CROP RESIDUE MANAGEMENT AND ITS IMPACTS ON SOIL PROPERTIES

by

YUXIN HE

B.E. China Agricultural University, 2007
M.S. Bemidji State University, 2010

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Agronomy
College of Agriculture

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Abstract

Crop residue removal for livestock feeding and biofuel production at large scales must be evaluated to assess impacts on soil productivity and properties. Among all the potential negative impacts, wind erosion is a major concern in the central Great Plains. We conducted an on-farm study from 2011 to 2013 by removing crop residue at five levels (0, 25, 50, 75, and 100%) to determine the effects of crop residue removal on soil wind erosion parameters such as dry aggregate size distribution including soil wind erodible fraction (EF <0.84 mm aggregates), geometric mean diameter (GMD) and geometric standard deviation (GSD), dry aggregate stability, and soil surface roughness. The sub-model of Wind Erosion Prediction System (WEPS) developed by the USDA-ARS, Single-event Wind Erosion Evaluation Program (SWEEP) is a stand-alone companion software package that can be applied to simulate soil loss and dust emission from a single windstorm event. We applied measured data (i.e. EF, GMD, GSD, and roughness) to SWEEP for predicting wind velocity that can initiate wind erosion and soil loss under each crop residue removal condition with wind velocity at 13 m s^{-1}. The threshold wind velocity to initiate wind erosion generally decreased with increase in crop residue removal levels, particularly for residue removal >75%. The total amount of soil loss in 3 hours ranged from about 0.2 to 2.5 kg m^{-2} and depends on soil condition and crop residue cover. On the other hand, high-yielding crops can produce abundant crop residue, which then raises the question that if a farmer wants to reduce residue, what could they do without removing it? The application of fertilizer on crop residue to stimulate microbial activity and subsequent decomposition of the residue is often debated. We conducted wheat straw decomposition field experiments under different fertilizer rates and combinations at three locations in western Kansas following wheat harvest in 2011 and 2012. A double shear box apparatus instrumented with a load cell measured the shear stress required to cut wheat straw and photomicrography was used to measure the cross-sectional area of wheat straw after shearing. Total C and N were also analyzed. The fertilizer rate and timing of application during summer 2012 and Fall 2013 at the Hays site had impacts on wheat straw shear stress at break point. Across site years, earlier (fall) fertilizer application generally resulted in lower remaining aboveground biomass as compared to a spring application. Multivariate and linear regressions suggested that N and C:N ratio partially explain the results observed with respect to treatment effects on winter wheat residue decomposition.

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Dedication

I would like to dedicate this work to my parents who consistently support and believe in me.

I also would like to dedicate this work to my uncle Zhigang Pan, who showed and taught me the importance of having a good health and the power from a family.

Chapter 1 - On-farm Assessment of Crop Residue Removal Impacts on Wind Erosion in the Central Great Plains

Abstract

Crop residue removal for livestock and biofuel production at large scales must be evaluated to assess impacts on soil productivity and ecosystem services. Among all the potential impacts, wind erosion is a major concern in the central Great Plains. We conducted an on-farm study from 2011 to 2013 by removing crop residue at five levels (0, 25, 50, 75, and 100%) to determine the effects of crop residue removal on soil wind erosion parameters such as dry aggregate size distribution including soil wind erodible fraction (EF <0.84 mm aggregates), geometric mean diameter (GMD) and geometric standard deviation (GSD), dry aggregate stability, and soil surface roughness. Five crop residue removal treatments with four replications were established after wheat harvest in 9×9 m plots on six farmers' no-till fields in western Kansas in summer 2011. Results consistently showed that a high level of crop residue removal (more than 75%) increased the soil wind erodibility as approximated by several soil parameters. Significant increase in EF, decrease in GMD, and decrease in surface roughness were measured after complete (100%) residue removal indicating that complete residue removal is not sustainable in that it degrades soil structure. A sub-model of the Wind Erosion Prediction System (WEPS), the Single-event Wind Erosion Evaluation Program (SWEEP) was applied to simulate soil loss and dust emissions. We applied measured data (i.e. EF, GMD, GSD, and roughness) to SWEEP for predicting wind velocity that can initiate wind erosion and soil loss under each crop residue removal condition with a wind velocity of 13 m s^{-1} for three hours. The threshold wind velocity to initiate wind erosion generally decreased with increase in crop residue removal levels,

particularly for >75% residue removal. The total amount of soil loss in 3 hours ranged from about 0.2 to 2.5 kg m^{-2} and depends on soil condition and crop residue cover.

Introduction

Large scale crop residue removal for bioenergy (i.e., ethanol) production is predicted in the near future due to the concerns over rising energy costs, dwindling crude oil supplies, increasing energy demand from developing economies, and increasing levels of greenhouse gas emissions from traditional fossil fuel combustion (Blanco-Canqui and Lal, 2009a; Lal, 2009). Corn (*Zea mays L.*) stover, sorghum (*Sorghum bicolor (L.) Moench*) stalks, and wheat (*Triticum aestivum L.*) straw are often considered as primary feedstocks for bioenergy production in the United States because of their acknowledged abundance and availability (Perlack et al., 2005; Sarath et al., 2008; Blanco-Canqui and Lal, 2009b). The magnitude of removal levels and its impacts on soil degradation, especially on soil wind erodibility, have not been well documented in the central Great Plains.

Wind erosion is a major concern in the central Great Plains (Evers et al., 2013). Dust storms are one of the major sources of regional transport of atmospheric particles. It threatens many other areas throughout the world, such as Beijing, Lanzhou in China (Chan and Yao, 2008), Sahelian and Saharan Africa (Schwanghart and Schutt, 2008), Eastern Mediterranean region (Saliba et al., 2010), and Las Pampas in Argentina (Colazo and Buschiazzo, 2010). Some of the worst dust storms in U.S. history happened during the 1930's across the Great Plains (Colacicco et al., 1989).

Crop residue on the ground, particularly the standing residue, can reduce the near surface wind speed, increase soil aggregation by adding soil organic matter (SOM) (Lyles and Allison, 1981; Rhoton et al., 2002; Lal, 2004; Wilhelm et al., 2007; Blanco-Canqui, 2010), and therefore reduce soil wind erosion. Bilbro and Fryrear (1988) found that herbaceous plant materials could reduce wind erosion and negative effects from wind erosion such as damage to plants and decreasing crop yield. Effectiveness of crop residue cover on soil wind erosion control depends on the amount and duration of soil surface cover. Evers et al. (2013) stated that the small susceptibility of wind erosion on a field of warm season grass could be attributed to the constant soil surface cover. In cultivated fields, limited or no residue cover and soil disturbance by tillage are the major factors that impact soil wind erosion (Mendez and Buschiazzo, 2010). Compared to conventional-tillage (CT), no-till (NT) or reduced tillage (RT) may increase surface soil water content (Lal, 1982; Mengel et al., 1982), enhance soil aggregate stability (Arshad et al., 1999; Wuest et al., 2005; Dam et al., 2005; Hobbs, 2007), and generally have greater bulk density (Hill, 1990; Dam et al., 2005; Kravchenko et al., 2006). It is assumed, therefore, that NT and RT might sustain more residue removal (Varvel et al, 2008).

Previous studies showed that 50 to 75% of the total residue production in the Corn Belt region might be available for removal (Nelson et al., 2004; Kim and Dale, 2004; Graham et al., 2007). However, Blanco-Canqui and Lal (2009a) observed that indiscriminate crop residue removal might not be sustainable. Without protection of crop residue on the surface, a $3 \pm 0.7\ cm$ crust was measured by Blanco-Canqui et al. (2006) in Ohio. By applying 2, 4, 8 and 12 $Mg\ \ ha^{-1}$ straw, Braida et al. (2006) detected smaller soil bulk density and found the residue can dissipate the compactive energy by 30%. Blanco-Canqui and Lal (2009a) found water retention decreased as the crop residue removal level increased across three NT sites in Ohio within one year after removal. One rainfall simulation completed in the central Great Plains by Kenney et al. (2014) reported significant carbon loss associated with runoff sediments on NT residue removal plots across three sites in Kansas.

Crop residue removal may rapidly change soil physical properties such as reduce aggregate stability (Blanco-Canqui et al., 2006), increase soil bulk density (Braida et al., 2006), and decrease SOM content (Wilhelm et al., 2004). Reduction in residue cover can increase the risk of wind erosion by reducing aggregate stability and a soil's ability to buffer wind erosive forces (Lyles and Allison, 1981; Lal, 2009). By removing the most fertile surface soil, reducing soil water-holding capacity, enhancing soil surface crusting, degrading soil structure and increasing soil variability, wind erosion can reduce soil quality and crop productivity (Leys and McTainsh, 1994). Larney et al. (1998) measured wheat yield loss and carbon (C) and nitrogen (N) enrichment in the depositional area due to soil wind erosion in Canada. Also, a study of phosphorous (P) transport by wind erosion showed a possibility of long-term soil productivity reduction (Okin, et al., 2004)

Although the function of crop residue on protection of soil from erosion has been long recognized (Lal, 1982; Mengel et al., 1982; Arshad et al., 1999; Wuest et al., 2005), the quantity of residue that is required to maintain soil health and productivity is not well documented (Wilhelm et al., 2007; Blanco-Canqui and Lal, 2009a). In semi-arid regions, where precipitation is limited, intensive and localized storm events can cause soil erosion (Kenny et al., 2014). In the central Great Plains, climatic fluctuations in spring can result in strong wind events while the freeze/thaw process weakens soil aggregation during early winter to spring (Tatarko, et al., 2001), which can exacerbate soil wind erosion.

To establish the permissible crop residue removal levels for different regions with different weather, soils, and cropping systems, an accurate prediction of soil wind erodibility based on experimental data is needed. Wind erosion models can be useful to assess potential effects of different soil conservation management practices and cropping systems (Feng and Sharratt, 2009). The Single-event Wind Erosion Evaluation Program (SWEEP) is the erosion sub-model of the Wind Erosion Prediction System (WEPS) model and has a graphical user interface. The WEPS model is a process-based model designed to simulate wind erosion soil loss from cultivated agricultural lands (Wagner, 2013). The SWEEP model can estimate total soil loss and the threshold velocity of wind required to initiate wind erosion under different crop residue removal rates, and therefore, may help determine the permissible residue removal levels for different soil conditions. The WEPS model can simulate soil wind erosion on annual and a periodic (two-week) basis (Hagen, 1991). Agricultural management practices, soil types, and field surface parameters are user inputs and long-term climatic data are applied to WEPS to simulate results that are more accurate estimates of soil loss compared to other empirical models (i.e. the Wind Erosion Equation – WEQ). Buschiazzo and Zobeck (2008) demonstrated that WEPS had better results than WEQ for simulating soil wind erosion in the Argentinean Pampas. Feng and Sharratt (2009) tested the SWEEP model by estimating soil loss during high winds on the Columbia Plateau and concluded that the model underestimated soil loss by overestimating the threshold friction velocity, but it should be noted that they studied only small intensity storms. Jia et al. (2014) applied the SWEEP model to simulate wind erosion from a tailing dam and estimated the soil loss in different fractions such as total material loss, saltation and creep loss, suspension loss, and particulate matter less than 10 microns in diameter (PM10) loss, etc. Among the soil erodibility parameters used in WEPS and SWEEP, aggregate size distribution and stability, random roughness, and vegetation were found by Hagen et al. (1999) to be among those that most influence wind erosion soil loss estimates.

Paired experimental and computer modeling data on soil wind erosion after crop residue removal are limited, particularly for on-farm conditions. To establish the threshold residue removal levels at which retained crop residues could provide sufficient ecosystem services in western Kansas, an assessment of soil wind erosion is essential. Therefore, the main objectives of this research are 1) to determine effects of corn, wheat, and sorghum residue removal from typical NT crop rotations on soil wind erodibility parameters under rainfed (e.g., dryland) conditions in western Kansas, 2) to use the SWEEP model and measured soil erodibility parameters to simulate the wind erosion under different residue treatments and determine the potential soil loss, and 3) to establish the preliminary threshold levels of residue removal based on soil wind erodibility for the representative soils under NT management in this region.

Materials and methods

Description of study sites and treatments

Research sites were initiated in summer 2011 and samples were collected during fall 2011, spring 2012, fall 2012 and spring 2013 across six on-farm producer-managed rainfed fields in western Kansas. The six on-farm experimental sites were at (1) La Crosse (38°33’N, 99°23’W, 627 m above mean sea level, i.e., AMSL), (2) Rush Center (38°29’N, 99°10’W, 599 m AMSL), (3) Colby (39°15’N, 101°12’W, 963 m AMSL), (4) Norcatur (39°47’N, 100°10’W, 806 m AMSL), (5) Garden City (38°04’N, 100°45’W, 865 m AMSL), and (6) Scott City (38°27’N, 101°00’W, 908 m AMSL). Soil types and textures at each location are listed (Table 1.1). Texture was determined using the pipette method (Gee and Bauder, 1986). Soil total C and N were also analyzed by combustion using a LEFO TruSpecCN analyzer (LECO Corp., St. Joseph, MI) (Table 1.1). Cropping systems were decided by the producers and therefore, they differed from site to site. All management practices including the crop rotation and years in NT production are given in Table 1.1.

Based on the standing height of wheat straw left in the field after harvest in summer 2011, residue removal heights were classified into 5 levels (i.e., 0, 25, 50, 75, and 100% removed). The experimental design was randomized complete block with four replications. Thus, a total of 20 plots were established at each site. A forage cutter cut wheat straw to the height of the assigned treatment. Due to the NT management of all research sites and historic residue on the ground, for 100% removal plots, a weed trimmer and leaf blower were also used to accomplish a complete removal. In the second and third research year, crop residue was cut by forage cutter into different heights according to the treatment at each site after crop harvesting. The dimension of the individual plots was 9.1×9.1 m. A 9.1 m wide alley-way was also established between blocks at each site. Field erodibility parameters (discussed below) were collected or measured in the field on the same date at each location where possible.

Aggregate size distribution

Soil aggregate size distribution samples were collected in October 2011, March 2012, and October 2012 from all six sites. In spring 2013, due to wet soil conditions, soil sampling was conducted at the Colby, Norcatur, Garden City and Scott City sites in March and at La Crosse and Rush Center in early May. An approximate 3-kg surface (0-5 cm) soil sample was collected from each plot using a flat shovel. Samples were then placed into collection containers for transport and drying. Samples were oven-dried at 60 °C for three days. A rotary sieve apparatus (Chepil, 1962 and Lyles et al., 1970) was used to separate aggregates into size classes that were weighed to determine the mass from each sieve size fraction. Sieve size openings were <0.42, 0.42-0.84, 0.84-2.0, 2.0-6.35, 6.35-14.05, 14.05-44.45, and >44.45 mm in diameter. To evaluate soil erodibility, soil wind erodible fraction (EF), geometric mean diameter (GMD), and geometric standard deviation (GSD) were calculated from the mass fraction of the different sizes.

EF is computed as the percentage of aggregates less than 0.84 mm in diameter (Chepil, 1952). The equation to calculate EF is

$$EF = \frac{M_a}{M_t} \times 100$$

where EF is the erodible fraction (%), M_a is the weight (g) of aggregates with diameter less than 0.84 mm, and M_t is the total weight (g) of total sample.

GMD describes the aggregate size in diameter at which 50% of soil sample in mass is larger than and 50% of it is smaller than and GSD describes the distribution pattern of soil aggregate size. GMD and GSD were calculated from Wagner and Ding (1994) method as below.

$$GMD = \exp\left[\sum_{i=1}^{n} m_i \ln d_i\right]$$

$$GSD = \exp\,[\sum_{i=1}^{n} m_i (\ln d_i)^2 - (\ln GMD)^2]^{0.5}$$

where m_i represents the mass of soil aggregates in a certain size collection pan, and d_i represents the mean diameter of each of the seven size fractions.

