CORN STOVER REMOVAL EFFECTS ON IRRIGATED SANDY OUTWASH SOILS IN NORTH DAKOTA

A Thesis
Submitted to the Graduate Faculty
of the
North Dakota State University of
Agriculture and Applied Science

By

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In Partial Fulfillment of the Requirements
for the Degree of
MASTER OF SCIENCE

Major Program:
Natural Resources Management

November 2015

Fargo, North Dakota

North Dakota State University
Graduate School

Title

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

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ABSTRACT

Recent interest in utilizing corn (*Zea Mays L.*) stover for cellulosic ethanol and supplements for distillers' grain in livestock rations has increased corn stover demand. A study was established to evaluate corn stover removal on selected soil properties in irrigated sandy outwash soils under no-tillage management including continuous corn and corn-soybean (*glycine max*) rotations. For continuous corn, increasing stover removal rates (0 to 100%) increased the wind erodible soil fraction (25.4 to 36.6%), decreased the field-moist water stable soil aggregates (58.78 to 48.3%) and water infiltration rates (22.4 to 8.6 cm/hr). Water infiltration rates decreased in the corn phase of the corn-soybean rotation (16.8 to 10.8 cm/hr) and air-dry water stable aggregates decreased in the soybean phase of the corn soybean rotation (88.1% to 77.7%) for 100% removal when compared to 0% removal. Longer-term evaluation of stover removal is needed to fully evaluate stover removal effects on soil properties.

ACKNOWLEDGEMENTS

I would like to convey my heartfelt gratitude and appreciations to the following people for their succor and guidance.

- Dr. Larry J. Cihacek for serving as my major adviser and for his fortitude, assistance and enlightening guidance throughout my study and during the preparation of this text.
- The North Dakota Corn Council for providing funding to conduct this research.
- Walt Albus, formerly of the Oakes Research Site; Leonard Bessman and Heidi Eslinger, Oakes Research Site and Ezra Aberle and Blaine Schatz, Carrington Research and Extension Center for the establishment, maintenance and agronomic data collection on the stover removal study plots that have contributed to this study.
- Raheem Sanders for his guidance in conducting statistical analysis with SAS.

DEDICATION

I would like to dedicate this publication to my parents whom sacrificed unconditionally to afford me the opportunity to pursue my education and shepherded my college education path.

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ARS.....Agricultural Research Service

C.....Carbon

CEC.....Cation exchange capacity

N.....Nitrogen

PSA .....Particle size analysis

P .....Phosphorus

K.....Potassium

RSF .....Renewable fuel standard

SOC.....Soil organic carbon

SOM.....Soil organic matter

USDA.....United States Department of Agriculture

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INTRODUCTION

North Dakota corn production has increased with the emergence of improved corn varieties that can withstand cooler summers and shorter growing seasons. According to the United States Department of Agriculture, National Agricultural Statistics Service (USDA-NASS, 2015) corn acreage harvested in North Dakota during 2012 equates to 3,460,000 acres with a slight increase in 2013 to 3,600,000. However, corn acreage decreased in 2014 to 2,530,000 acres due to economic factors. Although, traditionally, corn grain has been produced for livestock feed, the demand for grain corn in the United States has risen rapidly to meet the demand for alternative energy as ethanol (Schenpf and Yacobucci, 2013). The Energy Policy Act of 2005 expanded the Renewable Fuel Standard Act (RSF) requiring the use of 36 billion gallons of biofuels in the US by 2022, with at least 16 billion gallons from cellulosic biofuels and with a cap of 15 billion gallons for corn-starch ethanol (Schenpf and Yacobucci, 2013). In addition to ethanol, corn is utilized in the manufacture of other products such as corn sweeteners and plastics.

There has been significant interest in utilizing the corn stover, residue left behind in fields after harvest, in the production of additional alternative energy products. Although the production of cellulosic ethanol has not yet been commercially developed on a widely accepted basis, large amounts of corn stover are currently being removed from harvested corn fields by baling and utilization as livestock feed. This has been driven partially by dry conditions in parts of the Great Plains, where corn stover is supplementing other forages in short supply. Corn stover is added to distiller grains being used for livestock feeding to provide roughage for animals.

Although crop stover removal has its promising economic benefits, research has shown that the removal of crop stover may have varying degrees of negative impacts on soil organic matter and erosion (Mann et al., 2002). Crop stover provides the soil with protection from wind and water erosion; which permits the soil to preserve soil aggregate stability, water holding capacity and minimal compaction. Crop stover is essential to soil organic matter (SOM) as it is a source of nutrients to the microbial population, a foremost participant in the soils nutrient cycling. Larson et al. (1972) concluded that SOM decreases in proportion to the rates of stover removal as a function of the soil type, topography and climate. Carbon (C) and nitrogen (N) concentrations are higher in the surface soil of plots that experienced treatments of mulch opposed to unmulched plots (Salinas-Garcia et al., 2001). When crop stover is removed consistently it has the potential to decrease SOM, soil nutrient concentrations, soil C and N ratios and degrade soil physical properties which is likely to impact the soil quality and crop yields in the long term.

The objective of this research is to evaluate the impacts of variable stover removal rates on selected physical, chemical and biological properties of a soil in irrigated continuous corn and corn-soybean rotation on a sandy textured soil, that are highly susceptible to erosion, under lower humidity conditions with greater climactic variability than reported in previously published research that has focused on the Corn Belt region of the U.S.

LITERATURE REVIEW

The removal of crop stover can impact the maintenance of soil organic matter and soil productivity, soil loss by wind and water erosion and plant nutrients for future crops. The extent of these impacts are not yet well-known; and requires long-term (5 years +, the average time previous studies dedicated is 5 years) studies in order to identify and evaluate how crop stover removal practices will impact future soil productivity and sustainability.

Soil Biological and Chemical Properties

Barber (1979) examined the changes in SOM content associated with the change of cropping practices in field experiments. One trial examined a continuous corn system over a period of 11 years with 3 experimental treatments of stover removal, stover added, no stover removed and doubled stover applied. The second trial examined the varying levels of stover returned due to N level in soils over a sequence of 12 years. The experiments were conducted on a Raub silt loam, with soil samples taken from the surface during and after the experiments. The samples were analyzed for organic C. Results indicated a decomposition rate of 2.4% of the soil O.M. per year due to loss of organic matter from continually tilled plots after 6 years. After 10 years, the corn stover removed plots were compared to stover returned plots, the data showed about 11% of the C in stover produced new organic matter, thus increasing SOM. This experiment also showed that 8% of the C from stover was transformed into SOC. The end results of this experiment indicated no significant differences in yields associated with the stover treatments. Barber (1979) concluded that long-term experiments are useful to determine the new equilibrium for organic matter stover management when crop management practices are altered.

Doran (1980) conducted field and greenhouse investigations on changes in soil microbiological populations with stover management under reduced tillage in Nebraska. The field investigation was on a Crete-Butler silty clay loam under both field and greenhouse conditions. For field and greenhouse studies, chopped corn stover was applied at initial surface at rates of 0, 7 and 14 metric tons/ ha to soils. The following year, chopped corn stover was applied to the soil surface at rates of 0, 4 and 8 metric tons/ha. The greenhouse investigation was conducted on the same soil collected from the surface 15 cm of the field trial. Corn stover from the field analysis was blended into the soil to reach application rates of 0- and 14- metric tons/ha. This study resulted in an increase in the population of bacteria, actinomycetes and fungi by 2- to 6-fold due to mulching treatments. The fungi populations were limited by rival bacterial and actinomycetes population increases in response to changes in soil water increasing 2-5% in mulched plots and pH regimes which differed significantly between rows 5.51 compared to within rows 5.32. Doran (1980) reported counts of nitrifying and denitrifying organisms contained by the surface soil increased 2-to-20-fold and 3-to-43-fold, corresponding to the application of corn stover on the surfaces of field plots. The greenhouse investigation reported 2-to-5 fold increases in microbial population in response to the surface applications of corn stover combined with the uniformly controlled moisture and soil conditions.

Blanco-Canqui and Lal (2009) examined the changes in soil structural stability and soil fertility in reaction to 4 years of systematic stover removal. The analysis was conducted on a Rayne silt loam (10% slope), a Celina silt loam (20% slope) and a Hoytville clay loam (1% slope) under no- tillage practices. Stover was removed at rates of 0, 25, 50, 75 and 100% after harvest over a course of 4 years on plots planted with continuous corn. The results indicated that stover removal reduced total soil organic carbon (SOC) and N concentrations over the course of

the investigation. These reductions in total SOC and N concentrations were also dependent on the stover removal rates and soil type. Complete stover removal reduced soil plant available P by 40% and exchangeable Ca^{+2} and Mg^{+2} and the cation exchange capacity (CEC) decreased by 10% on the sloping Rayne silt loam. Exchangeable K^{+} decreased by 15% on the silt loam soils for stover treatments >75% removal and by 25% under complete removal on the clay loam in the 0-to 10 cm depth. Blanco-Canqui and Lal (2009) also compiled an assessment on the impact of crop stover removal on soil productivity and environmental quality based on the literature by Bohlen et al. (1997); Butt et al. (1999) and Shipitalo and Butt (1999). Earthworm populations decreased with the removal of crop stover. Reduced stover was found to generate a scarcity of food sources and habitats for soil organisms. They concluded that stover removal encourages earthworms to migrate to neighboring mulched soils and to lower soil depths. The reduction of earthworms were associated with a reduction in water infiltration rates and an increase in the occurrence of runoff and soil loss.

