;
random rep;
lsmeans trt /diff;
run;
proc univariate data = ColbyS10WSA normal plot;
		var B;
		by trt;
proc mixed data=ColbyS10WSA;
class trt rep;
model B=trt;
random rep;
lsmeans trt /diff;
run;
```

```
proc univariate data = ColbyS10WSA normal plot;
        var C;
        by trt;
proc mixed data=ColbyS10WSA;
class trt rep;
model C=trt;
random rep;
lsmeans trt /diff;
run;
proc univariate data = ColbyS10WSA normal plot;
        var D;
        by trt;
proc mixed data=ColbyS10WSA;
class trt rep;
model D=trt;
random rep;
lsmeans trt /diff;
run;
proc univariate data = ColbyS10WSA normal plot;
        var E;
        by trt;
proc mixed data=ColbyS10WSA;
class trt rep;
model E=trt;
random rep;
lsmeans trt /diff;
run;
proc univariate data = ColbyS10WSA normal plot;
        var F;
        by trt;
proc mixed data=ColbyS10WSA;
```

```
class trt rep;
model F=trt;
random rep;
lsmeans trt /diff;
run;
```

MWD, Bulk Density, AWC, Grain and Stover Yield, Stand Counts

```
dm 'log;clear;out;clear';
options nocenter;
data Colby1BD;
input Trt Rep  BD;
datalines;
;
proc sort data=Colby1BD;
by trt;
proc univariate data = Colby1BD normal plot;
        var BD;
        by trt;
proc mixed data=Colby1BD;
class trt rep;
model BD=trt;
random rep;
lsmeans trt /diff;
run;
```

Total Carbon and Nitrogen

```
dm 'log;clear;out;clear';
options nocenter;
data ColbyF10;
input Trt Rep  TN TC;
datalines;
```

```
;
proc sort data=ColbyF10;
by trt;
proc univariate data = ColbyF10 normal plot;
            var TN;
            by trt;
proc mixed data=ColbyF10;
class trt rep;
model TN=trt;
random rep;
lsmeans trt /diff;
run;
proc univariate data = ColbyF10 normal plot;
            var TC;
            by trt;
proc mixed data=ColbyF10;
class trt rep;
model TC=trt;
random rep;
lsmeans trt /diff;
run;
```

Temperature and Moisture

```
dm 'log;clear;out;clear';
options nocenter;
data ColbyMoist;
input Trt Rep  Date$ Moist;
datalines;
;
proc sort data=ColbyMoist;
by trt;
```

```
proc univariate data = ColbyMoist normal plot;
            var Moist;
            by trt;
proc mixed data=ColbyMoist;
class trt rep;
model Moist=trt;
random rep;
lsmeans trt /diff;
run;
```

Water Retention

(A= 0 cm H_2O, B = 14.3 cm, etc.)

```
dm 'log;clear;out;clear';
options nocenter;
data ColbyF10WR;
input Trt     Rep    A B C D E F G H I;
datalines;
;
proc sort data=ColbyF10WR;
by trt;
proc univariate data = ColbyF10WR normal plot;
            var A;
            by trt;
proc mixed data=ColbyF10WR;
class trt rep;
model A=trt;
random rep;
lsmeans trt /diff;
run;
```

```
proc univariate data = ColbyF10WR normal plot;
        var B;
        by trt;
proc mixed data=ColbyF10WR;
class trt rep;
model B=trt;
random rep;
lsmeans trt /diff;
run;
proc univariate data = ColbyF10WR normal plot;
        var C;
        by trt;
proc mixed data=ColbyF10WR;
class trt rep;
model C=trt;
random rep;
lsmeans trt /diff;
run;
proc univariate data = ColbyF10WR normal plot;
        var D;
        by trt;
proc mixed data=ColbyF10WR;
class trt rep;
model D=trt;
random rep;
lsmeans trt /diff;
run;
proc univariate data = ColbyF10WR normal plot;
        var E;
        by trt;
proc mixed data=ColbyF10WR;
```

```
class trt rep;
model E=trt;
random rep;
lsmeans trt /diff;
run;
proc univariate data = ColbyF10WR normal plot;
        var F;
        by trt;
proc mixed data=ColbyF10WR;
class trt rep;
model F=trt;
random rep;
lsmeans trt /diff;
run;
proc univariate data = ColbyF10WR normal plot;
        var G;
        by trt;
proc mixed data=ColbyF10WR;
class trt rep;
model G=trt;
random rep;
lsmeans trt /diff;
run;
proc univariate data = ColbyF10WR normal plot;
        var H;
        by trt;
proc mixed data=ColbyF10WR;
class trt rep;
model H=trt;
random rep;
lsmeans trt /diff;
```

```
run;
proc univariate data = ColbyF10WR normal plot;
        var I;
        by trt;
proc mixed data=ColbyF10WR;
class trt rep;
model I=trt;
random rep;
lsmeans trt /diff;
run;
```