Aggregate stability

Soil aggregates were collected from each plot at the same time with as soil aggregate size distribution samples. Aggregates were collected using a flat shovel from the top 5 cm soil and passed through a 12.7 mm diameter sieve in the field. Aggregate samples were then air dried in a greenhouse (≈25 ℃) for a week. A Soil Aggregate Crushing Energy Meter (SACEM) apparatus was used to measure and record the energy required to crush individual aggregates (Boyd et al., 1983). The SACEM is comprised of two parallel plates supported by a load cell, which is connected to a computer to measure force and energy as the plates crush the aggregate sample. For the test, a subsample of 30 aggregates from the dried field aggregates having mass ≈5 grams each were picked and reformed by minor finger manipulation to remove edges and form into approximate spherical shape. The result of SACEM is dry aggregate stability presented as the natural log of the crushing energy per unit mass ($\ln\,(\mathrm{J\ kg^{-1}})$) as described by Hagen et al., (1992).

Surface random roughness

A micro-relief pin meter was applied to measure the random surface roughness of each plot along the ridge tops (Wagner and Yu, 1991; Skidmore et al., 1994). Random roughness measurements were conducted for all site years except for La Crosse and Rush Center in spring 2012 due to the presence of a wheat crop growing in those fields. A pin meter consists of 101 pins (1 cm apart, 50 cm in length and 6 mm in diameter) mounted on a metal guide in front of a white backboard. The guide and pins are lowered to the soil surface so that the pin tops replicate the soil surface elevations. Any residues present were carefully removed so that the pins touched the actual soil surface. A digital image of the tops of the pins was captured in each plot by digital camera. Sigma Scan Pro 5 (SPSS Science, 1998) software was then used to analyze the digital photos to obtain soil elevation of each pin. Roughness was calculated as the standard deviation of the pin heights after correction for slope (Allmaras et al., 1966; Wagner and Yu, 1991).

SWEEP modeling

An 805×805 m square field with no wind barriers was simulated in SWEEP to estimate soil wind erosion under different residue removal levels at all six sites based on the measured parameters (i.e., GMD, GSD, aggregate stability, roughness, residue height, and residue characteristics). Biomass information was input into the SWEEP model for each treatment at different sites. According to the distance between the ground and the forage cutter blade for each treatment, 0.0, 0.075, 0.15, 0.225, and 0.3 m were applied as wheat straw residue average heights corresponding to 100, 75, 50, 25, and 0% residue removal levels at each site in the model. Likewise, 0.0, 0.15, 0.3, 0.45, and 0.6 m were used as sorghum stalk residue average heights and 0.0, 0.125, 0.25, 0.375, and 0.5 m were for corn stalk heights. Residue stem area index was calculated by SWEEP from stem diameter, stem height, and stem population. In this study, we used 3, 30, and 60 mm as wheat, sorghum, and corn residue diameters. According to the WEPS default database, stem populations for wheat straw, sorghum stubble, and corn stalks were 500.0, 24.71, 7.41 plant m^{-2}, respectively and these values were used in our simulations. Residue leaf area index was assumed to be zero under all treatments at all sites because the leaf parts of plant were removed during harvest. Residue flat cover parameters were estimated by comparing field plots with photographs of known cover. Cover values of 0.0, 0.3, 0.5, 0.6, and 0.7 m^2 m^{-2} corresponded to 100, 75, 50, 25, and 0% residue removal levels. Since crops had been harvested before sampling, growing crop parameters were all assumed to be zero in SWEEP. SWEEP has the capability to download the USDA-Natural Resource Conservation Service Soil Data Mart file to import basic soil information based on soil series at each site. Then field-measured parameters (i.e., EF, GMD, GSD, and random roughness) were replaced for database-generated values. To estimate air density at sampling time, elevation and daily average temperature for the sampling month were applied. To simulate the soil wind erosion under extreme conditions, mass of soil loss (kg m^{-2} h^{-1}) at a $13\ \mathrm{m\ s^{-1}}$ ($\approx 29\ \mathrm{miles\ hr^{-1}}$) wind speed for a 3-hour event was determined. In addition, threshold wind velocity (i.e., the wind velocity at which soil erosion initiates), and percent of days that greater than threshold wind velocities can be expected in the sampling month were determined by the SWEEP model using historical wind parameters at each site.

Statistical analysis

All data were statistically analyzed using analysis of variance (Mixed procedure) in SAS 9.3 (SAS Institute, 2011). Least square means at the 0.05 significance level was applied to test the differences among treatments (SAS Institute, 2011).

Results

Wind erodible fraction (EF)

Crop residue removal significantly affected soil EF at all six sites and for all sampling dates (Fig. 1.1 – Fig. 1.6). However, the magnitude of removal effects varied with site. Four months after research was initiated (fall 2011), residue removal had no significant impacts on EF at three out of six sites, while at Colby, Rush Center, and Scott City sites there were significant differences in EF among treatments. At Colby, EF was 26.58% at 25% removal, which was approximately 15% less than EF for the 75% removal plot. At Rush Center, the 100% removal plot had significantly greater EF compared to the 0 and 50% removal treatments. A similar pattern was also measured at the Scott City site. The EF at 100% removal treatment was 55.51%, which was approximately 54 and 55% greater than measured value at 25 and 0% removal plots, respectively.

In spring 2012, nine months after the plot establishment, significantly greater EFs with increased residue removal levels were measured at all sites. At La Crosse, residue removal did not have impacts on soil EF. However, EF was 54.68% under a 100% removal at Rush Center, which was approximately twice as much as the 0% removal plot. At Colby, EFs for the greater than 50% residue removal plots (i.e. 75 and 100% residue removal) were significantly greater compared to other treatments. The lowest value measured was for the 25% removal plots, which was 37.86%, and was half as many at 100% removal plot, which was the highest EF found at this site. At Norcatur, EF for complete residue removal (53.03%) was significantly greater than the other treatments, where EFs ranged from 23.97 to 27.36% among 0 to 75% removal plots. Significantly less EF was measured for the 0% removal treatment compared to 100% removal treatment at the Garden City site. The EF was 37.42% at 0% removal plot. In contrast, EF approximately doubled (68.47%) with 100% removal. Similar to the Norcatur site, 100% removal treatment had significantly greater EF than the other treatments at the Scott City site. The EF was 64.93% for the 100% removal plot, which was approximately twice as much as the other treatments, where the EFs ranged from 30.46 to 38.81%.

In fall 2012, residue removal had significant impacts on EF at four out of six sites. At Colby, and Garden City sites, there were no significant effects of residue removal on EF. At La Crosse, 100% removal plot had significantly greater EF at 44.28%, compared to other treatments where EFs ranged from about 24 to 28%. At Rush Center, EF for the complete residue removal treatment was significantly greater than for no residue removal. The measured EF was 55.50% for 100% removal treatment and was more than twice greater than 0% removal plot. At Norcatur, the complete cover treatment had significantly less EF compared to 25 and 100% removal treatments. The highest EF measured was at 100% residue removal, which was twice as much as

0% removal at 27.79%, while the 25% removal treatment had 36.11% EF. At Scott City, EF for 100% removal was significantly greater than the 25 and 0% removal treatments.

In spring 2013, significant impacts of residue removal on EF were found at all six sites. At La Crosse, EF for complete residue removal was significantly greater than for all other treatments. The EFs measured were 44.28% at 100% removal treatment, which was more than twice as much as other treatments, where the EFs ranged about from 17% to 22%. At Rush Center, 0, 25, and 50% removal treatments had less EF compared to 75 and 100% removal. At Colby, 50% removal had significantly greater EF than the complete covered plot. At Norcatur, highest EF was measured for the complete removal treatment. In contrast, 25 and 50% residue removal treatments had significantly less EFs, which were approximately 25%. EF at Garden City under complete residue cover was significantly less than the 50, 75, and 100% residue removal levels. Meanwhile, the highest EF was again observed for 100% removal, which was 65.40%. At Scott City, the complete residue removal treatment had the highest EF and the lowest EF measured was at 0% removal plot.

Geometric mean diameter (GMD)

Crop residue removal affected soil GMD at all six sites over time (Fig. 1.7 – Fig. 1.12). In fall 2011, immediate impacts of crop residue removal on GMD were found at four out of six sites (i.e., four months after study was initiated). They are Rush Center, Colby, Norcatur, and Scott City. At the Rush Center site, the smallest GMD (1.15 mm) was measured for 100% removal, versus 4.88 mm for the 0% removal treatment. At Colby, significantly different GMDs were found between 75% and 25% removal treatments. The largest GMD (2.61 mm) was measured under 25% removal treatment, which was more than twice the GMD than the 75% removal plot. At Norcatur, GMDs under the 0, 75, and 100% treatments were significantly less than the 50%

removal rate at 16.24 mm. The smallest value at this site was measured at 100% removal treatment. A similar pattern was observed at Scott City, where 50% removal had highest GMD while the lowest value was measured at the complete removal.

In spring 2012, significant impacts on GMD due to crop residue removal were observed at all six sites. At La Crosse, the smallest GMD (1.47 mm) was measured for 100% removal, which was less than half of what was observed for the 50% removal level. At Rush Center, compared to 0 and 25% removal, the 100% removal plot had significantly smaller GMD, which was 0.62 mm. At the Colby site, the smallest GMD was measured at 100% removal, which was significantly smaller than 0% removal plot. Meanwhile, the GMD at 75% removal was also significantly smaller than the complete removal. Similarly, the smallest GMD (0.68 mm) was measured for 100% removal at the Norcatur site, which was significantly smaller than 0, 25, and 50% removal plots. At Garden City, significantly different GMDs were measured between 0 and 100% removal plots. The largest value (1.27 mm) was measured at 0% removal plot, which was five times the GMD measured with complete removal. At the Scott City site, the highest GMD (3.82 mm) was measured at 50% removal plot, which is significantly larger than values under 0, and 100% removal.

In fall 2012, significant impacts of crop residue removal on GMD were measured at three out of six sites. At the La Crosse site, the smallest value (1.09 mm) was measured under 100% removal, which was significantly less than 0% removal. At Rush Center, GMD measured at 100% removal plot was significantly smaller than other treatments. At the Norcatur site, the highest GMD was 2.75 mm under 0% removal, and GMDs at 25 and 100% were significantly smaller.

In spring 2013, significant results were measured at four out of six sites. At La Crosse, the lowest value was observed for the complete removal treatment, which was 1.03 mm and was significantly smaller than at 50 and 75% removal levels. At Rush Center, highest GMD was measured at 25% removal while the significantly smaller values were measured at 0, 75, and 100% removal. At Garden City, the smallest GMD (0.33 mm) was measured at 100% removal plots. Comparatively, the highest value was measured at 0% removal that was twice as large as the complete removal treatment. At the Scott City site, GMD under the 100% residue removal treatment was significantly smaller than the 0 and 75% removal treatments.

Geometric standard deviation

As shown in Fig. 1.13 to Fig. 1.18, four months after the study was initiated, significant differences due to crop residue removal were measured at the La Crosse and Colby sites. At La Crosse, the smallest GSD (13.37 mm) was measured at 25% removal plot while the values measured at 0, 75, and 100% removal treatments were significantly greater. A similar pattern was measured at the Colby site. The smallest value was measured under 25% removal. Significantly greater GSDs were measured at 0, 75, and 100% removal plots.

In spring 2012, significant impacts of crop residue removal on soil GSD were found at three out of six sites (Rush Center, Colby, and Garden City). At Rush Center, the GSD measured at 0% removal was the smallest among all treatments, which was 8.21 mm. The GSDs measured at 25 and 100% removal plots were significantly greater (40 and 35% larger, respectively) relative to 0% removal plot. At Colby, the GSDs from 0, 25, and 50% removal rates were significantly greater than from 75 and 100% removal. At the Garden City site, the highest GSD was measured at 25% removal, which was 12.57 mm. Values from the 75 and 100% removal treatments were 20 and 26% less, respectively.

In fall 2012, significant differences were measured at the Colby and Scott City sites only. Similarly, the highest values were both from 25% removal treatment at these sites. The smallest GSD was measured at 75% removal at Colby and at 0% removal at Scott City, respectively.

In spring 2013, impacts of residue removal on GSD were measured at La Crosse, Rush Center, and Colby. At the La Crosse site, the greatest GSD (17.36 mm) was from 100% removal, which was significantly more than 0, 25, and 50% removal treatments (31, 40 and 49% greater, respectively). Similarly, the greatest GSD (15.77 mm) at Rush Center was from the complete removal plots as well. GSD was approximate 64% greater than the result from 50% removal treatment, which was the smallest result measured at this site. At Colby, significantly different results were measured between 25 and 50% removal treatments. GSD from 25% removal plot was 24% greater than the results from 50% removal treatment.

Dry aggregate stability

Residue removal impacts on dry aggregate stability (DAS) were significant at some sites and some sampling periods. However, the relationship between aggregate stability and residue removal levels greatly varied from site to site and time to time (Fig. 1.19 – Fig. 1.24). To apply stability to SWEEP modeling, natural log format of energy per unit mass is reported ($\ln(\mathrm{J\ kg^{-1}})$).

In fall 2011, a significant impact of crop residue removal on DAS was only measure at the Colby site. DAS measured at both 0 and 100% removal treatments were significantly greater than the 50% removal treatment in fall 2011.

Two out of six sites measured significant changes in DAS in spring 2012 sampling period. At La Crosse, complete residue removal was less stable as compared to the 0 and 50% removal treatments. At Scott City, the smallest stability value in spring 2012 was measured at complete residue removal plot, which was significantly less than the other treatments.

In fall 2012, significant differences in DAS due to crop residue removal were measured at La Crosse, Rush Center, and Colby. The 100% removal treatment had the lowest stability, which is significantly less than other treatments at the La Crosse site. At Rush Center, soil aggregates from the complete removal treatment were significantly less stable compared to the soil aggregates from 0, 25, and 50% removal plots. However, at Colby, the complete residue removal treatment had the most stable soil aggregates, which had significantly greater DAS than other treatments.

Four out of six sites showed significant impacts of residue removal on DAS during the spring 2013 sampling period. At Rush Center, DAS at 50% removal was significantly greater than 75 and 100% removal plots. DAS values at 0, 25, and 50% removal plots were significantly less than for the 100% removal treatment at the Colby site. At Norcatur, the largest DAS was measured at 25% residue removal plot, which was significantly greater than complete removal. At the Scott City site, the DAS measured under 75 and 100% removal treatments was significantly larger than for the 50% removal plot.

Surface random roughness

Impacts of crop residue removal on soil surface random roughness were significant at some sites. However, the data greatly vary between seasons and sites (Fig. 1.25 – Fig. 1.30). Due to the growing wheat at La Crosse and Rush Center sites, we did not measure surface roughness for this sampling period at those two sites in spring 2012.

At La Crosse, roughness values in fall 2011, fall 2012, and spring 2013 did not show any differences among all treatments in each sampling period. However, the average value in fall 2012 was greater than other times. The roughness values in fall 2011 and spring 2013 ranged from about 4 mm to 6 mm and from about 4.5 mm to 7.8 mm, respectively. In fall 2012, the values ranged from about 8.2 mm to 9.5 mm.

At Rush Center, roughness in fall 2011 and spring 2013 did not differ among all treatments. In fall 2012, values from 0, 25, and 50% removal treatments were significantly greater than from the complete removal plot. Roughness values in spring 2013 ranged from about 4.5 mm to 6.5 mm and were small compared to the other two sampling periods.

Impacts of residue removal on surface roughness were considerable in the first two sampling periods at Colby. Four months after research started, 75 and 100% residue removal treatments had significantly less roughness than 0, 25, and 50% removal plots. The flattest roughness measured was complete removal at 1.75 mm. The greatest roughness was from the 0% removal treatment, which was approximately six times as rough as the complete removal treatment. Similarly, in spring 2012, significantly less roughness was measured at 75 and 100% removal compared to 0, 25, and 50% removal treatments. Additionally, compared to complete residue cover, 25% removal had significantly lesser roughness. In fall 2012 and spring 2013, the surface roughness values were statistically the same among all treatments. Although not significant, Spring 2013 did show a trend where 100% removal had less roughness than 0% removal.