Soil organic matter supplies energy and cell components and constituents for most of the microorganisms as they decompose organic matter. Soil microorganisms obtain carbon (C) and nitrogen (N) from the mineralization of organic matter, which fuels their cellular activity and energy. According to Brady and Weil (2010), organic matter is decomposed by microorganisms in aerobic soil conditions and anaerobic conditions slowly increases oxidation of organic carbon, increases the decomposition rate as does the breaking up of stover into smaller fractions creating more surface for decomposition. This process produces CO_2 and water, as well as humic and nonhumic (compounds which are resistant to microbial action). The rate that soil microorganisms metabolize organic matter depends the C/N ratio of organic material. Organic matter with a high C/N ratio being incorporated into soils has the ability to cause plants to suffer

from N deficiency. Due to the depletion of the soil's available N by microorganism, which may lead to immobilization of N (Brady and Weil, 2010). The rate at which mineralization occurs to organic matter that is incorporated into soil can be hindered if there is not a sufficient nitrogen supply to meet the demands required by microorganisms (Brady and Weil, 2010). When the annual source of organic materials, like corn stover, are harvested, the r-strategist organisms (organisms with short reproductive times that allow them to respond rapidly to the presence of easily metabolized food sources) will lack adequate nutrients to maintain their metabolism (Brady and Weil, 2010). The r-strategist organisms will become the minority of the microorganism population. Meanwhile, k-strategist organisms (organisms with slow reproductive times) that specialize in metabolizing nonhumic compounds that other organisms cannot utilize, will become the majority population within the soil system (Brady and Weil, 2010). This imbalance within the soil system will create a decline in the humic substances that plants utilize for nutrient sources. Humic substances also encourage soil granulation and aggregate stability and improves soil water retention and soil cation exchange capacity (Brady and Weil, 2010).

Schmer et al. (2014) and the United States department of Agriculture-USDA-ARS researchers evaluated grain yield, SOC, and total soil N in a 10 year irrigated continuous corn study under conventional disk tillage and no tillage with variable stover removal rates (low, medium, and high). This investigation was conducted at the University of Nebraska Agricultural Research and Development Center on irrigated Tomek and Filbert soils. This study was designed in a randomized complete block with factorial treatments arranged in split plots; with the whole-plot factor being tillage treatment and the subplot factor the residue removal treatments (0, 35, 70 and 100%). Total SOC and N stocks experienced change within the 0-30 cm surface soils, and

there were no identifiable changes within 0 to 150 cm. The change in SOC was found to be greater than 0 for all depths and did not differ among N fertilizer rates in the 0-30 cm depths. The SOC for the conventional disk tillage was concluded to be affected by the residue removal treatments and found to decline over the duration of the investigation. Schmer et al. (2014) concluded that the results support the need to evaluate the SOC cycling process below near-surface soil layers.

Jin. et al. (2015) and the United States Department of Agriculture-USDA-ARS researchers have been conducting research at the US Corn Belt at the University of Nebraska Agricultural Research and Development Center on Yutan, Tomek and Filbert soils. This study evaluated the impact of systematic stover removal (0% or 55%) and nitrogen fertilizer treatments in a split-split-plot arrangement in a randomized complete block with three replication design with continuous corn, on bulk density, pH, SOC and particulate organic matter. Across all treatments N fertilizer treatments the soil bulk density increased (1.35 to 1.44 Mg m^{-3}), pH decreased (6.6 to 5.9-6.3), and SOC stocks increased (49.4 to 57.8 Mg C ha^{-1}). The stover removal was found to have no treatment effect on any of the above properties. The SOC were found to increase during the duration of this study depending on the N fertilizer rate in the 0-5 cm depth, but a comparison by year indicated that there were no difference between SOC stocks.

Osborne et al. (2015) and the United States Department of Agriculture-USDA-ARS researchers have been conducting research at the South Dakota USDA-ARS North Central Agricultural Research Laboratory on Kranzburg, and Brookings soils. This study evaluated the impact of systematic stover removal (low, medium and high) in a randomized block design with a corn-soybean rotation on soil properties. Cover crops were integrated into the overall design in 2005 transforming the design to a split-plot with residue removal remaining as the whole plot

treatment and cover crop representing the split-plot treatment. Osborne et al. (2015) evaluated SOC, total C, total N, hydrolysis of fluorescein diacetate. The crop residue removal and cover crop impacts on hydrolysis of fluorescein diacetate was evaluated on the 0-15 cm depth. The corn phase and cover crops did not impact the microbial activity. The soybean phase was significantly impacted by residue removal for all years (2008-2010). The hydrolysis of fluorescein diacetate within the low and high residue removal differed by 24% (2008), 18% (2009), and 31% (2010). The SOC significantly impacted the 0-5 cm depth for both the corn and soybean crop phases. The soybean phase SOC in 2008 at 0-5 cm was measured to be 30.0g kg^{-1} for the low stover removal, 28.3g kg^{-1} for the medium stover removal and 26.0g kg^{-1} for the high stover removal. The low stover removal was 15% higher and the medium stover removal was 7.7% higher than the high stover removal in 2008. The low stover removal increased by 17% (2009), 24% (2010), and 12% (2011); the medium stover removal increased by 12% (2009), 12% (2010), and 8% (2011) when they were compared to the high residue removal rates of those years. The corn phase SOC in 2008 at 0-5 cm was measured to be 27.0g kg^{-1} for the low stover removal, 25.4g kg^{-1} for the medium stover removal and 24.0g kg^{-1} for the high stover removal. The low stover removal was 12.5% higher than the high stover removal in 2008. The low stover removal increased by 19.2% (2009), 17.3% (2010), and 19.2% (2011) when compared to the high residue removal rates of those years. The medium stover removal was not significantly different for the corn phase. The cover crop showed no significant difference within any of the phases throughout the study. Osborne et al. (2015) attributed the differences in SOC between the treatments to be to the amount of corn stover returned to the soil surface.

Soil Physical Properties

Since soil organic matter is one of the soil components that influences soil physical properties, identifying the role that stover management plays is imperative. Skidmore et al. (1986) investigated the influence of various methods of stover management for winter wheat and grain sorghum on soil physical properties. The study was established on a Richfield silty clay loam in southwest Kansas. The study included: (a) stover removal by burning, (b) stover removal by baling and hauling, (c) incorporation of stover produced during the previous cropping season and (d) the incorporation of twice the amount of stover produced by the crop. They concluded that most of the soil physical properties measured were not significantly influenced by wheat or sorghum stover management treatments due to the brief period of this study. However, there was a difference in the soil physical properties measured between the two crops. The soil aggregates from the sorghum plots were smaller, more fragile, less dense and less stable when dry and more stable when wet compared to aggregates from the wheat. The saturated hydraulic conductivity was several times greater in the soil cores obtained from the sorghum plots than those obtained from the wheat plots.

Karlen et al. (1994) investigated the impact of crop stover on soil quality following 10 years of no-tillage corn. This investigation was done in Wisconsin on Rozetta and Palsgrove silt loam soils under no-tillage management. Corn stover was maintained in place, removed completely or added to create double-stover plots. They reported that the soil aggregates from the double stover treatments were more stable when immersed in water than the normal removal treatment cropping systems. The measures of force and energy required to crush soil aggregates showed significant differences for different aggregate sizes.

Blanco-Canqui and Lal (2007b) examined the impact that long-term straw management has on micro and macro-scale soil physical properties. The study was conducted in Ohio under no tillage management on a 10 year stover management plot. The soil in this plot was a Crosby silt loam. The stover management was accomplished with treatments of wheat stover mulched at 0, 8 and 16 Mg ha^{-1} $year^{-1}$. During the duration of this investigation, no crops were grown on these plots. The results showed that most changes in soil properties were predominantly confined in the upper 5 cm of the soil. The investigators reported that mulching increased SOC concentrations but did not significantly impact the shear strength due the shear strengths or cone index. The shear strengths and cone indexes did not indicate significant differences due to them being corrected to a common value of soil gravimetric water content because the gravimetric water contents varied significantly due to treatment effects. When compared to unmulched soil, bulk density decreased by 40-50%, aggregate density determined by the clod method decreased by 30-40%, particle density determined by pycnometer method using mineral and organic matter particles decreased by 10-15% and a >30% increase of soil water retention was observed within the upper 0-5 cm of soil between 0 and -1500 kPa. This study concluded that long term management of wheat stover on no-tillage age system increased SOC and improved the soil aggregate properties near the soil surface.

Blanco-Canqui and Lal (2009) examined the changes in soil structural stability and soil fertility in reaction to 4 years of systematic stover removal. The stover removal reduced soil macroaggregates (>4.75 mm) by 40% at stover removal rates >25%. One hundred percent stover removal reduced soil macroaggregates by 60% on sloping soils.

Blanco-Canqui and Lal (2009) compiled an assessment on the impact of crop stover removal on soil productivity and environmental quality. Based on the literature by Morachen et al. (1972), Black (1973) and Singh and Malhi (2006), they concluded that increases in crop stover removal rates are linked to decreases in aggregate stability. When these observations were compared with results from Karlen et al. (1994) and Roldán et al. (2003) the results concerning soil stover removal on aggregate stability contradicted each other. They concluded that the extent of the impacts of crop stover on soil structural properties are dependent on soil type, type of crop stover, cropping system, climate and relief. Soil bulk density and cone index was determined to be increased by crop stover removal. These evaluations of studies by Morachen et al. (1972), Black (1973), Blanco-Canqui and Lal (2006) and Blanco-Canqui and Lal (2007b), showed that soil type, tillage, stover type and cropping systems are all factors that are significant when the effects of crop stover removal on compaction is determined. They also concluded that the influence of stover removal on soil compaction is very small in clayey soils. The soils' capacity to resist against compaction is proportional to the amount of stover cover.

Osborne et al. (2014) and USDA-ARS researchers have been conducting multi-location studies (Minnesota, Nebraska, and South Dakota) to evaluate the impact of corn stover removal on soil physical properties (dry aggregate size distribution, erodible fraction and SOM components). The plots at Brookings, South Dakota were established 2000 under a randomized complete block design under a corn-soybean rotation with three replications, a cover crop treatment was added in 2005 under a split-plot design. Morris, Minnesota's plots were established in 2005 under a randomized complete block design with four replications with corn-soybean rotation. Ithaca, Nebraska's plots were established 1999 under continuous corn with a randomized complete block design with three replications. At the Minnesota and South Dakota

sites treatments include three levels of corn stover removal low stover removal, medium stover removal and high stover removal. The Nebraska site only included stover removal at two rates low stover removal and medium stover removal. Data collection included dry aggregate size distribution, erodible fraction, and SOM components. The soil aggregate size distribution for South Dakota showed that the proportion of soil samples in the largest aggregate size class >19.mm was greater for the low stover removal treatment compared to the two other treatments. There were no significant difference between the fractions of soil within 2.0-6.4-mm size classes for the different residue removal or cover crop treatments. When stover was removed from the soil surface under high stover removal and not replaced by a cover crop there was less desirable overall dry aggregate size distribution compared when the soil surface was protected by stover or cover crops. Minnesota showed that significant increases were observed in aggregates of <1 mm and significant decrease in aggregates of 5-9 mm in high stover removal when compared to medium and low stover removal. Nebraska showed that regardless of N application there were a greater amount of soil aggregates >2.0-mm with the low stover removal when compared to medium stover removal. The erodible fraction was found to be significantly lower than the high stover removal and medium stover removal for all three treatments regardless of tillage, cover crops or N treatments. There was a conclusion that when residue was removed there was an increase in the erodible fraction, the use of cover crops aided to reduce the impacts of stover removal. This study also concluded that the amounts of SOM (cPOM, fPOM, and tPOM) decreased as a result of the amount of stover that was removed from the soil surface.

Jin. et al. (2015) and the United States Department of Agriculture-USDA-ARS researchers conducted an evaluation on soil dry aggregate size distribution and aggregate stability. Dry aggregate size distributions were found to be impacted by stover removal. The

(>2.0mm) fraction decreased from 55 to 40 % at the 0-5 cm, 72 to 60% at the 5-10 cm and 72 to 68% at the 10-30 cm. The water stable dry aggregates were found to not be affected by stover removal or N fertilizer treatment.

Osborne et al. (2015) and the United States Department of Agriculture-USDA-ARS researchers examined the stover removal impact on water stable aggregates and soil water retention. The water stable aggregates for the 2010 corn phase of the rotation, low stover removal (44.2%) was found to be 30.8% higher than the medium stover removal (33.8%) and 17.6% higher than the high stover removal (37.6%). Water stable aggregates for the soybean phase was found to be significantly higher in the low stover removal in 2008 and 2010. The low residue removal in 2008 (52.0%) was found to be 61% higher than the medium stover removal (32.2%) and 62% higher than the high stover removal (30.3%). The low residue removal in 2010 (44.2%) was found to be 22.5% higher than the high stover removal (37.6%). Cover crops did not impact water stable aggregates throughout either phase of the study. The soil water retention at a 0-15 cm depth was found to not be significantly different between the soybean phase and cover crop treatments. The soil water retention in the same depth for the corn phase were found to have significant at -6,-8,and -100 kPa and cover crops did not have and influence on soil water retention. Osborne et al. (2015) concluded that soil water retention for the low stover removal was improved compared with those of the high stover removal.

Yield Responses

Wilhelm et al. (1986) conducted an investigation on the yield response of continuous corn and continuous soybean with crop stover management under no-tillage age. This study was on a Crete-Butler silty clay loam. The amount of stover returned was applied in treatments of 0, 50, 100, or 150 % of the amount that was produced. They reported that grain and stover yield

had a positive linear response to the amount of stover applied to the soil. This study concluded that changes in soil water and soil temperature associated with stover treatments impacted crop yields.

Blanco-Canqui and Lal (2009) evaluated the impact of crop stover removal on soil productivity and environmental quality. Based on the literature by Morachen et al. (1972), Wilhelm et al. (1986), Karlen et al. (1994), Sow et al. (1997) and Linden et al. (2000) they found that crop yields are highly variable and dependent on crop management, soil texture, relief, topography and climate. Morachen et al. (1972) concluded that mulched stover retention at rates as high as 16 Mg ha on a no-tillage silty clay loam in Iowa increased yields during the first year and reduced yields during the second year. After the 13 year study ended, mulched stover had no effects on corn yields 10 out of the 13 years. Wilhelm et al. (1986), observed stover removal on a no-tillage silty clay loam in Nebraska, this study concluded that stover removal rates of 50% reduced corn grain yields by 0.80 Mg ha in 2 out of 4 years. Complete stover removal reduced corn grain yields by 1.5 to 3.0 Mg ha every year. Karlen et al. (1994) researched stover removal from no-tillage continuous corn on silt loams in Wisconsin for 10 years. Complete stover removal on continuous corn did not effect grain yields during the first 8 years of the study. Grain yields did increase by 0.5 Mg ha in the 9th year and declined by 2.8 Mg ha in the 10th year. Sow et al. (1997) evaluated a no-tillage clay loam in Texas for stover removal of sorghum straw impact on crop yields. This study resulted in a reduction in crop yields from 4.69 to 4.02 Mg ha. Linden et al. (2000) evaluated stover removal on a silt loam in Minnesota impact on corn grain yields of continuous corn for 12 years under no-tillage, chisel plow and moldboard plow systems. Corn grain yields were reduced by 1.0 Mg ha during 3 out of 12 years under no-tillage, by 0.5 to 1.0 Mg ha during 4 out of 12 years under chisel plowing, and by 0.5 to 2.0 Mg ha during 4 out of 12

years in moldboard plowing. The various studies concluded that crop yield responses to stover management depends on the in-situ conditions and can vary yearly. More research is required to understand the relationships between variability in weather conditions, fertilizer and organic amendments, invasive species of weeds and pest, soil water and temperature relationships and soil compaction as it relates with stover removal treatment.

Schmer et al. (2014) and the USDA-ARS researchers evaluated grain yield N in a 10 year irrigated continuous corn study under conventional disk tillage and no tillage with variable stover removal rates (low, medium, and high). Mean grain yields were 7.5 to 8.6% higher for no tillage when stover was removed compared with no stover removal. The conventional disk tillage mean grain yields were similar across all stover removal treatments.

Jin. et al. (2015) and the USDA-ARS researchers conducted an evaluation on yield responses to stover removal under N fertilizer treatments and found that there were no affect on the mean stover and grain yields from 2000-2011 growing seasons. Jin et al. (2015) attributed the various stover and grain yields experienced throughout the duration of the study as a response to growing conditions due to dryer climates and soil water retention due to stover accumulation on the surface.

Little is reported about the impacts of corn stover removal on soil properties in North Dakota especially coarse textured outwash soils. The climate in North Dakota can be highly variable and soils can be fragile and susceptible to wind erosion especially in areas of sandy outwash soils. As previously stated, the objectives of this research was to evaluate impacts of variable corn stover removal rates on selected physical, chemical and biological properties of a soil under irrigated continuous corn and corn-soybean rotation on a sandy soil. This research will focus on stover removal impacts on wind erodibility, aggregate stability, soil compaction,

water infiltration and stover removal impacts on SOC changes and N mineralization. This will answer the question of does residue removal affect these soil properties; with the hypothesis being: the soil physical, chemical and biological properties will be impacted if corn stover is removed.