The change of surface roughness due to crop residue removal at Norcatur did not show a clear pattern. In fall 2011, the greatest roughness was measure at 50% removal, which was 8.3 mm. Similar to fall 2011, 50% removal had greatest surface roughness in spring 2012. In fall

2012, the greatest roughness value was 8.5 mm fort 75% removal treatment, and was significantly greater than both 50 and 100% removal. In spring 2013, roughness values at all treatments were statistically similar.

At Garden City, in fall 2011, 0 and 25% removal plots had significantly greater roughness values than complete residue removal. A similar pattern was also observed in spring 2012. In fall 2012, there was no statistical difference between treatments on roughness values. In spring 2013, the greatest roughness was measured at 50% removal, which was significantly greater than complete removal.

The effects of residue removal on surface roughness had a clear pattern at Scott City, where complete residue removal treatment had the smallest roughness values, in other words, had the smoothest surface. In fall 2011, values from 100% removal was significantly less than values from 0, 25, and 50% removal. In spring 2012, fall 2012, and spring 2013, the complete residue removal treatment was the smoothest.

SWEEP: Wind erosion threshold velocity and probability

At each site, the SWEEP simulated threshold velocity (V_t) required to initiate wind erosion decreased with increase in residue removal levels. Smallest V_t (ranged from 6 to 10 m s^{-1}) was always estimated at 100% removal plots, whereas the largest values (ranged from 17 to 21 m s^{-1}) were estimated at 0% removal treatment at each site (Fig. 1.31 – Fig. 1.36). Threshold velocities under the 100% removal treatments at each site were all significantly less than 75% removal plots during every sampling period. A similar pattern was found between 75 and 50% removal treatments. The only exception was at Garden City during the first sampling period (4 months after study initiated). No significant difference of threshold velocities was measured between these two treatments at this site.

The V_t under 50 and 25% residue removal treatments had no significant difference at La Crosse, Rush Center, Colby, and Norcatur at all 4 sampling periods. At Garden City, wind erosion V_t under 50% removal plots was significantly less than 25% removal treatments in the fall 2011 and spring 2012. The estimated V_t for the 50% removal treatments were 14.75 and 15.75 m s^{-1} in the fall 2011 and spring 2012, respectively, and velocities under the 25% removal treatments were 18.5 and 17 m s^{-1} for fall 2011 and spring 2012.

For most of the sampling periods, the difference of V_t between 25 and 0% removal treatments were not significant at all six sites. However, at La Crosse, Rush Center, and Garden City, significant less V_t at 25% residue removal plots was measured in spring 2012. Also, in fall 2012, V_t at 25% residue removal treatment was estimated significantly less than 0% residue removal plot at Scott City.

The probability of days when wind speed reaches the V_t is reported in Table 1.3. At all six sites, the probability of having days with wind speed greater than V_t at 100% residue removal plots was significantly greater than other treatments. The probability also varies from site to site and time to time. Smaller probability values were estimated at La Crosse, which for complete residue removal plots ranges from 9.6% to 17.7%. The largest values were found at Garden City and Scott City, which vary from about 14.4% to 50.9% for 100% residue removal treatment.

For 75% residue removal treatment, the greatest probability of days with wind speed greater than V_t was significantly less relative to 100% removal. The largest probabilities were measured at Colby and Garden City, which were approximately 5%. At other sites, the probability was usually less than 3%. The probability declined to less than 1% when more than 50% residue was left on the soil surface at all 6 sites for most of the sampling periods.

SWEEP: Amount of soil loss at 13 m s^{-1} wind speed

When wind erosion was simulated using field measured parameters and a 13 m s^{-1} velocity, the soil wind erosion is only initiated when at least 75% residue is removed from the field at all six sites (Table 1.4). For all plots, ≥50% residue retained had no soil loss predicted at wind velocity of 13 m s^{-1}. For 100% residue removal plots, wind erosion happens at all sites with a wind speed of 13 m s^{-1}. At La Crosse, total soil loss increased from 0.97 kg m^{-2} in the fall 2011 to 1.69 kg m^{-2} in spring 2012. A similar increase from fall 2011 to spring 2012 was found at all sites (Table 1.4). From fall 2012 to spring 2013, four sites (i.e. La Crosse, Norcatur, Garden City, and Scott City) had simulated increase in soil loss and another two sites (i.e. Rush Center and Colby) had a decrease.

Discussion

Data on soil wind erosion parameters showed that crop residue removal could result in severe wind erosion at some sites. The magnitude and frequency of the impacts of residue removal on soil erodibility varied likely due to the differences in soil types, cropping systems, historic managements, and local climatic factors. For wind erosion control purposes, keeping a minimum crop residue of more than 25% on the ground after harvest could reduce the soil's susceptibility to wind erosion in the Great Plains.

Soil texture can be used to partially explain the magnitude of the effects of crop residue removal on soil erodibility. Mild changes from fall 2011 to spring 2012 in EF were observed at Rush Center and Scott City compared to other sites, particularly for the complete removal treatment (Fig. 1.1— Fig. 1.6). Although all six sites have silt loam, the soils at La Crosse and the Scott City have greater (18%) clay content (Table 1.1). Clay enriched soil usually has better wind erosion resistant ability due to the stronger cohesive forces between soil particles and better bonding conditions from humus resulting in stronger aggregation. Zobeck and Bilbro (2001) found that eroded soil surface tend to have greater clay content.

Indiscriminate crop residue removal could expose soils to weathering that could degrade soil structure and cause a wind erosion issue in western Kansas. This is particularly true when considering the EF values across the six research sites. High EF indicates increased wind erodibility under certain conditions. At almost all sites, complete residue removal significantly increased EF. According to Chepil (1945), initiation of soil movement by wind begins with saltation of soil particles. Without the protection of crop residue, a bare soil with a higher EF could be exposed to wind; when the V_t is reached, wind erosion can occur.

EF values increased at five sites from fall 2011 to spring 2012 (Fig. 1.1 – Fig. 1.6), particularly for high removal rate plots (i.e. 75 and 100% removal). This increment could be attributed to the local weather conditions (Li et al., 2004). The most likely period of the year to have wind erosion in western Kansas is late winter to early spring due to, among other factors, the freeze/thaw effects on soil aggregates (Layton et al., 1993). In this period, the plant height is not high enough to slow the wind at the soil surface. Also during winter, due cold temperatures, soil pore water is often frozen which has larger volume than liquid water. The freezing process will expand the pore size between soil aggregates, which can cause soil aggregates to break up and weaken stability and therefore, increase the susceptibility of soil wind erosion (Bullock et al., 2001; Li et al., 2004; Wang et al., 2014). In this study, in early spring 2012, winter wheat was growing at La Crosse and Rush Center. At this time, winter wheat is usually short and sparse in the field. Due to the low humidity during the winter in US Great Plains, sublimation of frozen water can be expected at the soil surface leaving empty soil pores and weakened aggregates. Tatarko et al. (2001) found that the freeze/dry process caused less stable soil aggregates regardless the soil water content and stability decrease as soil water increases. In the early spring, warmer temperatures will additionally thaw deeper soil.

A similar increase of EF after winter was not observed in samples from fall 2012 to spring 2013, which is likely due to management changes necessitated by a major drought. In spring 2012, sorghum was planted at La Crosse and Scott City sites and corn was planted at Colby and Norcatur sites. Due to a severe drought in summer and fall 2012 for about two thirds of Kansas, particularly in western part (HPRCC, 2012), crop yields were extremely low and producers at La Crosse, Colby, Norcatur, and Scott City decided not to harvest. Therefore, the residue height remaining in the field at these sites for that year was greater than the previous years. Meanwhile, for wind erosion control purposes, the producer at Rush Center imported additional wheat straw into field after harvest in May 2012, which resulted in large amounts of in situ crop residue. Although we harvested forage to different heights accordingly after the producers abandoned the crops in fall 2012, greater aboveground biomass was observed, which provided extra protection on the surface soil during winter, hence the probable cause why EF did not increase over the winter of 2012-2013.

Effects of residue removal on soil aggregate stability are complicated by other factors such as soil texture, water, temperature, snow cover, and management history. Results from many sites showed that differences in aggregate stability among treatments were not significant. There was no significant difference found at Garden City at all four sampling periods. Garden City has the shortest NT management history among all study sites before research initiated, which was 5 years. Strong soil structure might not develop in such a short period compared to other sites. Six et al. (1999) found that tillage could gradually reduce soil aggregate stability. Meanwhile, Garden City has greatest clay content among all sites (Table 1.1), which may offset the effects of crop residue removal on DAS. At the Norcatur site, significant differences were only measured at the last sampling period. One reason is that Norcatur has the longest NT history, which was 20 years and aggregation may be more developed at this site. Rhoton (2000) stated that NT practices could enhance soil erodibility-related properties. Meanwhile, two out of four sampling periods showed significant impacts of crop residue removal on soil aggregate stability at La Crosse, Rush Center, and Scott City. Also, significant results were measured three times at the Colby site. It is hypothesized that stability would decrease with increase in residue removal levels. This pattern was only found in the spring 2012 at Colby and Scott City, and fall 2012 at Rush Center. However, the opposite pattern in which aggregate stability increased with increase in residue removal was found in fall 2012 at Colby, and spring 2013 at Colby and Scott City. A possible reason for this phenomenon could be the soil surface sealing and crusting was visually observed for the lower residue treatment plots. Precipitation from May to September may also reconsolidate and strengthen aggregates. Without the protection of crop residue, raindrop energy is directly transferred to the soil particles. The release, movement, and orientation of fine particles can clog the pores near the soil surface and eventually cause soil surface sealing. During the drying process, a soil seal can develop into a high physical strength crust (Blanco-Canqui et al., 2006). Surface crusts can temporarily increase soil strength and decrease water infiltration rate (Benyamini and Unger, 1984). A complete and continuous crop residue cover on the ground could eliminate the formation of surface seals (Ruan et al., 2001).

Rough soil surfaces can reduce the near surface wind velocity (Bielders et al., 2000) by absorbing wind energy and can trap soil particles, reducing wind erosion. For five out of six sites, soil surface roughness decreased with increase in residue removal levels. Precipitation can flatten the soil surface and reduce aggregation as observed by Tatarko et al. (2001). This was likely the reason for reduced random roughness under the complete removal treatment where surface soil was exposed to freezing temperatures and precipitation.

The SWEEP model predicted the V_t, the probability of an erosion event, and total soil loss for a three-hour wind at 13 m s^{-1} under every treatment at each site. Reduced V_t with complete residue removal indicates the importance of protection of crop residue on reducing soil wind erodibility. This decrease was consistently simulated at every site suggesting other factors (i.e. management history, cropping system, and local weather condition, etc.) do not affect soil wind erodibility as much as the presence of crop residues, particularly in the short term (1-2 years of this study). The results indicate that aggressive residue removal (>75%) can increase the possibility of soil wind erosion. That is especially essential in the semi-arid area, where wind erosion has always been a threat due to high winds and periodic drought.

The probability of days when wind erosion can be initiated, which was based on historic wind statistics in SWEEP, also increases significantly with excessive crop residue removal (>75%) (Table 1.3), particularly in the early spring when there is a high probability for windy weather. At all sites, the probabilities of days with wind speed that can initiate soil erosion at less than 75% residue removal plots are extremely small. Therefore, a complete residue removal may not be sustainable, but partial removal up to as much as 75% may be possible depending on timing of removal (e.g., just prior to planting) and local conditions (e.g., high biomass present).

Soil loss for a three-hour wind velocity of 13 m s^{-1} was simulated for 100% residue removal treatment at all six sites over four sampling periods. Such wind speeds are not uncommon in the study area (Table 1.5). In addition, over half of the erosion losses at 100% removal were in excess of the tolerable limit of 1.12 kg m^{-2} (5 T ac^{-1}) for these soils (Table 1.4), and all but one (Rush Center, Fall 2011) were in excess of 0.45 kg m^{-2} (2 T ac^{-1}). However, none of the showed had soil wind erosion at wind speed of 13 m s^{-1} when more than 50% of residue remained in the field. At Colby and Garden City, results show that wind erosion could even happen for the soil conditions measured at 75% residue removal, which are significantly different compared to 0, 25, and 50% removal treatments. NT systems often have better soil aggregation at the soil surface than other tillage practices (Devine et al., 2014). Therefore, greater soil wind erodibility at Garden City may potentially be attributed to the short NT management history (5 years) and associated aggregation. However, this reason cannot be used to explain the Colby site since it has 15 year NT history. Overall, across six sites, the SWEEP model indicates crop residue removal >75% is a threshold when severe wind erosion can occur.

Conclusions

This study in western Kansas conducted at six on-farm sites in a precipitation zone ranging from 495 mm to 595 mm consistently showed that a high level of crop residue removal (>75%) increased the soil wind erodibility at all six sites as approximated by several soil parameters. In addition, at Colby and Garden City, significant soil loss can happen to fields with >50% crop residue removal. Significant increase in EF, decrease in GMD, and decrease in surface roughness were measured after complete (100%) residue removal indicating that complete residue removal is not sustainable in that it degrades soil structure. According to results from the SWEEP model, excessive crop residue removal (>75%) can cause severe soil wind erosion for as little as three hour wind at 13 m s^{-1}, which makes the agricultural system unsustainable. In semi-arid regions, the amount of crop residue produced each year is highly dependent upon precipitation, particularly for rain-fed farming conditions. Even with lower residue removal levels, there may not be enough residue retained in low residue production years to control wind erosion. Therefore, it is strongly suggested, for the future studies, a long-term systematic research about permissible residue removal levels that comprehensively considers the relationship among soil properties, amount of biomass retained in field, local weather conditions, cropping system, and crop productivity.

Figures and Tables

Figure 1.1 Wind erodible fraction (EF) (% <0.84 mm) at the La Crosse site. Treatments with different letters indicate significant differences at the p=0.05 level. Results were separately compared among treatments at each sampling period. The absence of letters indicates no significant differences among treatments for that particular sampling period.

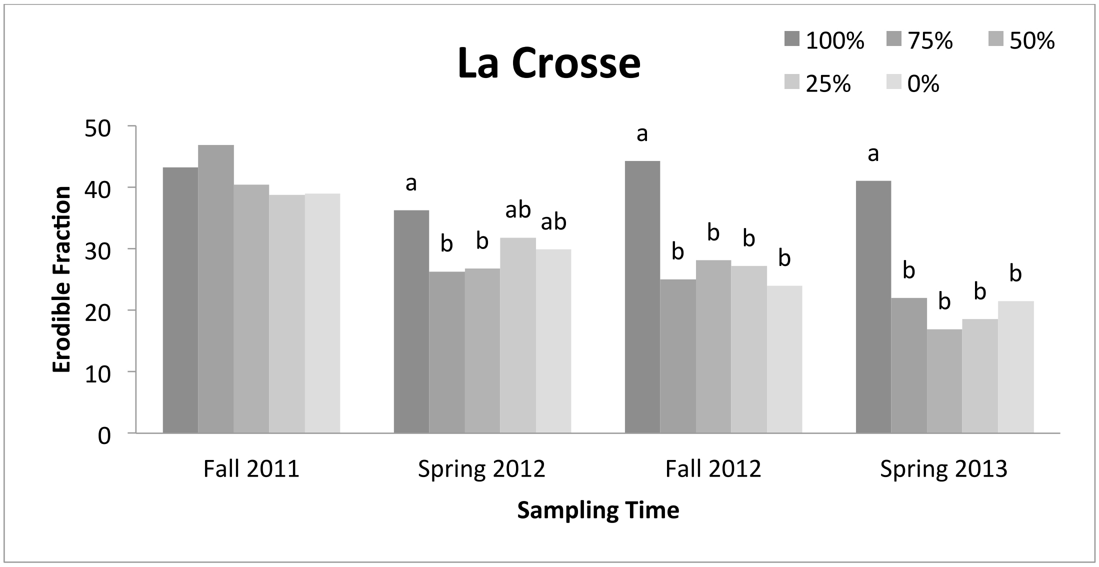


Figure 1.2 Wind erodible fraction (EF) (% <0.84 mm) at Rush Center. Treatments with different letters indicate significant differences at the p=0.05 level. Results were separately compared among treatments at each sampling period.