MATERIALS AND METHODS

Site Description

The study was conducted at the North Dakota State University's Oakes Research Site near Oakes, ND (46°04'24.96"N and 98°05'31.86"W). Corn stover removal plots were established in 2008 using a randomized complete block design with 4 replications, including continuous corn and corn/soybean rotation plots under irrigation and no-tillage management. The continuous corn and each phase of the corn/soybean rotation are located in separate adjacent plot areas, with 4 replications of each stover removal treatments including a) no stover removal; b) 33% stover removal; c) 67% stover removal; and, d) 100% stover removal. This site is located on a complex of Embden sandy loam (coarse-loamy, mixed, superactive, frigid Pachic Hapludolls), Hecla sandy loam (sandy, mixed, frigid Oxyaquic Hapludolls) and Maddock sandy loam (sandy, mixed, frigid Entic Hapludolls) soils (USDA-NRCS, 2014). Vegetable crops (onion) were previously grown and thereafter, the new research plots were conditioned with corn for the initial crop. Beginning in the fall of 2008, corn stover was removed annually from the continuous corn plots. On the corn/soybean rotation plots, the stover was removed from the plots in the corn phase of the rotation with no stover removal from the soybean plots. The stover was removed from the plots using a small plot forage harvester with a 30 inch cutting width. Each plot was 12 rows wide and the row spacing was 30 inches so that the number of rows was divisible by 3. The remaining stover was left in place unaltered and the harvested rows were rotated for each year so the stover was equally removed from all rows over the duration of the study. For the 33% removal plots, stover was removed from 1 out of every 3 rows. For the 67% removal plots, stover from 2 out of every 3 rows was removed. No stover was removed from the 0% removal plots and all of the stover was removed from the 100% removal plots. The annual

irrigation applied was based on crop needs estimated from growing season rainfall and evapotranspiration rates. The annual total irrigation applied and corn yields are presented in the Appendix. The crop cycles since 2007 including the 2008 are shown in Table 1.

Table 1. Plots and their respective crop occurrence each year since the establishment of the crop rotation cycle

Plots	Year						
	2007	2008†	2009	2010	2011	2012	2013
Continuous corn	Corn ‡	Corn	Corn	Corn	Corn	Corn	Corn
Corn/soybean 1	Corn ‡	Soybean	Corn	Soybean	Corn	Soybean	Corn
Corn/soybean 2	Onion	Corn	Soybean	Corn	Soybean	Corn	Soybean

† Plots were conditioned for the study during 2008 growing season.
‡ Plots were planted into the corn/soybean rotation in the first corn year occurrence.

Field Methods

Soil properties (OM, fertility) were evaluated in September and October of 2008, 2011 and 2013 after irrigation was completed for the season. The study was originally established (2008) to evaluate stover removal on crop yields and agronomic factors contributing to yield. Therefore soil physical and chemical properties studied here were not evaluated in 2008 to provide a baseline for the study. The 2011 sampling was to evaluate soil C only and soil physical properties were only evaluated in 2013. However, since the plots were historically managed in a uniform manner, soil differences due to management were assumed to be minimal. Soil differences were mainly influenced by normal variability attributed to the soil types found in the area. The data reported here represents soil conditions after 6 years for the continuous corn and corn/soybean plot 1 and 5 years for the corn/soybean plot 2.

Soil Sampling

Soil samples were collected using a hydraulic soil coring machine (Giddings probe) with a 59 mm diameter steel tube with a plastic tube liner. The initial sampling (2008) was to a 60 cm depth after harvest from each plot and the subsequent sampling (2011 and 2013) was to a depth of 1m after harvest. Two core samples were taken per plot and combined after being subsampled. These cores were composited by 0-10, 10-20 and 20-30 cm depths from the surface 30 cm of the core and by 15 cm depth increments thereafter for the remainder of the cores for each plot. Composited core sample increments were hand crushed and air dried before mechanically crushing to pass a 2 mm sieve. The initial cores were collected in 15 cm depths to 60 cm, but the subsamples were handled similarly to the later sampling. The samples were utilized for soil total C and bulk density determinations. All sampling for soil measurements (aggregate analysis, infiltration rates, penetrability resistance) were done in inter-row areas that did not have equipment traffic.

Soil Aggregate Stability and Wind Erodibility

Composite soil samples were collected to a depth of 5 cm from 6 points within each plot for the soil aggregate analysis using a flat bottom shovel. A portion of the composite soil samples were subsampled for soil aggregates and were hand screened to obtain the 1-2 mm fraction. The 1-2mm fraction was separated into 2 portions; one of which was air dried and the other was refrigerated in small air tight plastic containers until they were analyzed. The remaining unscreened bulk samples were placed in plastic buckets, taken to a greenhouse and air-dried for wind erodible fraction (<0.84 mm) determination (Chepil, 1954).

Water Infiltration Rate

Water infiltration was conducted using 15.24 cm diameter aluminum single ring infiltrometer driven into the soil to a depth of 10 cm (Bouwer, 1986). Two rings were installed in each plot and were sealed along the inner wall with bentonite clay. The soil was covered with a circle of filter paper to prevent soil disturbance when adding water. Two liters of water were added to each ring followed by maintenance of at least 10 cm of water in each ring for 90 minutes to minimize errors due to lateral divergence of flow. Bouwer (1986) suggest the use of an infiltrometer with a diameter large enough that the ratio of critical pressure head to cylinder diameter is equal to 0; to eliminate the error associated with lateral divergence of flow. The soils at this site are coarse textured and thus have a high infiltration rate. Normally soil saturations for infiltration measurements take longer than 90 minutes to equilibrate on finer textured soils (Reynolds et al., 2002). These soils were considered to be near saturation when the filter paper on the soil surface at the bottom of the infiltrometer began to float (the hydraulic conductivity of the wetted zone equals depth of wetting front) and the soil surface surrounding the aluminum ring began to glisten due to upward wicking of water from the saturated zone. Lateral divergence due to capillary flow occurs when the pressure heads in the unsaturated soil adjacent to the infiltrometer are more negative than the pressure heads vertical to the infiltrometer (Bouwer, 1986). Field saturated hydraulic conductivity accuracy is increased with increasing the cylinder radius, decreasing depth of water ponding, increasing depth of ring insertion and increasing the macroscopic capillary length according to Reynolds et al. (2002). A 30 cm ruler was then placed in the rings and water depth readings were taken in millimeters (mm) at 10 minute intervals for a minimum of 6 readings over a 60 minute time period to determine the infiltration rate. Water was added as needed to maintain a 10 cm water head in the rings. The water utilized in the

infiltration study was from the well water system that supplies the irrigation system that is used to irrigate the plots. An analysis was conducted on a sample of the irrigation well water at the NDSU soil testing laboratory is reported in the Appendix. The electrical conductivity of the water was 984 umho/cm and the sodium adsorption ratio is 0.21; these values show that the water is suitable for irrigation and will not negatively impact the soil.

Laboratory Methods

Bulk density, texture, organic matter, total C, aggregate stability, nitrogen availability indexes and wind erodible fraction were determined in the laboratory. These are described in the following subsections.

Bulk Density

Bulk density was determined on the cores collected with hydraulic probe. The ratio of the mass of dry solids to the bulk volume of the soil, known as the bulk density, was determined using the core method as described by Blake and Hartge (1965). The oven dried weight of each depth increments (0-10, 10-20 and 20-30 cm) was divided by its volume to determine the bulk density values. These values for each treatment per block were averaged and are presented in the Appendix. Since the soils were sampled to a depth of 1 m using a Giddings hydraulic probe, with plastic core liners, attempts were made to collect bulk density data on all depths. However, sandy soils are difficult to sample for bulk density by the core method at the lower depths due to compaction during sampling. Only the bulk density values for the 0-30 cm depths were unaffected by compaction based on data revisions and thus only these are reported for this study.

Total C

The composite soil samples from the core samples divided into their respective depth intervals were air dried and crushed to pass a 2 mm sieve. A 10 g subsample was milled with a ball carborundum media to pass 100-mesh screen for C analysis by high combustion (1000 $^{\circ}$C) (Cihacek and Jacobson, 2007). Carbon analysis was performed with a Skalar Primacs^{TM} solid carbon analyzer. The soil total C determinations for each plot (%C x B.D) were taken to a depth of 30 cm were summed up for the 3 depth increments. Although soils were sampled to either 0.6 or 1 m for soil C determinations, unreliable bulk density data below 30 cm for calculating the soil C values resulted in the reporting of soil C only to a 30 cm depth.

Inorganic C

Inorganic C on the 2008 samples were performed by release of CO_2 by phosphoric acid addition using a Skalar Primacs^{TM} instrument. The 2011 and 2013 inorganic C in soils was determined on the subsamples prepared for the total C by the method of Williams (1948). The inorganic C was subtracted from the total C determinations to derive the organic C determinations per plot.

Aggregate Stability

The cohesive forces between particles allows a groups of particles to cohere to each other. When a disruptive force is applied to aggregates and if the aggregate does not experience failure, the aggregate is considered to be stable. The air-dry aggregates were air-dried with minimum disturbance before wet sieving for stability determination. The wet aggregate stability samples were collected and stored in plastic containers with refrigeration to retain field moisture conditions. Both the air-dried and field moist aggregate samples were wet using a modified

vaporizer as described by Kemper and Rosenau (1986) to decrease disintegration by ion hydration and osmotic swelling forces. The stable fraction of the aggregates were determined using the method of Kemper and Rosenau (1986). The stability values are based on the average of analysis of four subsamples on each plot sample.