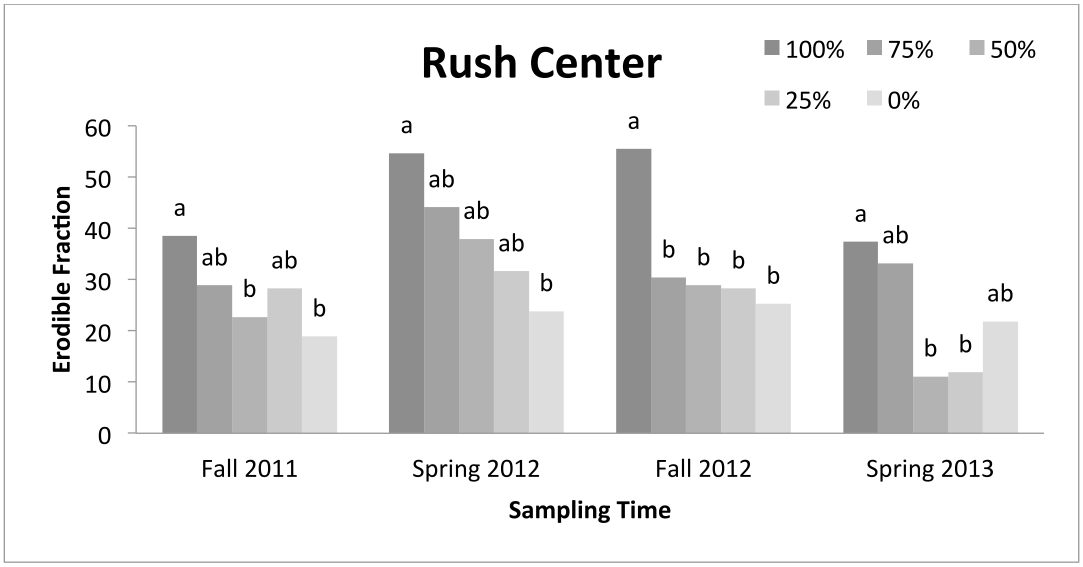


Figure 1.3 Wind erodible fraction (EF) (% <0.84 mm) at Colby. Treatments with different letters indicate significant differences at the p=0.05 level. Results were separately compared among treatments at each sampling period.

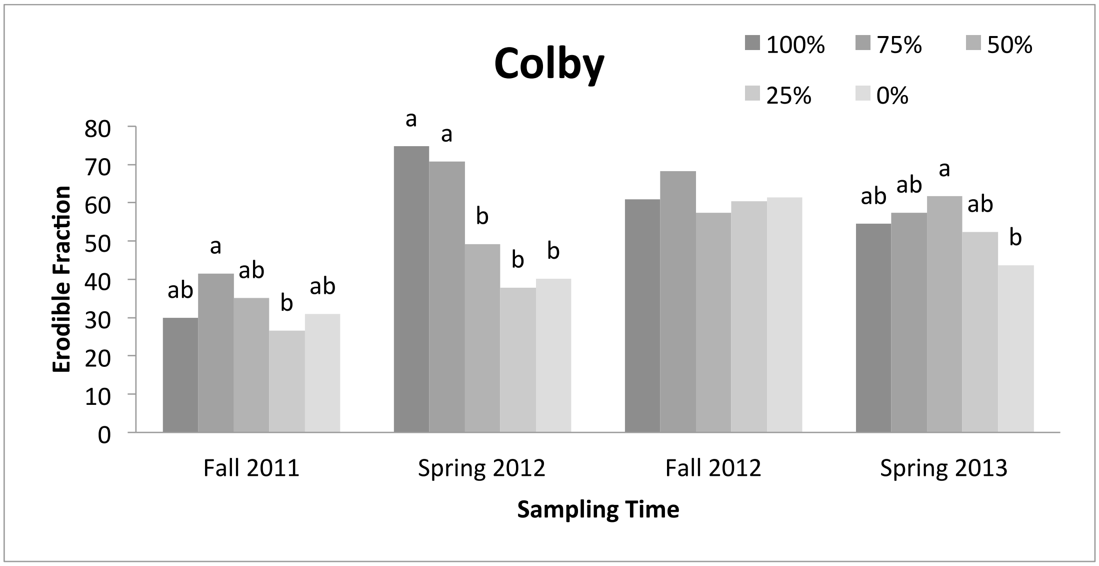


Figure 1.4 Wind erodible fraction (EF) (% <0.84 mm) at Norcatur. Treatments with different letters indicate significant differences at the P=0.05 level. Results were separately compared among treatments at each sampling period.

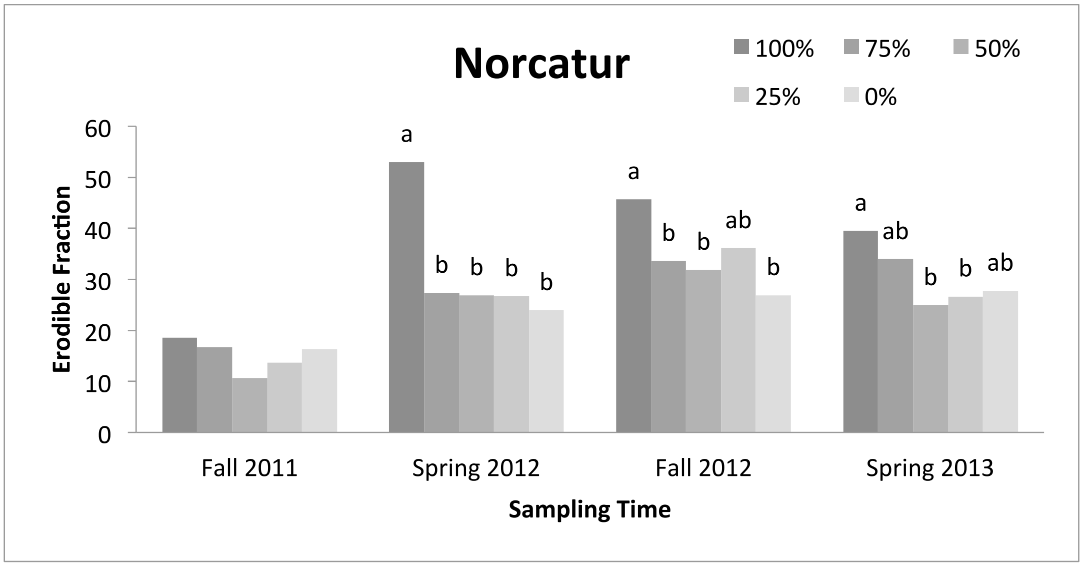


Figure 1.5 Wind erodible fraction (EF) (% <0.84 mm) at Garden City. Treatments with different letters indicate significant differences at the p=0.05 level. Results were separately compared among treatments at each sampling period. The absence of letters indicates no significant differences among treatments for that particular sampling period.

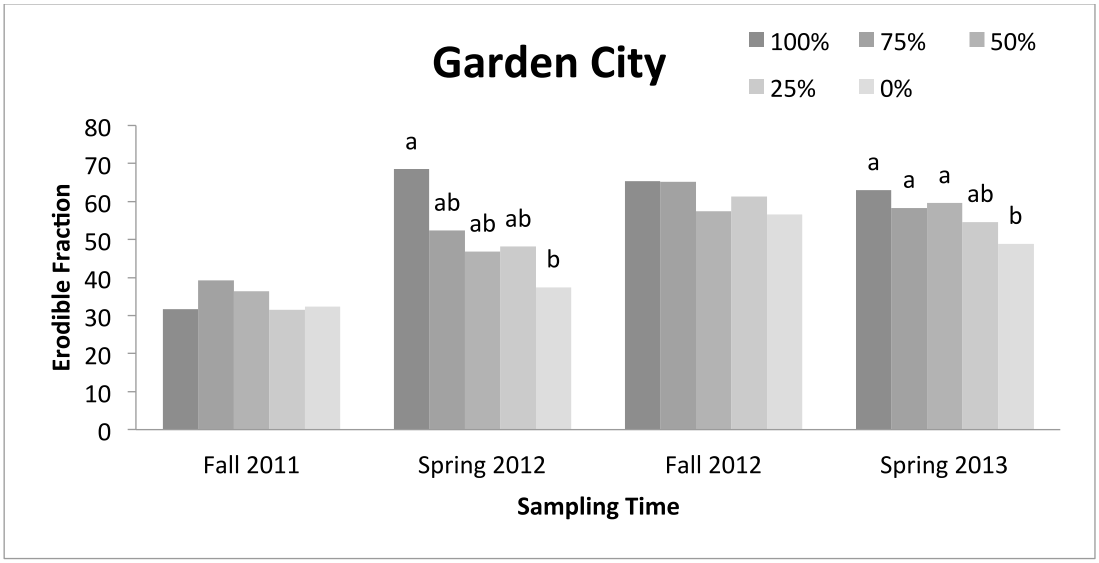


Figure 1.6 Wind erodible fraction (EF) (% <0.84 mm) at Scott City. Treatments with different letters indicate significant differences at the p=0.05 level. Results were separately compared among treatments at each sampling period. The absence of letters indicates no significant differences among treatments for that particular sampling period.

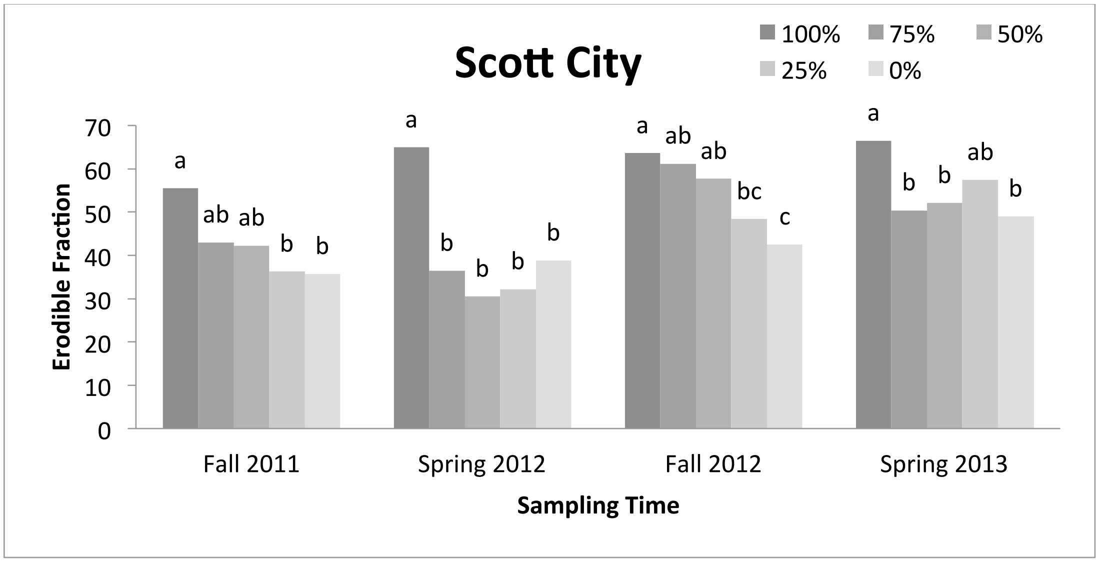


Figure 1.7 Geometric mean diameter (GMD) of dry aggregates at La Crosse. Treatments with different letters indicate significant differences at the p=0.05 level. Results were separately compared among treatments at each sampling period. The absence of letters indicates no significant differences among treatments for that particular sampling period.

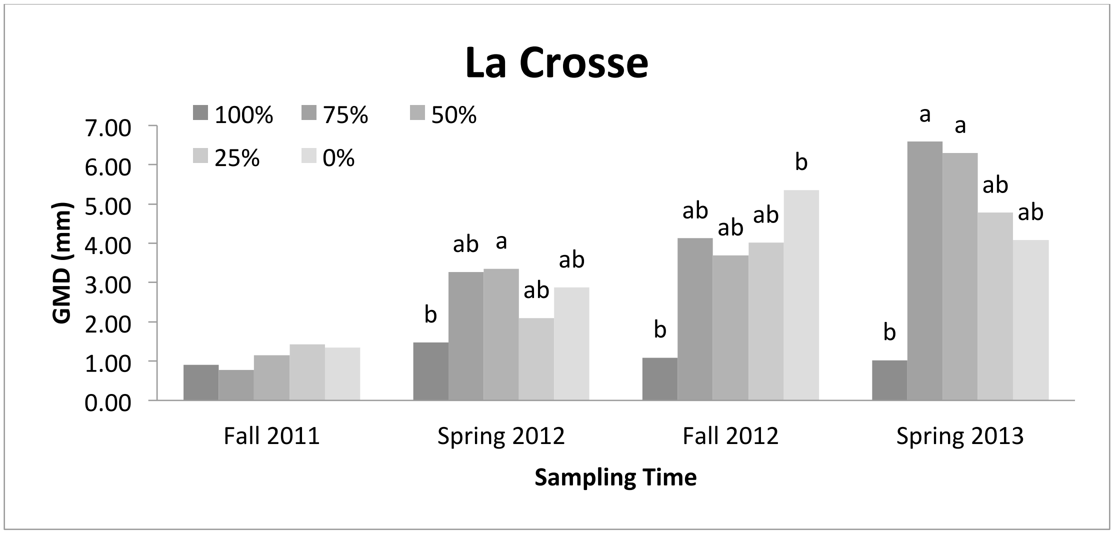


Figure 1.8 Geometric mean diameter (GMD) of dry aggregates at Rush Center. Treatments with different letters indicate significant differences at the p=0.05 level. Results were separately compared among treatments at each sampling period.

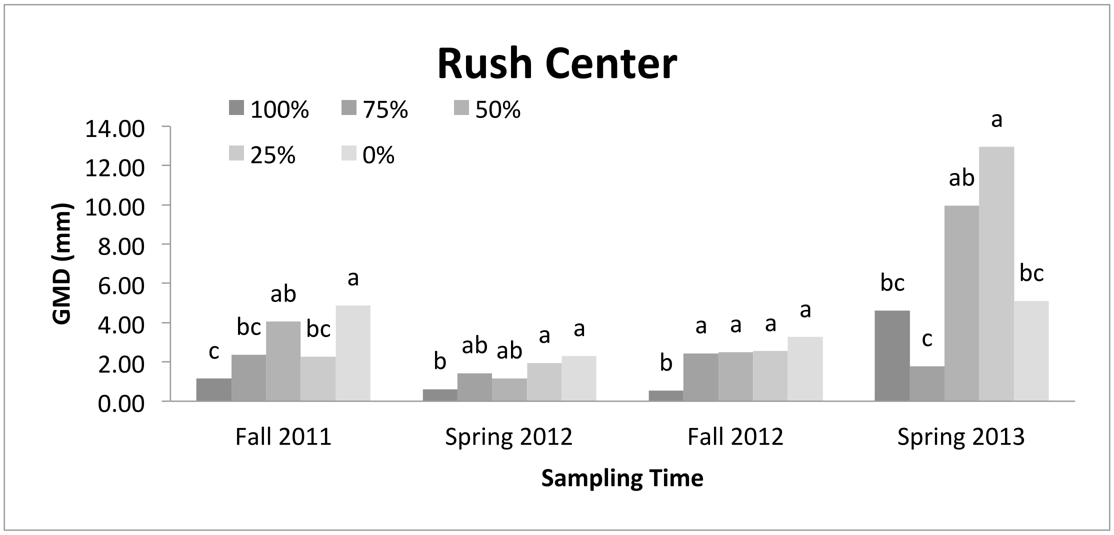


Figure 1.9 Geometric mean diameter (GMD) of dry aggregates at Colby. Treatments with different letters indicate significant differences at the p=0.05 level. Results were separately compared among treatments at each sampling period. The absence of letters indicates no significant differences among treatments for that particular sampling period.