Particle Size Analysis

The particle size analysis (PSA) (Table 2) was determined by the hydrometer method of Gee and Bauder (1986). Volumetric samples of 10 g using an NCERA-059 standard 10g dipper were composited from the 0-20 cm depths of the core samples, from the 0% stover removal treatment on the 2013 samples. The use of the 10 g dipper was to get the subsample across the plot areas as homogenous as possible with proportional representation of soils over the plot area. A separate analysis was made for each of the three plot areas (continuous corn; corn/corn-soybean; soybean/corn-soybean). The PSA results are shown in Table 2.

Table 2. Particle size analysis of the 0% residue removal treatment during 2013

Plots	Depth (cm)	Particle size analysis †			Soil Texture
		Percent sand	Percent silt	Percent clay	
Continuous corn	0-20	70.3	20.3	9.4	Sandy
Corn/soybean 1 ‡	0-20	70.1	21.7	8.2	Sandy
Corn/soybean 2 §	0-20	78.5	16.4	5.1	Loamy

†PSA determined by the hydrometer method. (Gee and Bauder, 1986)
‡ Corn phase during 2013
§ Soybean phase during 2013

Nitrogen Availability Indexes

A biological estimation of the mineral-N formed under incubation conditions that promote mineralization of soil-N were determined utilizing a 14 day incubation at 25 °C of the 0-10 cm core samples (Keeney and Bremner, 1966). The available NH_4^+N and NO_3^-N in incubated samples was determined by steam distillation method described Bremner (1965). Analysis was

done on samples at day 0 and day 14 and the values reported are the difference between initial N values and N value after incubation.

Wind Erodible Fraction

Approximately 500g of the air dried bulk soil samples was accurately weighed and placed on a rocker sieve with a 0.84 mm screen. The sieve was oscillated 30 times over a two minute time period and the soil that passed through the screen and residual soil on the screen were weighed to determine the mass of the separate fractions. The wind erodible fractions were then calculated according to the methodology of Chepil (1954).

Irrigation Water Evaluation

A 16 oz. sample of irrigation water was collected in a plastic bottle and evaluated by the North Dakota State University Soil Testing Laboratory for electrical conductivity and SAR. The results of this irrigation water evaluation is available in the Appendix. This water was used for determination of water infiltration rates of the various treatments.

Statistical Methods

Analysis of variance of the data for determination of significant differences was conducted using the PROC ANOVA routine with least significant difference (LSD) determination at $P \leq 0.05$ using SAS version 9.3 (SAS Institute, 2010).

Crop Cultivation Methods

The corn and soybean crops were managed by the staff of the Oakes Research Station (ORS) and the Carrington Research and Extension Center (CREC) based on their standards and protocols. Agronomic data collected by the ORS and CREC personnel are presented in the

Appendix. Other data can be found at Oakes irrigation research site: (http://www.ag.ndsu.nodak.edu/oakes/oakes.htm) with their annual reports under the Optimum corn stover removal for bio-fuel and the environment sections.

RESULTS AND DISCUSSION

Wind Erodible Fraction

Results for the wind erodible aggregate fraction, field-moist and air-dry water stable aggregate fraction and water infiltration rates as influenced by stover removal treatment are shown in Table 3 (continuous corn), Table 4 (corn/corn-soybean), and Table 5 (soybean/corn-soybean). The wind erodible fraction or the fraction of soil aggregates and individual particles is that portion of the soil that is subject to wind detachment and displacement. Generally, these aggregates and particles are sand sized or smaller (<0.84 mm) and are easily detachable when the soils are dry. Within the continuous corn plots, the fraction of wind erodible aggregates and particles was lowest for the 0 % stover removal rate (25.4 %) and highest for the 100 % stover removal rate (36.6 %). The corn-corn/soybean plots during 2013 plots showed no significant differences between stover removal treatments that were observed for the wind erodible fraction of aggregates and particles. Within the soybean-corn/soybean plots there were no significant differences between stover removal treatments for the wind erodible fraction. However, there did appear to be a slight trend for an increase in the wind erodible fraction as the stover removal rate increased. These results are likely due both to quicker drying of the relatively bare soil for the 100 % removal rate as well as the lack of protective cover and decreased surface roughness due to the removal of stover covering the soil surface. There may also be a difference in the organic matter composition which acts as a binding agent for soil particles when the surface stover is reduced. Determining the composition of the organic matter was beyond the scope of this study. The trend observed when reside was removed and the soil surface was less protected in regards to the increase within the wind erodible fraction was similar to the findings of Osborne et al. 2014.

Field-Moist and Air-dry Aggregate Stability

Field-moist aggregate stability represents the potential for soil aggregate dispersion due to wetting (e.g. rainfall) when the soils are in a "as-is" condition in the field. Air-dry aggregate stability represents the potential for soil aggregate dispersion when soils dry out in a field environment. The difference between these two types of stability is influenced by a number of factors of which physical wetting and drying forces can break up aggregates. There was a significant reduction of field-moist aggregate stability for the continuous corn plots when 100 % removal rate is compared with the 0 % rate (48.3 % vs. 58.7 %, respectively) (Table 3). The 33% and 67 % removal rates were intermediate to the 0 % and 100 % rates. The corn/corn-soybean and soybean-corn/soybean plots indicated no significant differences in field-moist and air-dry aggregate stability due to corn stover removal (Table 4). These research result supports the concepts of the Skidmore et al. 1986; Karlen et al. 1994; Blanco-Canqui et al. 2009; Jin et al. 2015; and Osborne et al. 2015, that failure to manage enough stover on the soil surface in plots without cover crops limits the materials that can be produced for soil aggregation, thus creating the conditions experienced with an increase in aggregation attributed to increased stover remaining on the soil surface.

Water Infiltration Rate

Water infiltration rate within the continuous corn plots showed a significant decline as the corn stover removal rate increased (Table 3). The infiltration rate for the 100 % stover removal rate was 38 % of the 0 % removal rate. Corn/corn-soybean plots indicated that the removal of corn stover, although done on an alternating year basis, significantly reduced the water infiltration rate (Table 4). The water infiltration rate for the 100 % stover removal treatment was 64 % of the control treatment. There were no significant differences observed in the water

infiltration rates for the stover removal treatments within the soybean/corn-soybean plots. However, the water infiltration rate for the 100 % stover removal treatment was 81 % of the control treatment.

Table 3. Wind erodible fraction, water stable aggregate fractions and water infiltration rates as influenced by corn stover removal rates for the continuous corn

Stover Removal Treatment	Wind Erodible Fraction	Water Stable Aggregates		Infiltration Rate
		Field Moist	Air-dry	
	----------%----------			-cm/hr-
0	25.4 a†	58.7 a	89.5 a	22.4 a
33	36.9 a	54.6 b	84.9 a	12.6 b
67	35.5 ab	55.5 a	81.7 a	13.8 bc
100	35.5 a	48.3 b	82.2 a	8.6 c

†Values followed by the same letter are not significantly different at $P \geq 0.05$.

Table 4. Wind erodible fraction, water stable aggregate fractions and water infiltration rates as influenced by corn stover removal rates for the corn phase 2013-corn-soybean rotation

Stover Removal Treatment	Wind Erodible Fraction	Water Stable Aggregates		Infiltration Rate
		Field Moist	Air-dry	
	----------%----------			-cm/hr-
0	35.1 a†	52.0 a	83.1 a	16.8 a
33	43.6 a	51.4 a	84.2 a	11.6 b
67	35.5 a	53.6 a	82.1 a	11.9 ab
100	47.1 a	50.6 a	82.9 a	10.8 b

†Values followed by the same letter are not significantly different at $P \geq 0.05$.

Table 5. Wind erodible fraction, water stable aggregate fractions and water infiltration rates as influenced by corn stover removal rates for the soybean phase 2013-corn-soybean rotation

		Water Stable Aggregates		
Stover Removal Treatment	Wind Erodible Fraction	Field Moist	Air-dry	Infiltration Rate
	----------%----------			-cm/hr-
0	40.2 a†	63.9 a	88.1 a	16.4 a
33	44.7 a	60.2 a	84.4 b	15.9 a
67	48.8 a	67.2 a	84.9 b	16.7 a
100	46.7 a	56.7 a	77.7 c	13.3 a

†Values followed by the same letter are not significantly different at $P \geq 0.05$.

Soil Organic Carbon (SOC)

Soil organic carbon (SOC) data including initial and final SOC mass and change in mass are shown in Table 6 (continuous corn), Table 7 (corn/corn-soybean), and Table 8 (soybean/corn-soybean). The SOC mass (adjusted for soil bulk density) increased from the initiation of the plots in 2008 to the final sampling in 2013. Soil OC mass is a more precise way of expressing changes in SOC because it is adjusted for treatment effects that affect soil bulk density. The SOC mass frequently identifies subtle changes in SOC that regular analysis for percent (%) C does not pick up. Significant differences were observed for the continuous corn plots that appear to be partially related to soil variability at the beginning of the study. The trends between treatments at the initiation of the study in 2008 (prior to stover removal) appear to be reflected in the 2013 data. Significant differences in the SOC change tend to reflect the soil variability more than stover removal treatments.