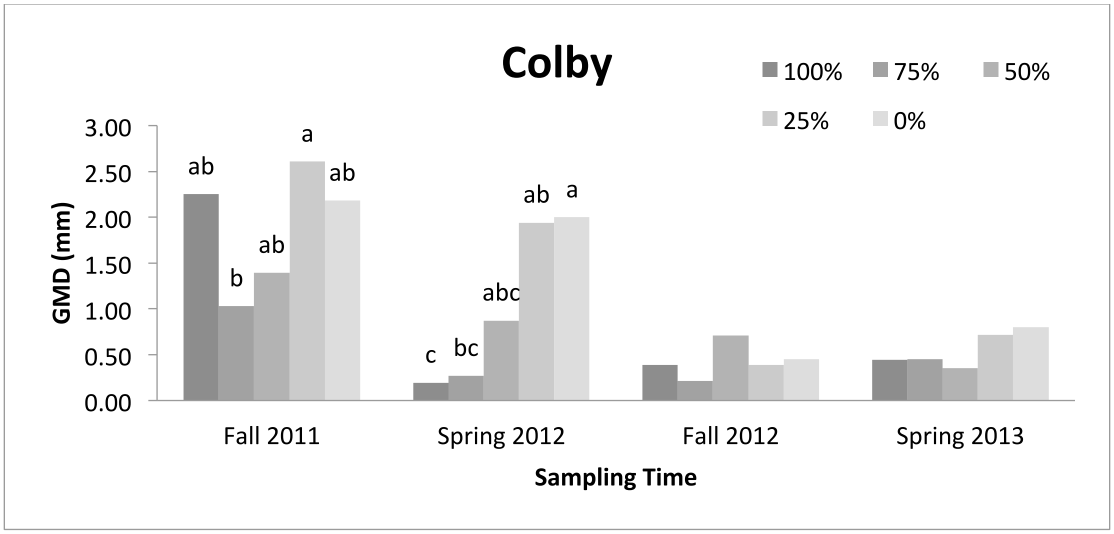


Figure 1.10 Geometric mean diameter (GMD) of dry aggregates at Norcatur. Treatments with different letters indicate significant differences at the p=0.05 level. Results were separately compared among treatments at each sampling period. The absence of letters indicates no significant differences among treatments for that particular sampling period.

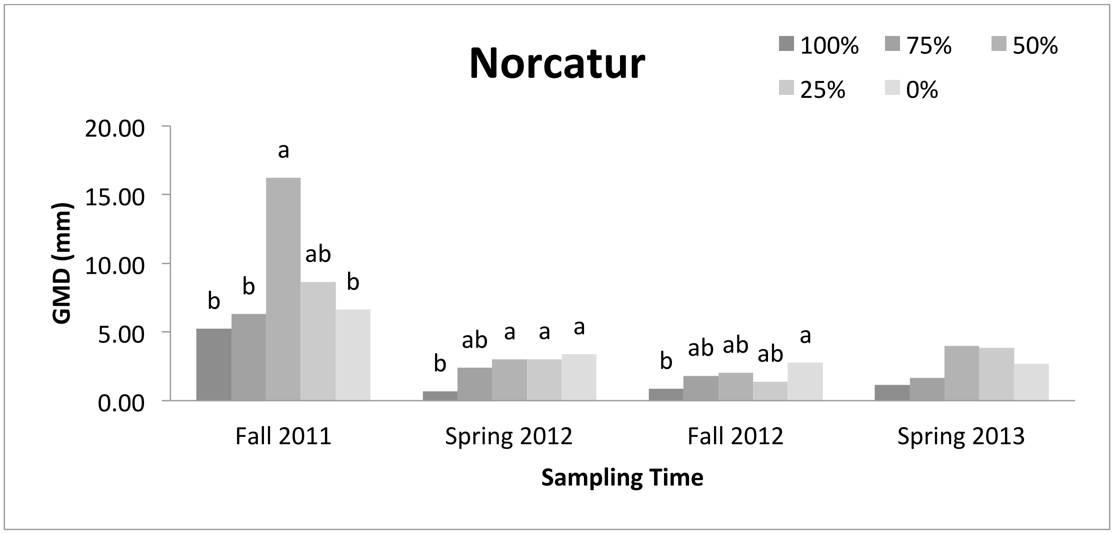


Figure 1.11 Geometric mean diameter (GMD) of dry aggregates at Garden City. Treatments with different letters indicate significant differences at the p=0.05 level. Results were separately compared among treatments at each sampling period. The absence of letters indicates no significant differences among treatments for that particular sampling period.

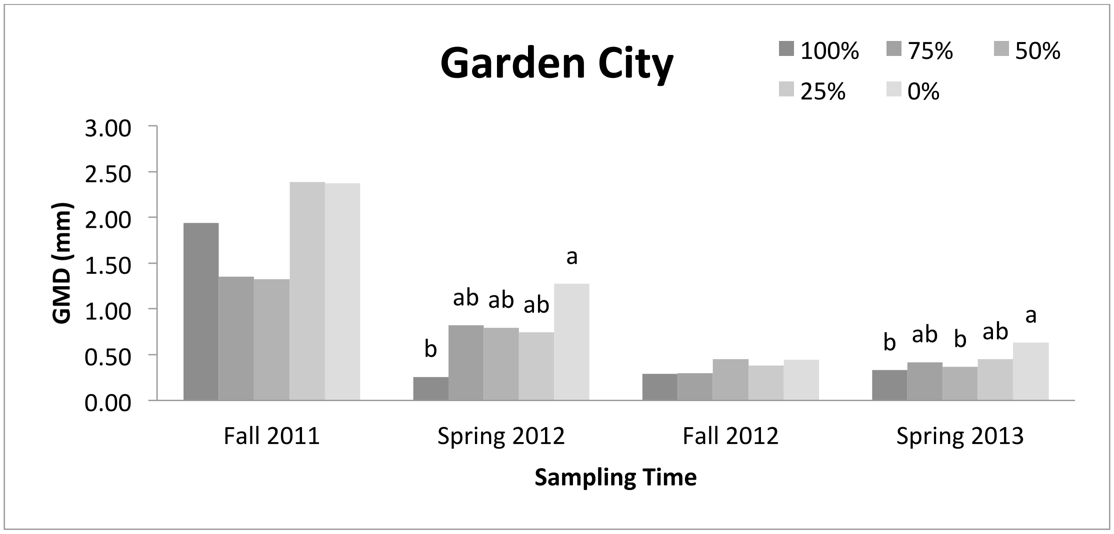


Figure 1.12 Geometric mean diameter (GMD) of dry aggregates at Scott City. Treatments with different letters indicate significant differences at the p=0.05 level. Results were separately compared among treatments at each sampling period. The absence of letters indicates no significant differences among treatments for that particular sampling period.

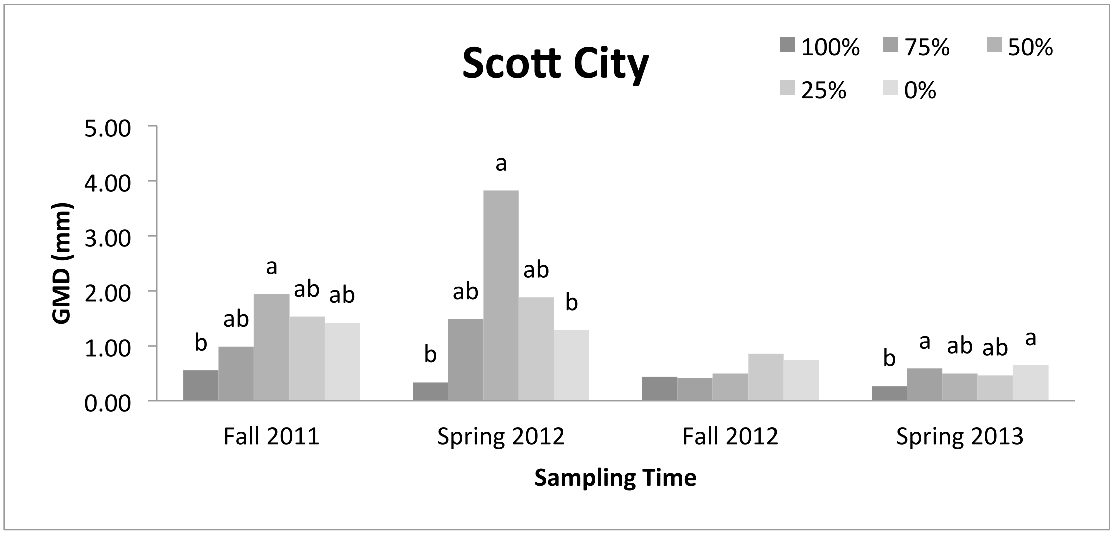


Figure 1.13 Geometric standard deviation (GSD) of dry aggregates at La Crosse. Treatments with different letters indicate significant differences at the p=0.05 level. Results were separately compared among treatments at each sampling period. The absence of letters indicates no significant differences among treatments for that particular sampling period.

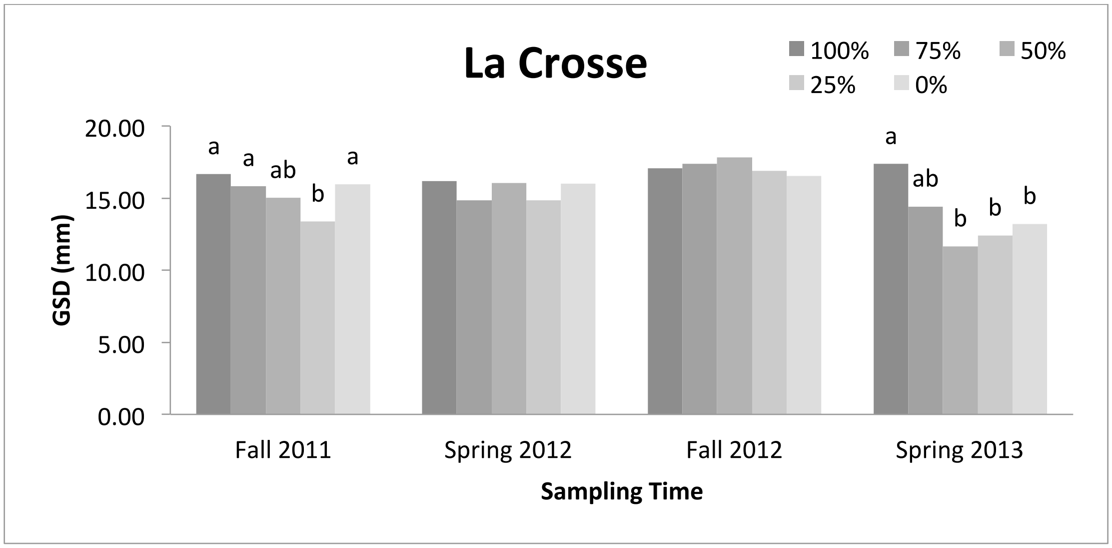


Figure 1.14 Geometric standard deviation (GSD) of dry aggregates at Rush Center. Treatments with different letters indicate significant differences at the p=0.05 level. Results were separately compared among treatments at each sampling period. The absence of letters indicates no significant differences among treatments for that particular sampling period.

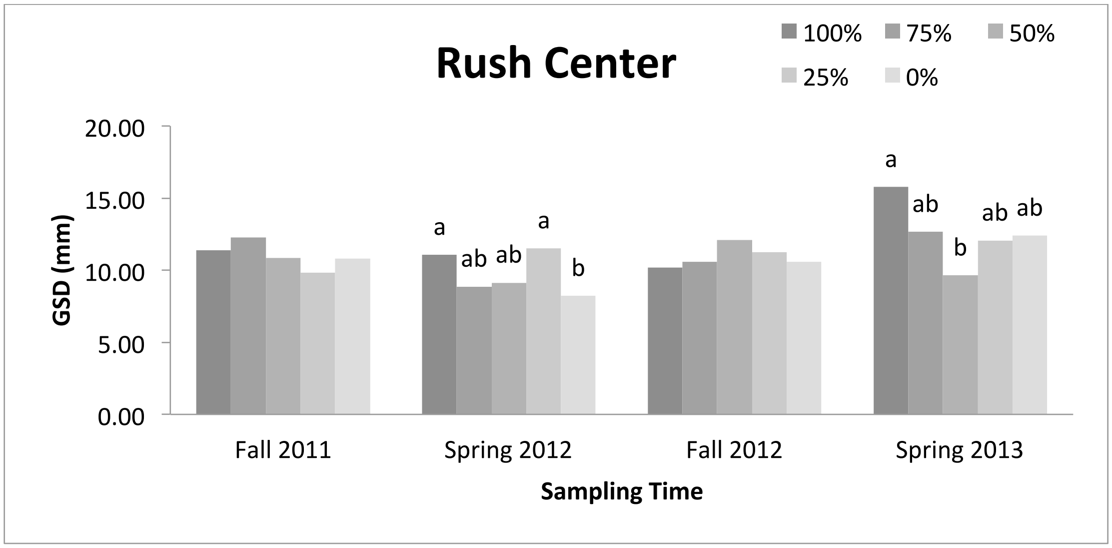


Figure 1.15 Geometric standard deviation (GSD) of dry aggregates at Colby. Treatments with different letters indicate significant differences at the p=0.05 level. Results were separately compared among treatments at each sampling period. The absence of letters indicates no significant differences among treatments for that particular sampling period.

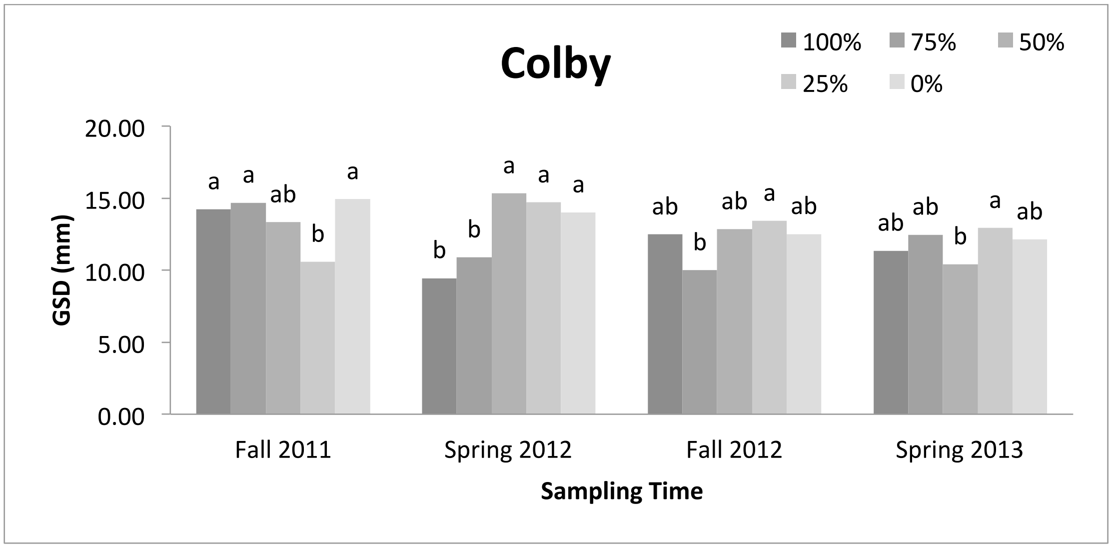


Figure 1.16 Geometric standard deviation (GSD) of dry aggregates at Norcatur. Treatments with different letters indicate significant differences at the p=0.05 level. Results were separately compared among treatments at each sampling period. The absence of letters indicates no significant differences among treatments for that particular sampling period.

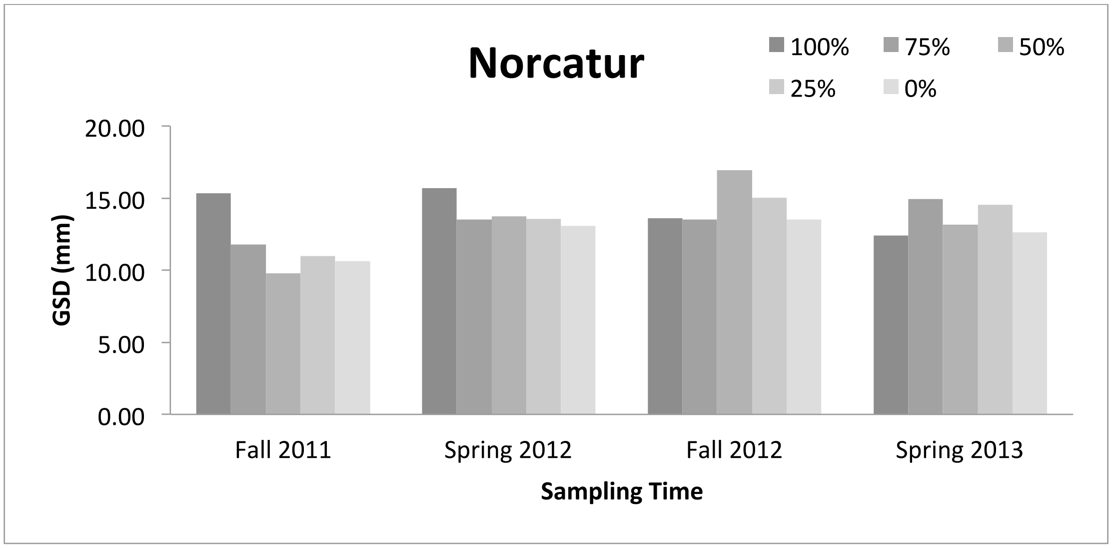


Figure 1.17 Geometric standard deviation (GSD) of dry aggregates at Garden City. Treatments with different letters indicate significant differences at the p=0.05 level. Results were separately compared among treatments at each sampling period. The absence of letters indicates no significant differences among treatments for that particular sampling period.

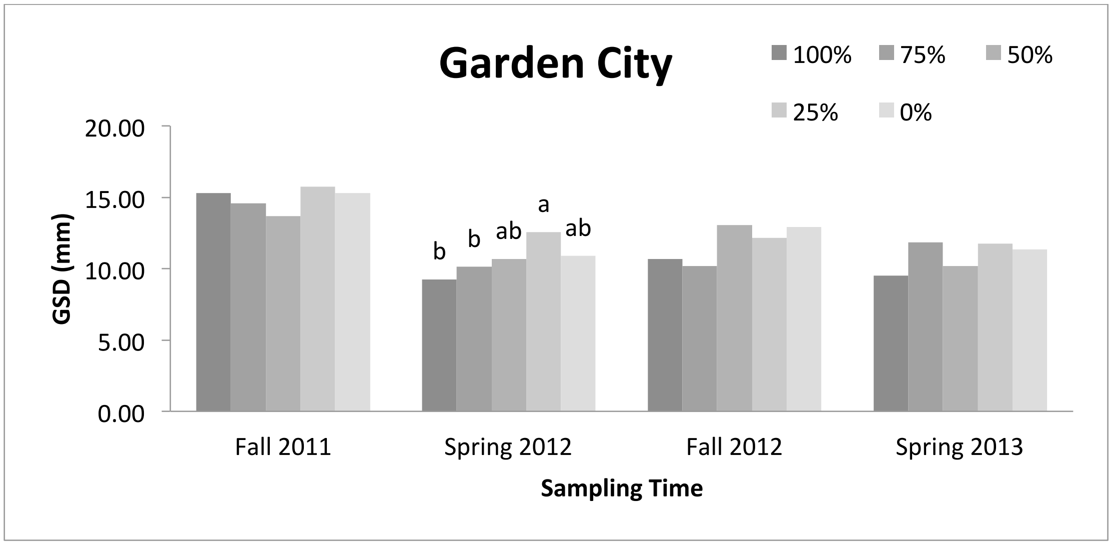


Figure 1.18 Geometric standard deviation (GSD) of dry aggregates at Scott City. Treatments with different letters indicate significant differences at the p=0.05 level. Results were separately compared among treatments at each sampling period. The absence of letters indicates no significant differences among treatments for that particular sampling period.

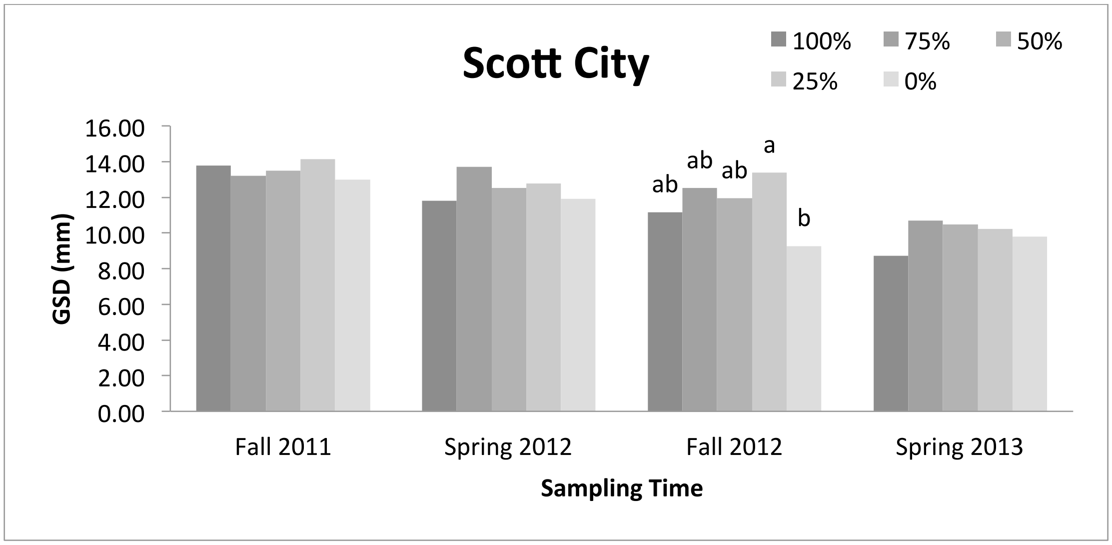


Figure 1.19 Soil dry aggregate stability (DAS) at La Crosse. Treatments with different letters indicate significant differences at the p=0.05 level. Results were separately compared among treatments at each sampling period. The absence of letters indicates no significant differences among treatments for that particular sampling period.

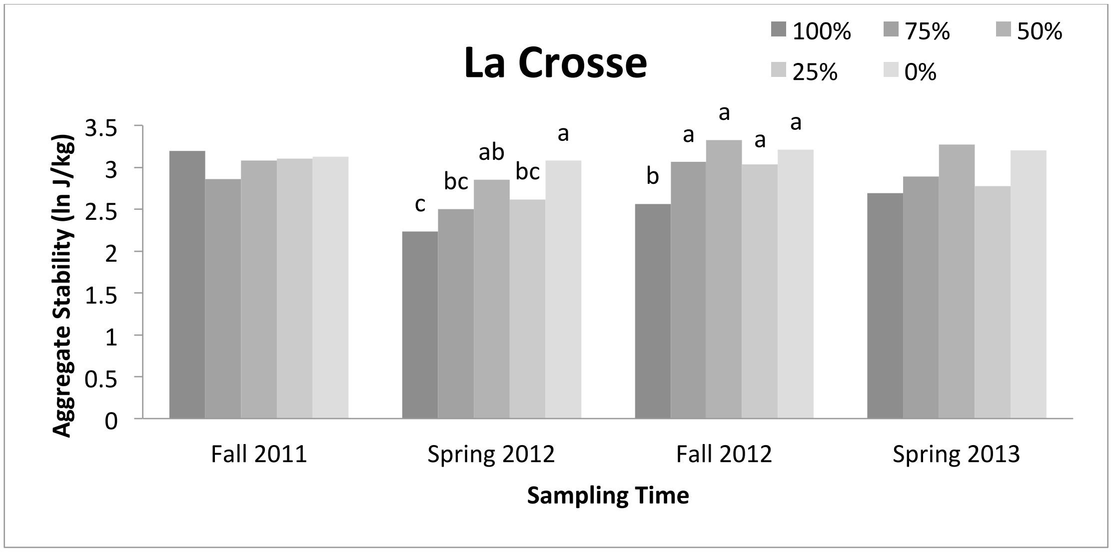


Figure 1.20 Soil dry aggregate stability (DAS) at Rush Center. Treatments with different letters indicate significant differences at the p=0.05 level. Results were separately compared among treatments at each sampling period. The absence of letters indicates no significant differences among treatments for that particular sampling period.

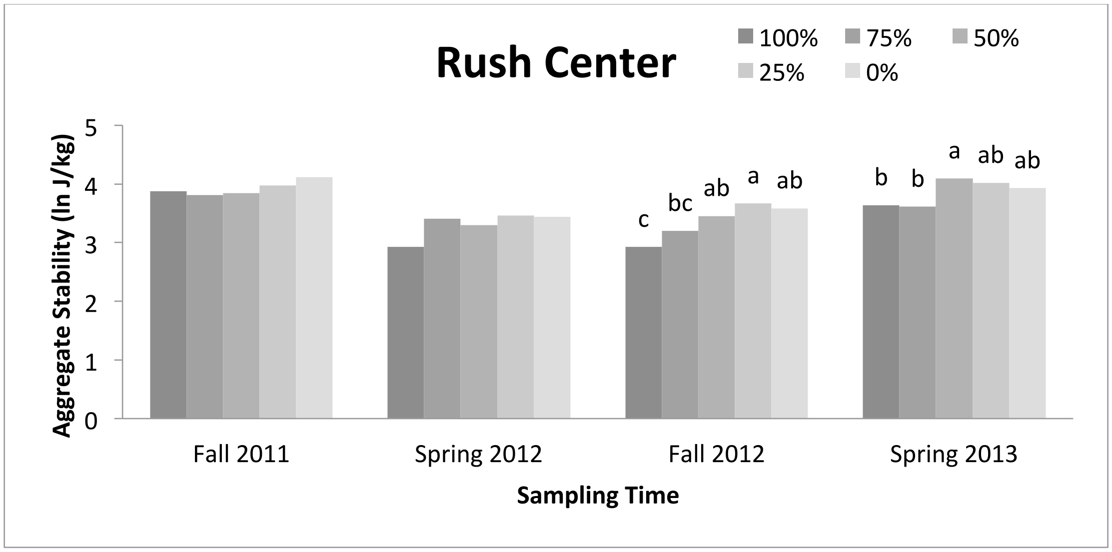


Figure 1.21 Soil dry aggregate stability (DAS) at Colby. Treatments with different letters indicate significant differences at the p=0.05 level. Results were separately compared among treatments at each sampling period. The absence of letters indicates no significant differences among treatments for that particular sampling period.

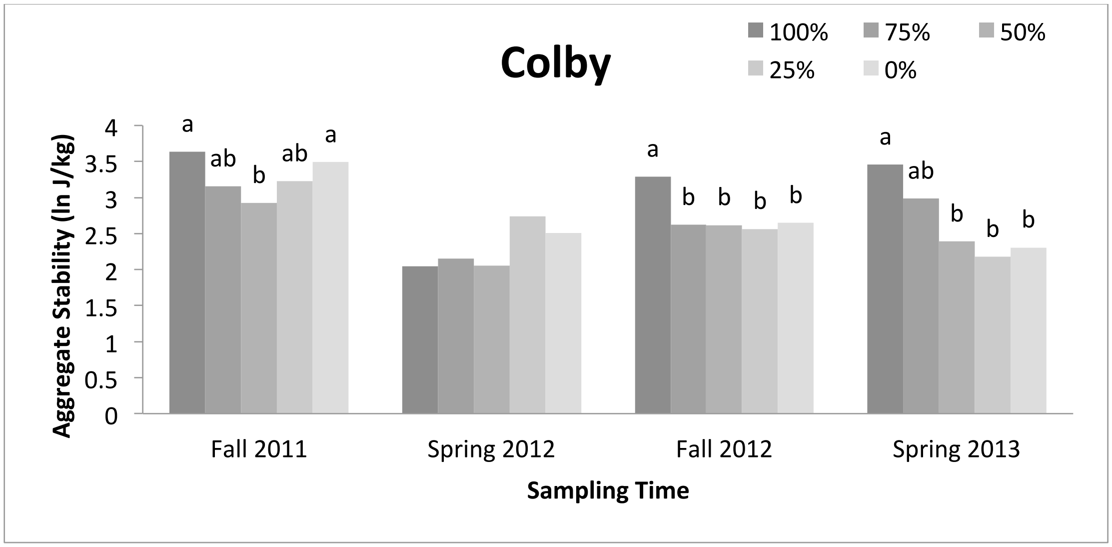


Figure 1.22 Soil dry aggregate stability (DAS) at Norcatur. Treatments with different letters indicate significant differences at the p=0.05 level. Results were separately compared among treatments at each sampling period. The absence of letters indicates no significant differences among treatments for that particular sampling period.

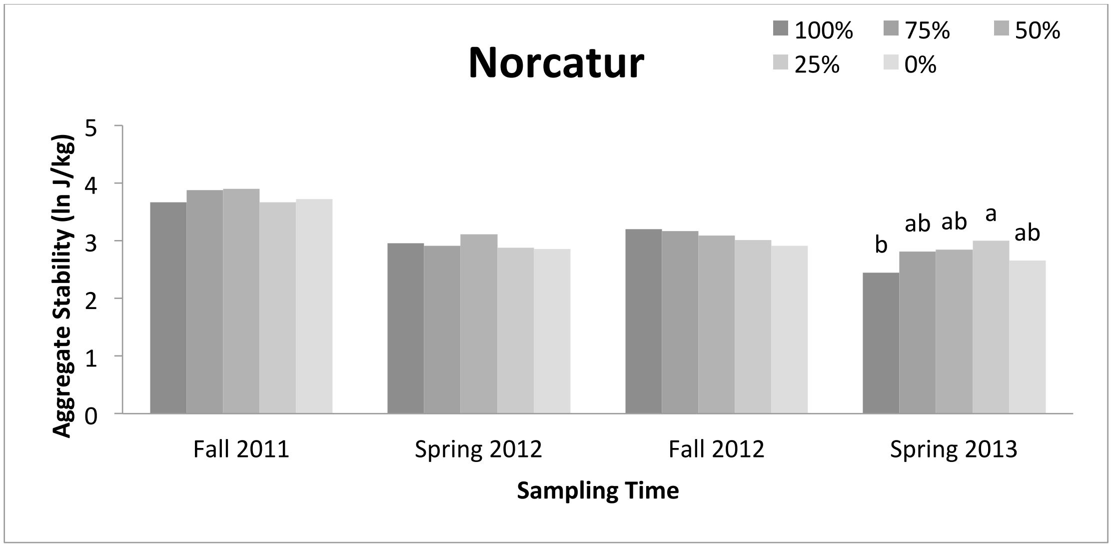


Figure 1.23 Soil dry aggregate stability (DAS) at Garden City. Treatments with different letters indicate significant differences at the p=0.05 level. Results were separately compared among treatments at each sampling period. The absence of letters indicates no significant differences among treatments for that particular sampling period.

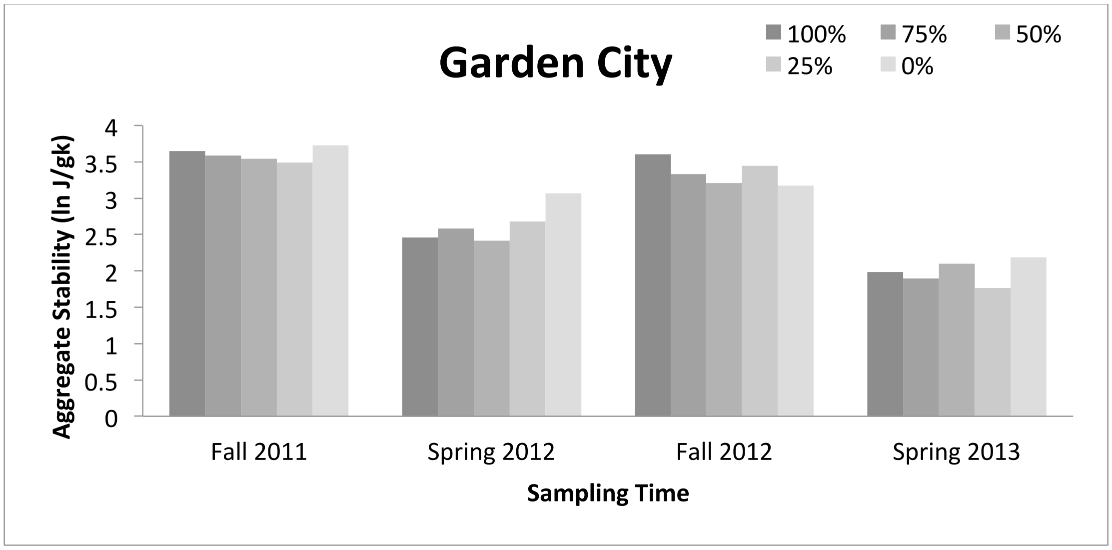


Figure 1.24 Soil dry aggregate stability (DAS) at Scott City. Treatments with different letters indicate significant differences at the p=0.05 level. Results were separately compared among treatments at each sampling period.