Corn-corn/soybean plot area appears to have more uniform soils as compared to the data shown for the continuous corn plots (Table 7). There were no significant differences between the

stover removal treatments for both the initial and final samplings. However, there were significant differences between the 0 % and 100 % stover removal rates for SOC mass change. The 0 % removal treatment had the greatest change while the 100 % removal treatment had the least change. The levels of SOC and SOC change for the 2013 sampling do not appear to be in as great a magnitude as for the continuous corn because the total amount of plant biomass (most of which comes from corn) is less than for continuous corn plots. Thus, the potential for increasing SOC in a corn-soybean rotation system is lower. Soybean-corn/soybean plots trends toward more coarse sand in the sand fraction of the soil which may influence the soil's ability to accrete and store SOC. Differences in SOC for the initial (2008) sampling date which occurred prior to application of the stover removal treatments tends to support this idea. However, there were no significant differences in the SOC mass for the final sampling date (2013). The SOC mass changes as influenced by stover removal treatment were very low and not statistically different from each other. There was a trend, however, to lower levels of SOC mass change for the higher stover removal rates. The soybean phase of the corn-soybean rotations has the lowest total overall plant biomass input due to the lower frequency of corn during the five years previous to the 2013 sampling.

This study differs by the impact stover removal have on SOC compared to previous studies. Schmer et al. 2014 researched tillage and stover management effects on SOC under irrigated continuous corn on silt loam textured soils. There were no change identified in the SOC within the 0-15 cm depths from 2001 to 2010 in the no-tillage plots. Within the low stover removal treatment in the no-tillage plots there was an increase in SOC stocks, the medium stover removal there was not a change with time and the high stover removal experienced a decline in SOC stocks. When compared to Schmer et al. (2014), this study showed increases in SOC from

2008 to 2013 among the treatments. This may be influenced by low initial SOC level and the soils having a high C storage capacity according to Jin et al. 2015; who also investigated a no-tillage site with systematic stover removal in continuous corn response to N-fertilizer applications. This study also resulted in an increase in SOC within the 0-30 cm depth after 12 years. Overall, SOC changes are dependent on stover removal rate and soil type (Blanco-Canqui and Lal, 2009; Osborne et al., 2015).

Table 6. Initial and final soil organic carbon (SOC) masses in the surface foot of the soil at the initiation of the study (2008), the final year of the evaluation period (2013) and the change over 5 years of continuous corn

Residue Removal Treatment	Soil Organic Carbon Mass		
	2008	2013	Change
---%---	--------kg/m^2/30 cm---------		
0	5.97 b[‡]	8.59 bc	2.62 ab
33	4.87 a	6.80 a	1.93 a
67	5.76 b	8.84 c	3.08 b
100	5.49 ab	7.63 ab	2.20 ab

[†]Change = 2013 SOC mass – 2008 SOC mass.
[‡] Values followed by the same letter are not significantly different at $P \geq 0.05$.

Table 7. Initial and final soil organic carbon (SOC) masses in the surface foot of the soil at the initiation of the study (2008), the final year of the evaluation period (2013) and the change over 5 years in the corn phase 2013-corn-soybean rotation

Residue Removal Treatment	Soil Organic Carbon Mass		
	2008	2013	Change
---%---	--------kg/m^2/30 cm---------		
0	4.82 a[†]	7.29 a	2.47 b
33	4.41 a	6.22 a	1.81 ab
67	4.86 a	7.03 a	2.17 ab
100	5.04 a	6.02 a	0.96 a

[†]Values followed by the same letter are not significantly different at $P \geq 0.05$.

Table 8. Initial and final soil organic carbon (SOC) masses in the surface foot of the soil at the initiation of the study (2008), the final year of the evaluation period (2013) and the change over 5 years in the soybean phase 2013-corn-soybean rotation

Residue Removal Treatment	Soil Organic Carbon Mass		
	2008	2013	Change
----%----	----------kg/m^2/30 cm----------		
0	3.39 a†	4.04 a	0.65 a
33	3.46 a	4.20 a	0.74 a
67	4.04ab	4.24 a	0.10 a
100	4.63 b	4.66 a	0.22 a

†Values followed by the same letter are not significantly different at $P \geq 0.05$.

Soil N Mineralization Potential

Potential soil N mineralization for the surface 0-10 cm depth are shown in Table 9 (continuous corn), Table 10 (corn/corn-soybean), and Table 11 (soybean/corn-soybean), the values reported here were corrected for the initial soil NH_4-N and NO_3-N prior to incubation. This measure is a proxy index for the microbiological activity as affected by corn stover removal as well as an index of a component of soil health. All plots did not have a significant ammonium-N (NH_4-N) and nitrate-N (NO_3-N) mineralization treatment affect. The NH_4-N mineralization was very low and the NO_3-N was substantially higher which may be due to the repeated crop planting allowing the microbiological community to mature and adapt to the environment unlike the corn/soybean rotation plots. The mineralized NH_4-N in the soybean-corn/soybean plots is higher than the continuous corn or the corn phase of the corn-soybean rotation possibly due to higher N enriched fresh soybean crop stover on the soil at the time of the 2013 sampling. Mineralized NO_3-N was somewhat higher in the soybean phase than for the corn phase; again likely to be related to the presence of soybean stover on the soil. The soybeans were harvested

earlier than the corn and the soybean stover was on the soil surface longer than the corn stover. Several fall rains may have leached nitrogenous compounds into the soil which were likely mineralized during the incubations. Although the soil microbiological counts weren't conducted like Doran's (1980) investigation, this study also indicates that there probably are changes in microbial ecology associated with systematic stover management due to the varied mineralized NO3-N levels observed.

Table 9. Effects of corn stover removal on potential mineralizable ammonium- and nitrate-N after fourteen days of incubation for the surface soil (0-10 centimeters) of continuous corn

Stover Removal Treatment	Mineralizable N	
	NH_4-N	NO_3-N
----%----	----------ppm----------	
0	0.17 a†	18.7 a
33	0.00 a	12.8 a
67	0.14 a	20.6 a
100	0.11 a	13.2 a

†Values followed by the same letter are not significantly different at $P \geq 0.05$.

Table 10. Effects of corn stover removal on mineralizable ammonium- and nitrate-N after fourteen days of incubation for the surface soil (0-10 centimeters) of the corn phase 2013 - corn-soybean rotation

Stover Removal Treatment	Mineralizable N	
	NH_4-N	NO_3-N
----%----	----------ppm----------	
0	0.04 a†	2.56 a
33	0.04 a	0.04 a
67	0.00 a	4.63 a
100	0.00 a	4.30 a

†Values followed by the same letter are not significantly different at $P \geq 0.05$.

Table 11. Effects of corn stover removal on mineralizable ammonium- and nitrate-N after fourteen days of incubation for the surface soil (0-10 centimeters) of the soybean phase 2013-corn-soybean rotation

Stover Removal Treatment	Mineralizable N	
	NH_4-N	NO_3-N
----%----	----------ppm----------	
0	3.63 a†	0.50 a
33	4.39 a	2.99 a
67	7.43 a	4.05 a
100	5.03 a	4.10 a

†Values followed by the same letter are not significantly different at $P \geq 0.05$.

SUMMARY AND CONCLUSIONS

The results of this study located on an area of potentially fragile soils from an erosion standpoint, generally, gave mixed results for all of the factors studied. Differences in soil physical properties appeared to be most pronounced on the continuous corn plots. Evaluating effects of corn stover removal after five years of applied treatments is probably the shortest time frame over which to conduct a study such as this. Soils have some level of inherent resilience which resists change when management or inputs change. Changing inputs, management or agronomic conditions often require at least 3 to 5 years in order to create enough change in the soil so that the effects can be measured. This study encompassed a minimum time period of systematic stover removal research due to its irrigated conditions which maintains a high level of crop productivity. In addition, this study is on sandy soils, whereas, most other studies were on loams, silt loams, or clay loams.

In summary, five years of stover removal in a continuous corn system increased the wind erodible fraction and decreased field-moist aggregate stability and water infiltration rate. However, it had very little effect on SOC changes and N mineralization. For the corn phase in a corn-soybean rotation, stover removal decreased water infiltration rate, and appeared to decrease the magnitude of SOC change. Again, N mineralization did not appear to be affected by stover removal. For the soybean phase in a corn-soybean rotation, air-dry water stable aggregates were decreased. Although SOC change appeared to decrease with stover removal, the changes were small and not significant.

This study also agrees with Blanco-Canqui (2009), where further long-term studies are needed to evaluate the real impacts of changing management on the soil to advance upon the existing near-term (< 5 years) investigations. From the information obtained in this study and

others already published, short-term effects appear to be minor but longer-term studies may be required to identify the lasting impacts of management. The treatments of this study site will be continued into the future and the study parameters that were reported here should be revaluated again in another 3 to 5 years.