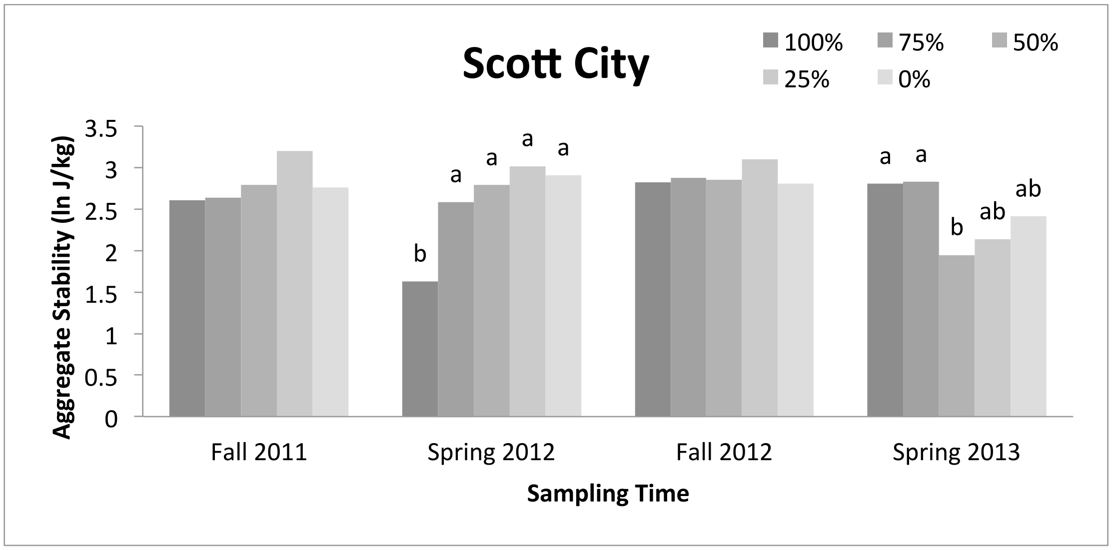


Figure 1.25 Surface random roughness at La Crosse. Treatments with different letters indicate significant differences at the p=0.05 level. Results were separately compared among treatments at every site at each sampling period. The absence of letters indicates no significant differences among treatments for that particular sampling period.

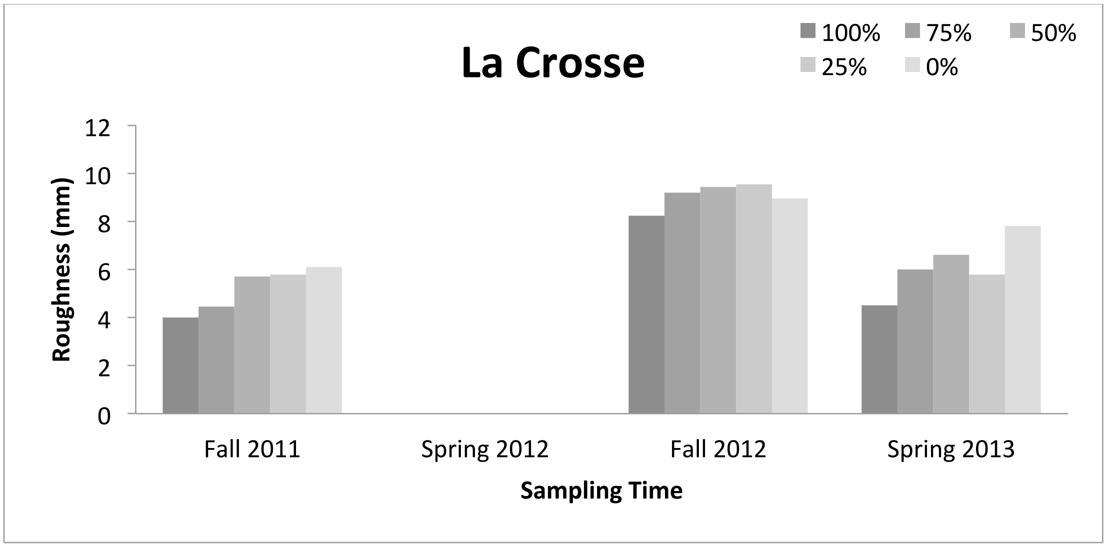


Figure 1.26 Surface random roughness at Rush Center. Treatments with different letters indicate significant differences at the p=0.05 level. Results were separately compared among treatments at every site at each sampling period. The absence of letters indicates no significant differences among treatments for that particular sampling period.

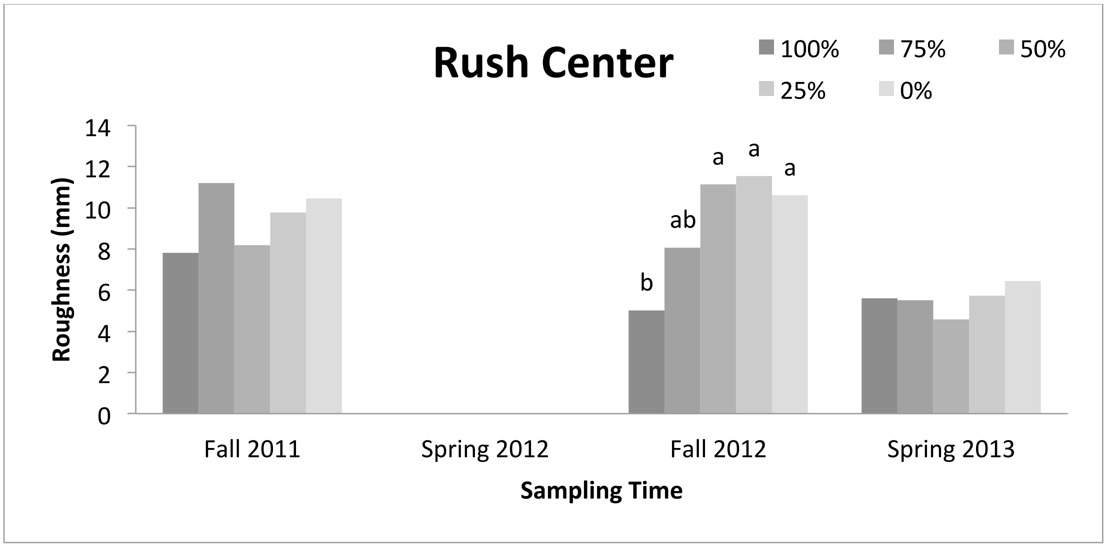


Figure 1.27 Surface random roughness at Colby. Treatments with different letters indicate significant differences at the p=0.05 level. Results were separately compared among treatments at every site at each sampling period. The absence of letters indicates no significant differences among treatments for that particular sampling period.

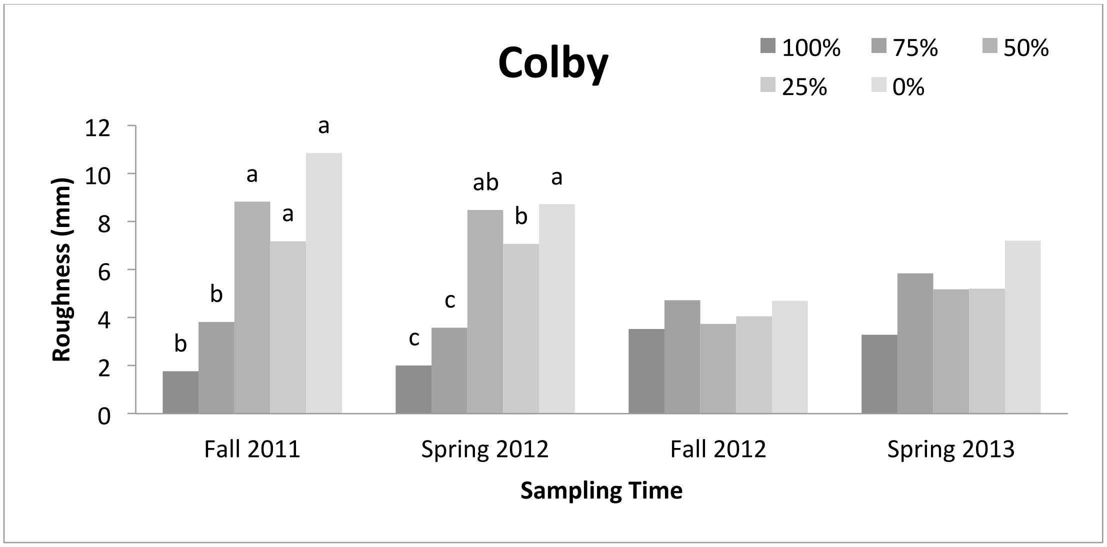


Figure 1.28 Surface random roughness at Norcatur. Treatments with different letters indicate significant differences at the p=0.05 level. Results were separately compared among treatments at every site at each sampling period. The absence of letters indicates no significant differences among treatments for that particular sampling period.

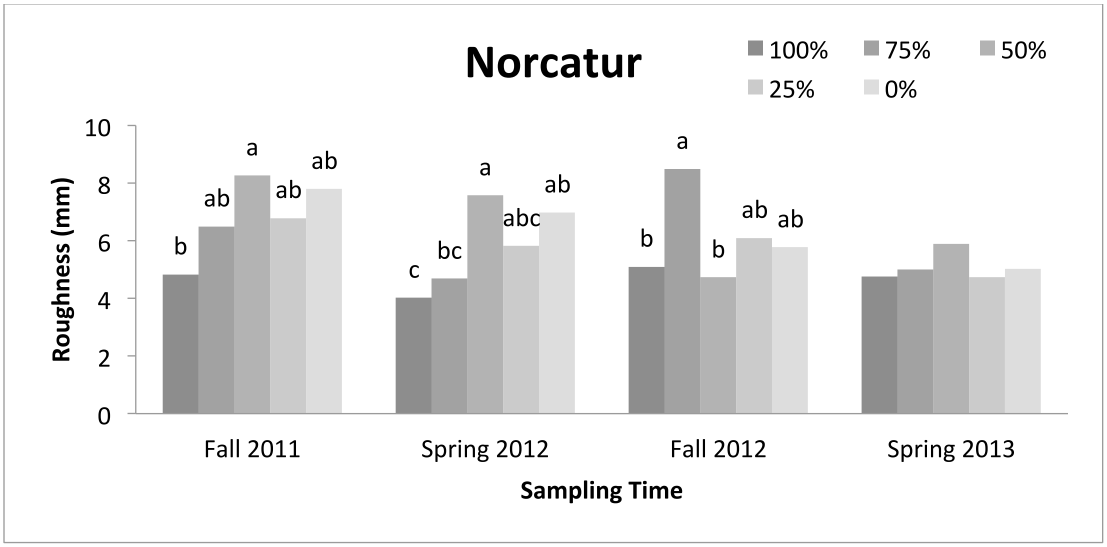


Figure 1.29 Surface random roughness at Garden City. Treatments with different letters indicate significant differences at the p=0.05 level. Results were separately compared among treatments at every site at each sampling period. The absence of letters indicates no significant differences among treatments for that particular sampling period.

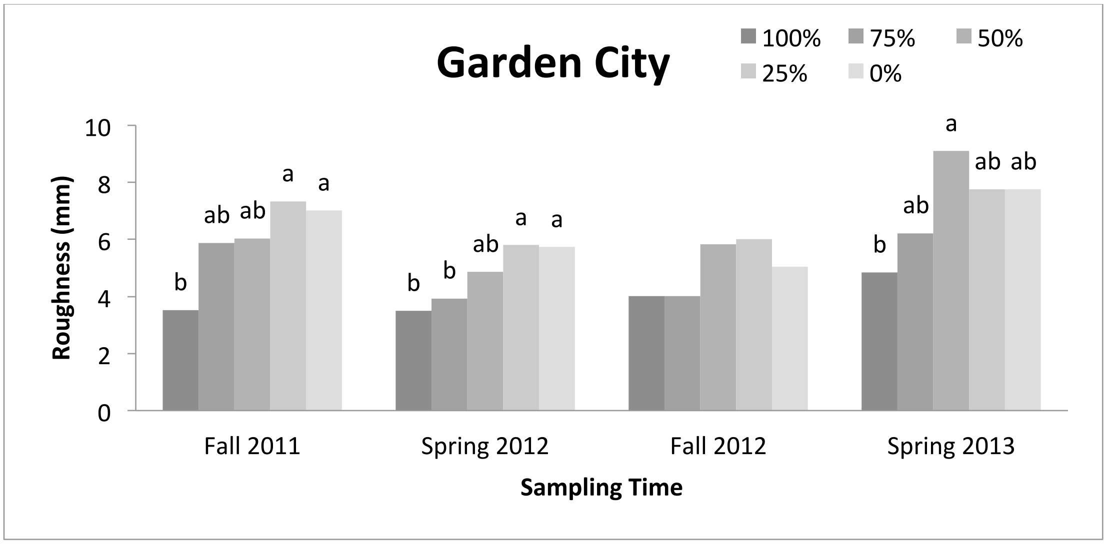


Figure 1.30 Surface random roughness at Scott City. Treatments with different letters indicate significant differences at the p=0.05 level. Results were separately compared among treatments at every site at each sampling period. The absence of letters indicates no significant differences among treatments for that particular sampling period.

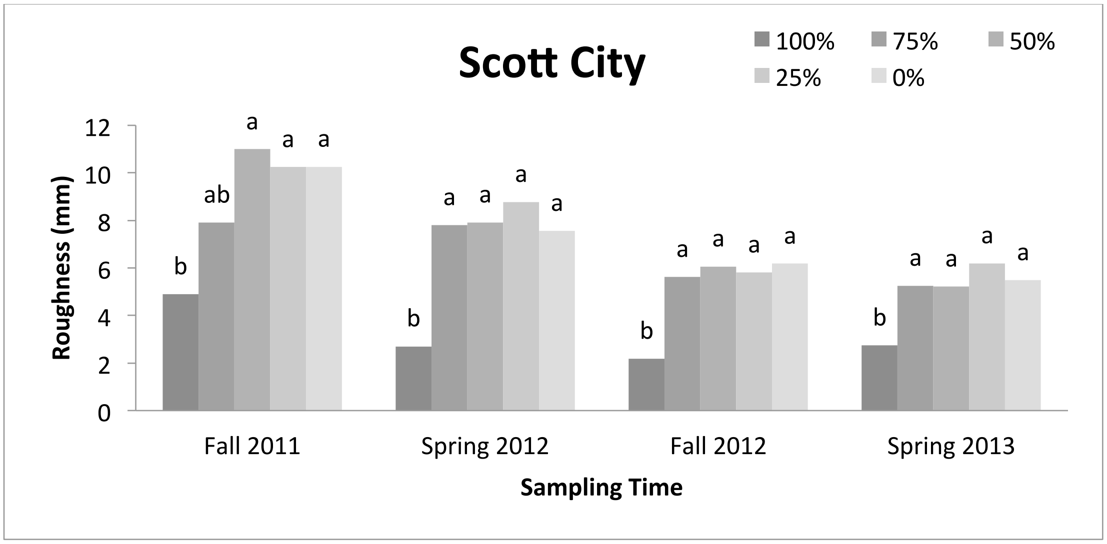


Figure 1.31 Wind erosion threshold velocity simulated by SWEEP at La Crosse. Treatments with different letters indicate significant differences at the p=0.05 level. Results were separately compared among treatments at each sampling period. The absence of letters indicates no significant differences among treatments for that particular sampling period.