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APPENDIX

Continuous Corn

Border 18 rows	401 0%	402 67%	403 33%	404 100%
	301 67%	302 100%	303 0%	304 33%
	201 33%	202 67%	203 100%	204 0%
Border 18 rows	101 100%	102 0%	103 67%	104 33%

North

East

Corn phase 2013 – corn-soybean rotation

Border 18 rows	401 100%	402 33%	403 0%	404 67%
	301 0%	302 67%	303 100%	304 33%
	201 33%	202 0%	203 67%	204 100%
Border 18 rows	101 67%	102 100%	103 0%	104 33%

North

East

Soybean phase 2013 – corn-soybean rotation

Border 18 rows	401 0%	402 67%	403 33%	404 100%
	301 67%	302 100%	303 0%	304 33%
	201 33%	202 67%	203 100%	204 0%
Border 18 rows	101 100%	102 0%	103 67%	104 33%

North

East

Figure A1. The experimental design

LABORATORY ANALYSIS :

pH:	7.5		Sodium Adsorption Ratio (SAR):	0.21
Electrical Conductivity (EC):	984	umho / cm	SAR Adjusted for high bicarbonates (SARadj):	0.29
Total Dissolved Solids (TDS):	1250	mg/L	Residual Sodium Carbonate (RCS):	-12.1
Hardness (mg/L CaCO3):	861			

Cations :	meq/L	mg/L (ppm)	Anions :	meq/L	mg/L (ppm)
Calcium (Ca) :	12.77	256	Carbonates (CO3) :	0.00	0
Magnesuim (Mg) :	4.44	54	Bicarbonates (HCO3) :	5.08	310
Sodium (Na) :	0.61	14	Chlorides (Cl) :	0.28	10
Potassium (K) :	0.08	3	Sulfates (SO4) :	12.55	603

Figure A2. Irrigation water analysis

Table A1. Soil infiltration, soil moist and dry aggregate stable fraction, gravimetric H2O, Soil wind erodible fraction

Block	Treatment	Infiltration	Moist Stable fraction	Air Dried Stable fraction	Gravimetric H_2O	Mineralized NH_4N	Mineralized NO_3N	Wind erodible fraction (<0.84 mm)
		(cm/hr)	——————— —%	———————	———	(ppm)	(ppm)	%
1	100	8.76	0.49	0.84	12.64	0.00	7.15	0.3834
1	67	16.53	0.58	0.79	18.80	0.00	39.71	0.3449
1	33	10.14	0.57	0.90	11.68	0.00	5.08	0.3286
1	0	22.53	0.67	0.96	13.35	0.07	9.24	0.218
1	100	11.22	0.47	0.89	13.11	0.00	15.93	0.2486
1	67	13.26	0.56	0.88	14.49	0.00	8.73	0.3191
1	33	16.11	0.55	0.83	12.89	0.00	12.23	0.2833
1	0	26.58	0.52	0.89	14.22	0.61	20.33	0.2432
1	100	8.25	0.50	0.73	12.44	0.43	19.06	0.4346
1	67	13.8	0.51	0.74	10.61	0.00	12.04	0.3383
1	33	12.3	0.44	0.79	13.74	0.00	25.26	0.3809
1	0	21.27	0.49	0.84	12.79	0.00	12.26	0.2882
1	100	6.03	0.47	0.84	8.58	0.00	10.73	0.3964
1	67	11.67	0.56	0.86	10.59	0.53	21.77	0.3379
1	33	11.85	0.62	0.88	7.92	0.00	8.73	0.4832
1	0	19.35	0.67	0.90	10.31	0.00	32.89	0.2672
2	100	9.51	0.54	0.84	13.78	0.00	10.34	0.3684
2	67	13.44	0.50	0.80	14.02	0.00	0.51	0.3017
2	33	10.02	0.44	0.81	14.26	0.18	0.18	0.3623
2	0	13.74	0.48	0.87	9.91	0.00	0.00	0.3088
2	100	14.82	0.51	0.82	13.94	0.00	4.86	0.4479
2	67	8.07	0.54	0.87	14.53	0.00	4.80	0.3623
2	33	13.41	0.50	0.90	11.40	0.00	0.00	0.3953
2	0	22.11	0.55	0.88	11.00	0.18	8.40	0.3313
2	100	8.43	0.51	0.85	14.39	0.00	1.99	0.5789
2	67	15.66	0.56	0.76	11.07	0.00	8.91	0.4223
2	33	12.09	0.57	0.80	12.84	0.00	0.00	0.5755
2	0	19.56	0.54	0.71	12.69	0.00	0.42	0.3711
2	100	10.35	0.47	0.81	11.13	0.00	0.00	0.491
2	67	10.62	0.55	0.86	11.39	0.00	4.30	0.3333
2	33	10.74	0.54	0.86	13.37	0.00	0.00	0.4108
2	0	11.91	0.51	0.87	10.31	0.00	1.43	0.3939
3	100	20.67	0.56	0.72	8.71	5.91	7.12	0.452
3	67	19.74	0.67	0.90	6.14	12.89	9.96	0.4267
3	33	14.19	0.57	0.80	9.62	7.86	0.00	0.3808
3	0	14.49	0.63	0.87	5.35	2.15	0.00	0.4393
3	100	10.71	0.67	0.79	11.76	5.96	3.61	0.4103
3	67	15.48	0.64	0.82	6.21	6.53	1.34	0.44
3	33	12.39	0.69	0.87	4.43	5.19	0.00	0.4875
3	0	10.56	0.57	0.87	49.52	8.06	0.00	0.3075
3	100	8.82	0.46	0.79	8.23	7.19	5.65	0.4652
3	67	12.57	0.65	0.82	9.12	6.56	4.88	0.5943
3	33	32.25	0.60	0.88	6.75	1.51	10.52	0.5243
3	0	19.11	0.61	0.88	6.87	2.69	1.99	0.434
3	100	12.9	0.58	0.81	11.24	1.07	0.00	0.5437
3	67	19.23	0.52	0.86	10.51	3.76	0.00	0.4922
3	33	4.8	0.55	0.83	10.26	3.00	1.42	0.3972
3	0	21.33	0.75	0.90	9.82	1.61	0.00	0.4294

Table A2. Continuous corn bulk densities and soil organic carbon mass for three years during the study

Plot	Depth	Residue Removal Treatment	Bulk Density Mean	Soil Organic Carbon Mass		
				2008	2011	2013
		--------	--------(g/cm^3)----------	----------(kg/m^2)----------		----
101	0-4	100	1.50	1.993	2.743	3.277
101	4-8	100	1.58	1.842	2.536	2.954
101	8-12	100	1.70	1.705	1.295	2.902
102	0-4	0	1.70	2.608	3.375	3.496
102	4-8	0	1.53	2.083	3.358	3.404
102	8-12	0	1.65	1.967	2.934	2.85
103	0-4	67	1.48	1.892	2.240	2.857
103	4-8	67	1.73	1.996	2.918	4.57
103	8-12	67	1.79	1.842	3.128	2.401
104	0-4	33	1.49	1.748	2.316	2.831
104	4-8	33	1.58	1.494	2.007	2.617
104	8-12	33	1.65	1.184	1.760	2.716
201	0-4	33	1.49	1.801	2.225	2.437
201	4-8	33	1.58	1.636	2.071	2.312
201	8-12	33	1.65	1.423	1.559	1.777
202	0-4	67	1.48	1.955	2.421	2.992
202	4-8	67	1.73	2.231	2.462	3.217
202	8-12	67	1.79	2.252	1.346	3.110
203	0-4	100	1.50	1.980	2.682	2.972
203	4-8	100	1.58	2.003	2.44	2.745
203	8-12	100	1.70	2.067	1.313	2.193
204	0-4	0	1.70	2.316	2.458	3.513
204	4-8	0	1.53	1.832	2.394	2.845
204	8-12	0	1.65	1.709	2.079	2.414
301	0-4	67	1.48	1.729	2.421	3.143
301	4-8	67	1.73	1.830	2.865	2.847
301	8-12	67	1.79	1.696	2.692	2.582
302	0-4	100	1.50	2.012	2.515	2.682
302	4-8	100	1.58	1.83	1.91	2.344
302	8-12	100	1.70	1.658	2.055	2.370
303	0-4	0	1.70	2.178	2.838	3.496
303	4-8	0	1.53	1.776	2.503	2.083
303	8-12	0	1.65	1.721	1.878	2.632
304	0-4	33	1.49	1.696	1.347	1.817
304	4-8	33	1.58	1.74	2.633	2.151
304	8-12	33	1.65	1.755	2.213	1.458
401	0-4	0	1.70	2.153	2.042	3.842
401	4-8	0	1.53	1.78	2.394	2.098
401	8-12	0	1.65	1.754	2.246	1.693
402	0-4	67	1.48	1.738	2.376	2.391
402	4-8	67	1.73	1.947	2.584	2.724
402	8-12	67	1.79	1.927	2.401	2.580
403	0-4	33	1.49	1.944	2.256	2.619
403	4-8	33	1.58	1.69	3.259	2.520
403	8-12	33	1.65	1.377	2.534	1.961
404	0-4	100	1.50	1.748	1.661	2.286
404	4-8	100	1.58	1.613	2.793	2.007
404	8-12	100	1.70	1.489	2.746	2.004

Table A3. Corn phase 2013 – corn-soybean rotation bulk densities and soil organic carbon mass for three years during the study

Plot	Depth	Residue Removal Treatment	Bulk Density Mean	Soil Organic Carbon Mass		
				2008	2011	2013
		--------	--------(g/cm^3)----------	----------(kg/m^2)----------		
101	0-4	67	1.5	1.993	2.76	2.835
101	4-8	67	1.59	1.876	2.97	3.15
101	8-12	67	1.5	1.547	1.55	2.438
102	0-4	100	1.65	2.223	3.49	3.185
102	4-8	100	1.54	1.884	2.47	2.175
102	8-12	100	1.6	1.758	0.31	2.195
103	0-4	0	1.62	1.913	3.61	2.716
103	4-8	0	1.5	1.529	1.97	2.042
103	8-12	0	1.54	1.320	1.00	2.034
104	0-4	33	1.46	1.380	2.52	2.269
104	4-8	33	1.55	1.236	2.28	2.031
104	8-12	33	1.6	1.038	1.67	0.992
201	0-4	33	1.46	1.896	2.42	2.655
201	4-8	33	1.55	1.746	2.38	2.173
201	8-12	33	1.6	1.527	1.71	2.325
202	0-4	0	1.62	2.049	3.06	2.88
202	4-8	0	1.5	1.737	2.47	2.53
202	8-12	0	1.54	1.619	2.21	2.613
203	0-4	67	1.5	1.697	2.82	2.377
203	4-8	67	1.59	1.531	2.68	2.472
203	8-12	67	1.5	1.192	2.26	1.737
204	0-4	100	1.65	1.880	3.27	2.565
204	4-8	100	1.54	1.441	2.36	0.485
204	8-12	100	1.6	1.170	1.66	1.187
301	0-4	0	1.62	1.847	3.06	2.847
301	4-8	0	1.5	1.528	1.97	2.195
301	8-12	0	1.54	1.382	1.00	2.222
302	0-4	67	1.5	1.865	2.59	2.606
302	4-8	67	1.59	1.786	2.70	2.407
302	8-12	67	1.5	1.504	2.21	0.945
303	0-4	100	1.65	2.119	3.05	2.632
303	4-8	100	1.54	1.665	2.64	1.737
303	8-12	100	1.6	1.404	2.76	0.862
304	0-4	33	1.46	1.572	2.43	2.433
304	4-8	33	1.55	1.521	0.41	2.22
304	8-12	33	1.6	1.417	1.38	1.723
401	0-4	100	1.65	1.799	2.62	2.766
401	4-8	100	1.54	1.500	2.44	2.378
401	8-12	100	1.6	1.372	2.16	1.902
402	0-4	33	1.46	1.723	2.40	2.625
402	4-8	33	1.55	1.455	1.83	1.965
402	8-12	33	1.6	1.115	0.83	1.447
403	0-4	0	1.62	1.812	2.83	2.65
403	4-8	0	1.5	1.398	2.30	2.393
403	8-12	0	1.54	1.118	2.02	2.05
404	0-4	67	1.5	1.696	2.39	2.484
404	4-8	67	1.59	1.535	2.33	2.633
404	8-12	67	1.5	1.201	1.86	2.027

Table A4. Soybean phase 2013 – corn-soybean rotation bulk densities and soil organic carbon mass for three years during the study

Plot	Depth	Residue Removal Treatment	Bulk Density Mean	Soil Organic Carbon Mass		
				2008	2011	2013
		----------	--------(g/cm^3)----------	----------(kg/m^2)----------		
101	0-4	100	1.64	2.179	2.033	2.000
101	4-8	100	1.53	1.649	1.897	1.825
101	8-12	100	2.12	1.753	1.960	1.852
102	0-4	33	1.58	1.338	1.718	1.589
102	4-8	33	1.63	1.277	0.613	1.557
102	8-12	33	1.71	1.232	2.050	1.425
103	0-4	0	1.54	1.206	1.705	1.580
103	4-8	0	1.59	1.186	1.486	1.341
103	8-12	0	1.66	1.176	1.400	1.130
104	0-4	67	1.5	1.060	0.198	1.143
104	4-8	67	1.58	1.091	1.477	0.995
104	8-12	67	2.08	1.402	2.198	0.824
201	0-4	0	1.54	1.377	1.158	1.878
201	4-8	0	1.59	1.231	1.874	1.551
201	8-12	0	1.66	1.086	1.771	0.961
202	0-4	100	1.64	1.440	1.816	1.433
202	4-8	100	1.53	1.162	1.415	1.275
202	8-12	100	2.12	1.354	1.357	0.754
203	0-4	67	1.5	1.164	1.082	1.417
203	4-8	67	1.58	1.052	1.637	1.124
203	8-12	67	2.08	1.157	1.754	0.972
204	0-4	33	1.58	0.998	1.381	1.541
204	4-8	33	1.63	0.993	1.242	1.242
204	8-12	33	1.71	0.963	1.598	0.869
301	0-4	100	1.64	1.470	1.583	1.899
301	4-8	100	1.53	1.228	2.021	1.352
301	8-12	100	2.12	1.490	2.132	1.745
302	0-4	67	1.5	1.410	1.768	1.890
302	4-8	67	1.58	1.333	1.557	1.814
302	8-12	67	2.08	1.547	1.205	2.198
303	0-4	33	1.58	1.076	1.926	1.685
303	4-8	33	1.63	1.043	2.004	1.143
303	8-12	33	1.71	1.023	0.792	1.007
304	0-4	0	1.54	1.069	1.768	1.142
304	4-8	0	1.59	0.975	1.357	1.034
304	8-12	0	1.66	0.883	0.438	1.990
401	0-4	33	1.58	1.405	1.525	1.108
401	4-8	33	1.63	1.304	0.712	1.789
401	8-12	33	1.71	1.215	0.903	1.859
402	0-4	0	1.54	1.282	1.408	1.017
402	4-8	0	1.59	1.128	0.630	1.535
402	8-12	0	1.66	0.900	0.573	0.995
403	0-4	100	1.64	1.389	1.300	1.500
403	4-8	100	1.53	1.181	0.606	0.979
403	8-12	100	2.12	1.497	14.754	2.046
404	0-4	67	1.5	1.239	0.457	1.676
404	4-8	67	1.58	1.109	0.495	1.525
404	8-12	67	2.08	1.202	0.592	1.395

Table A5. Continuous corn bulk density bulk density averages

Treatment	Depth		
	0-4	4-8	8-12
	———	g/cm^3	———
0	1.49 ± 0.20	1.92 ± 0.69	1.82 ± 0.58
33	2.50 ± 0.62	1.39 ± 0.18	1.58 ± 0.06
67	1.41 ± 0.07	1.58 ± 0.16	1.82 ± 0.44
100	1.40 ± 0.08	1.58 ± 0.07	1.70 ± 0.06

Table A6. Corn phase 2013 – corn-soybean rotation bulk density averages

Treatment	Depth		
	0-4	4-8	8-12
	———	g/cm^3	———
0	1.62 ± 0.07	1.41 ± 0.17	1.54 ± 0.05
33	1.41 ± 0.08	1.47 ± 0.14	1.60 ± 0.09
67	1.56 ± 0.14	1.52 ± 0.11	1.93 ± 0.46
100	1.76 ± 0.80	1.58 ± 0.13	1.59 ± 0.06

Table A7. Soybean phase 2013 – corn-soybean rotation bulk density averages

Treatment	Depth		
	0-4	4-8	8-12
	———	g/cm^3	———
0	1.63 ± 0.13	1.91 ± 0.49	1.92 ± 0.41
33	1.57 ± 0.15	1.56 ± 0.06	1.61 ± 0.22
67	1.86 ± 0.55	1.60 ± 0.08	1.64 ± 0.22
100	1.73 ± 0.18	1.79 ± 0.37	2.05 ± 0.90

Table A8. Corn yields for continuous corn †

Residue Removal Treatment	Crop Year				
	2009	2010	2011	2012	2013
---%---	----------bu/ac----------				
0	199.5	220.1	193.8	258.9	218.1
33	205.8	217.8	189.9	265.8	219.8
67	206.2	215.0	207.5	257.8	221.6
100	209.4	211.1	204.9	260.1	221.4

†Data from North Dakota State University Oakes irrigation research site yields were only taken on corn crops.

Table A9. Corn yields for corn phase 2013– corn soybean rotation†

Residue Removal Treatment	Crop Year				
	2009	2010	2011	2012	2013
	----------bu/ac----------				
---%---			--		
0			205.1		241.3
33			183.7		247.3
67			200.6		243.1
100			196.9		247.5

†Data from North Dakota State University Oakes irrigation research site yields were only taken on corn crops.

Table A10. Corn yields for soybean phase 2013 – corn soybean rotation†

Residue Removal Treatment	Crop Year				
	2009	2010	2011	2012	2013
---%---	----------bu/ac----------				
0		219.4		261.2	
33		214.7		257.7	
67		213.1		252.8	
100		213.0		256.6	

†Data from North Dakota State University Oakes irrigation research site yields were only taken on corn crops.