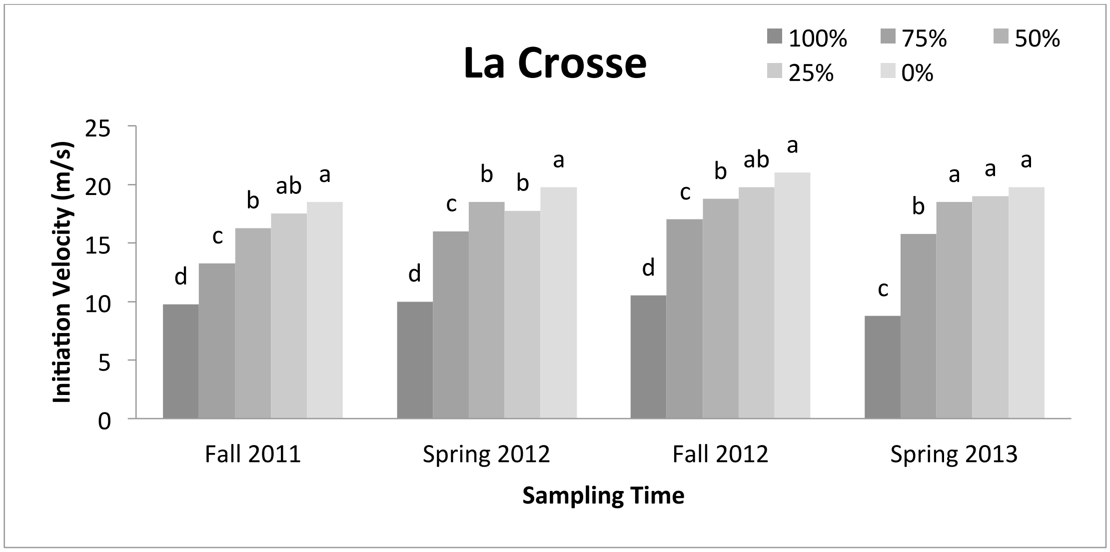


Figure 1.32 Wind erosion threshold velocity simulated by SWEEP at Rush Center. Treatments with different letters indicate significant differences at the p=0.05 level. Results were separately compared among treatments at each sampling period. The absence of letters indicates no significant differences among treatments for that particular sampling period.

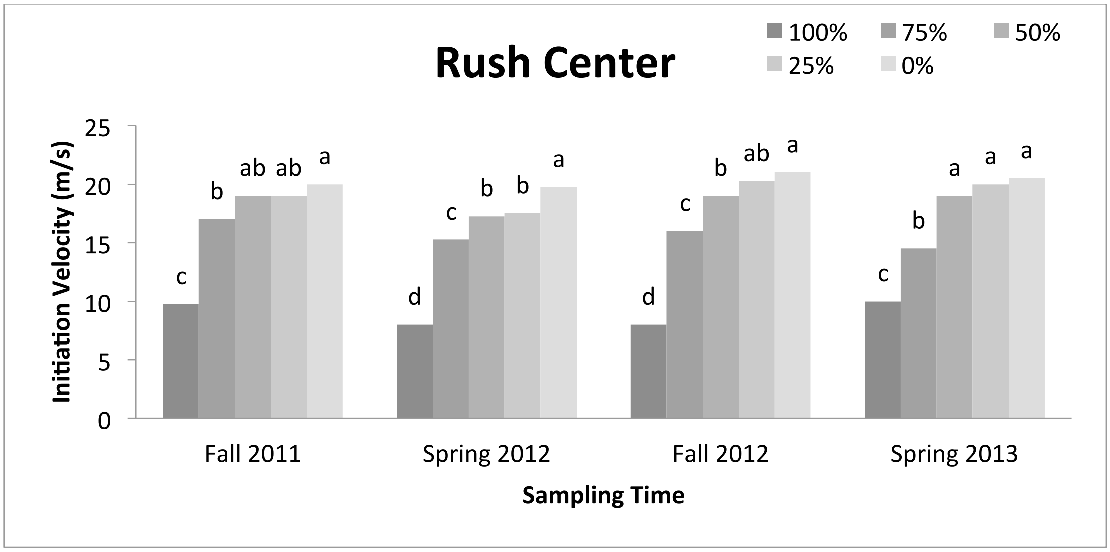


Figure 1.33 Wind erosion threshold velocity simulated by SWEEP at Colby. Treatments with different letters indicate significant differences at the p=0.05 level. Results were separately compared among treatments at each sampling period.

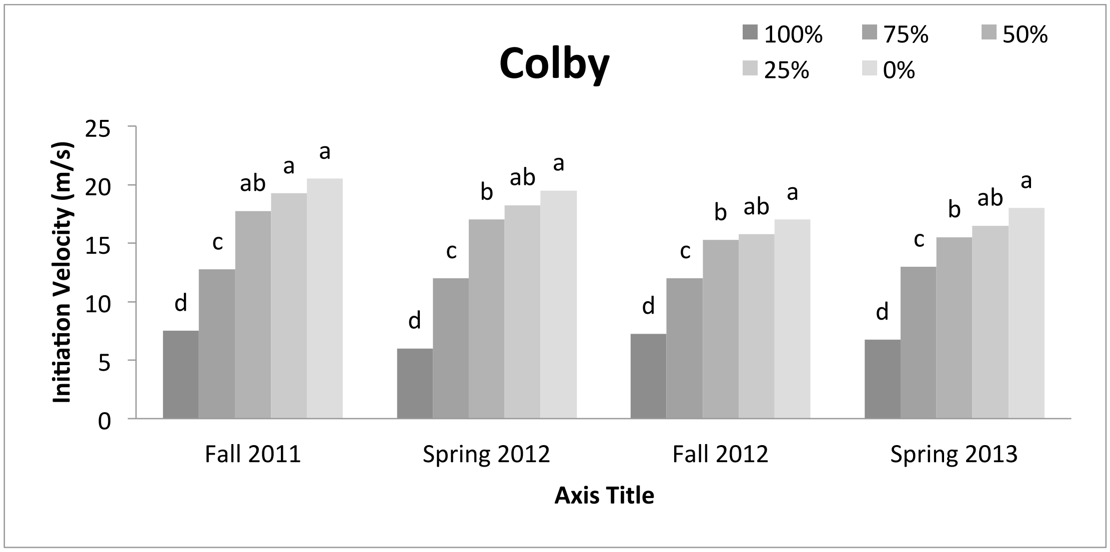


Figure 1.34 Wind erosion threshold velocity simulated by SWEEP at Norcatur. Treatments with different letters indicate significant differences at the p=0.05 level. Results were separately compared among treatments at each sampling period.

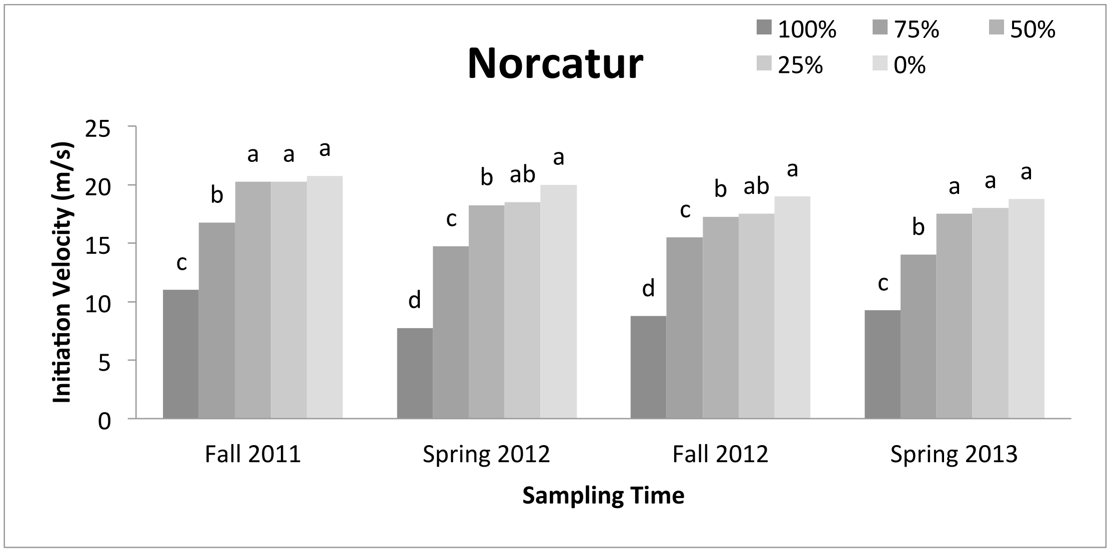


Figure 1.35 Wind erosion threshold velocity simulated by SWEEP at Garden City. Treatments with different letters indicate significant differences at the p=0.05 level. Results were separately compared among treatments at each sampling period.

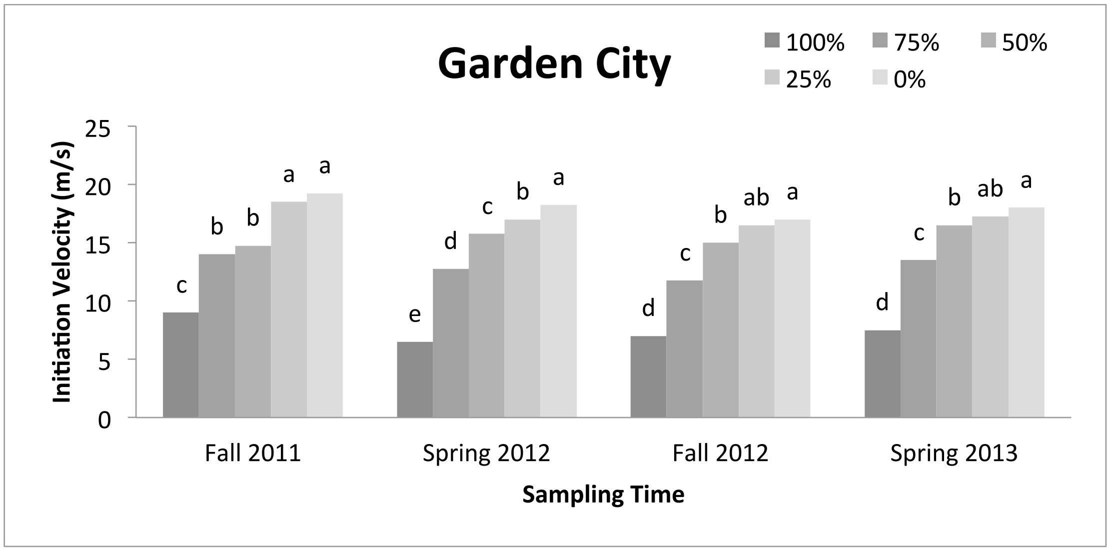


Figure 1.36 Wind erosion threshold velocity simulated by SWEEP at Scott City. Treatments with different letters indicate significant differences at the p=0.05 level. Results were separately compared among treatments at each sampling period.

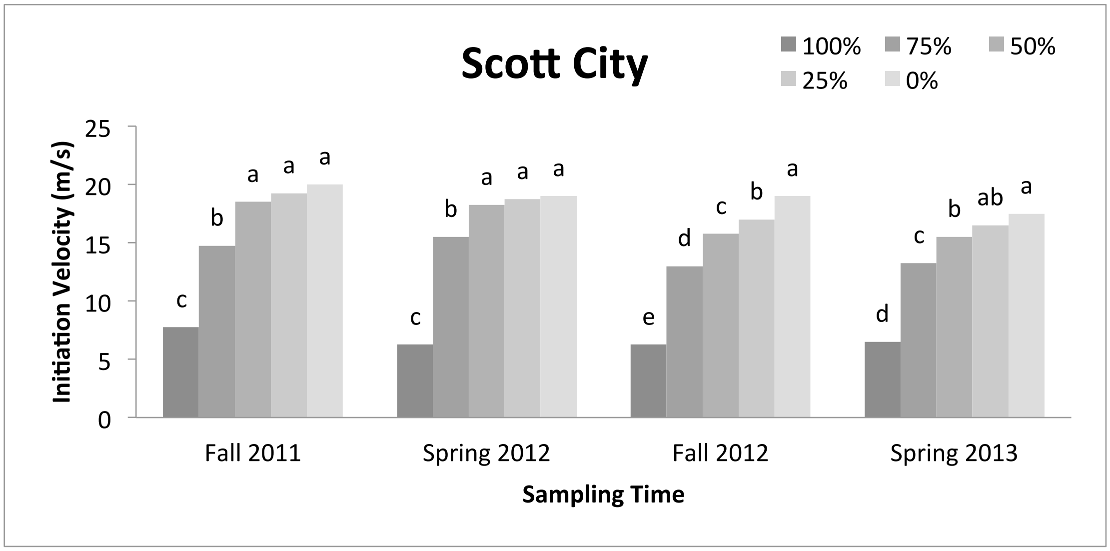


Figure 1.37 Precipitation in 2011, 2012, 2013 and monthly average at the La Crosse site.

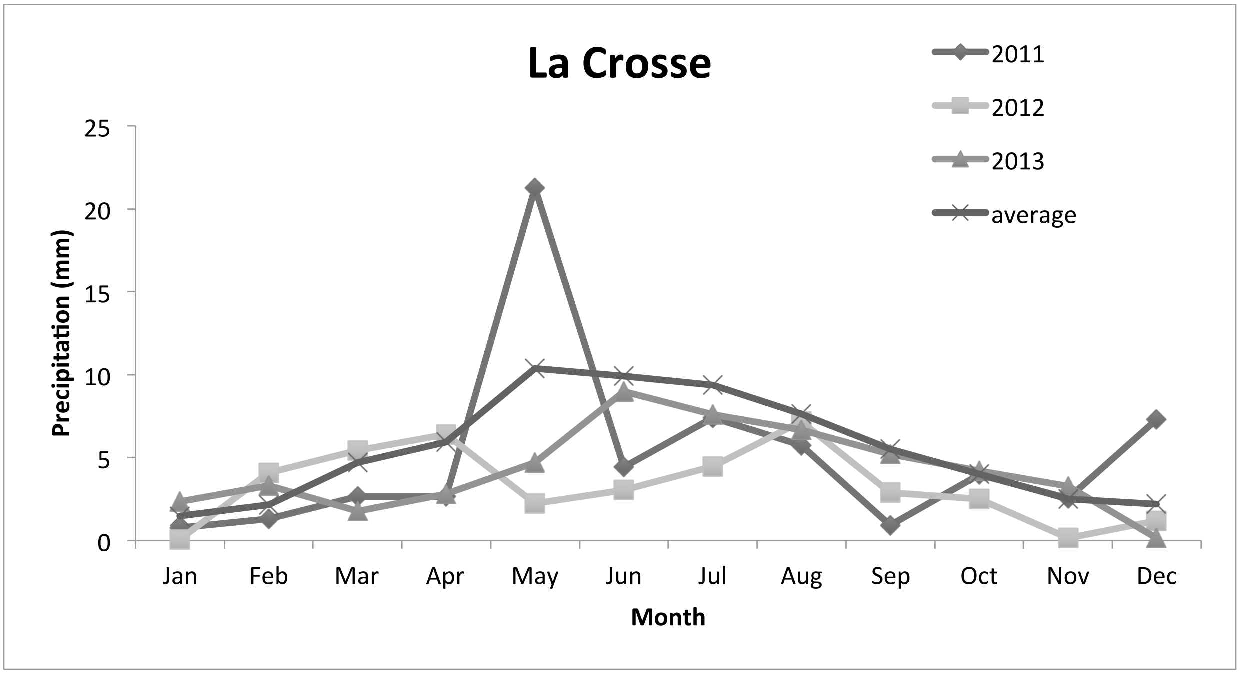


Figure 1.38 Precipitation in 2011, 2012, 2013 and monthly average at the Rush Center site.

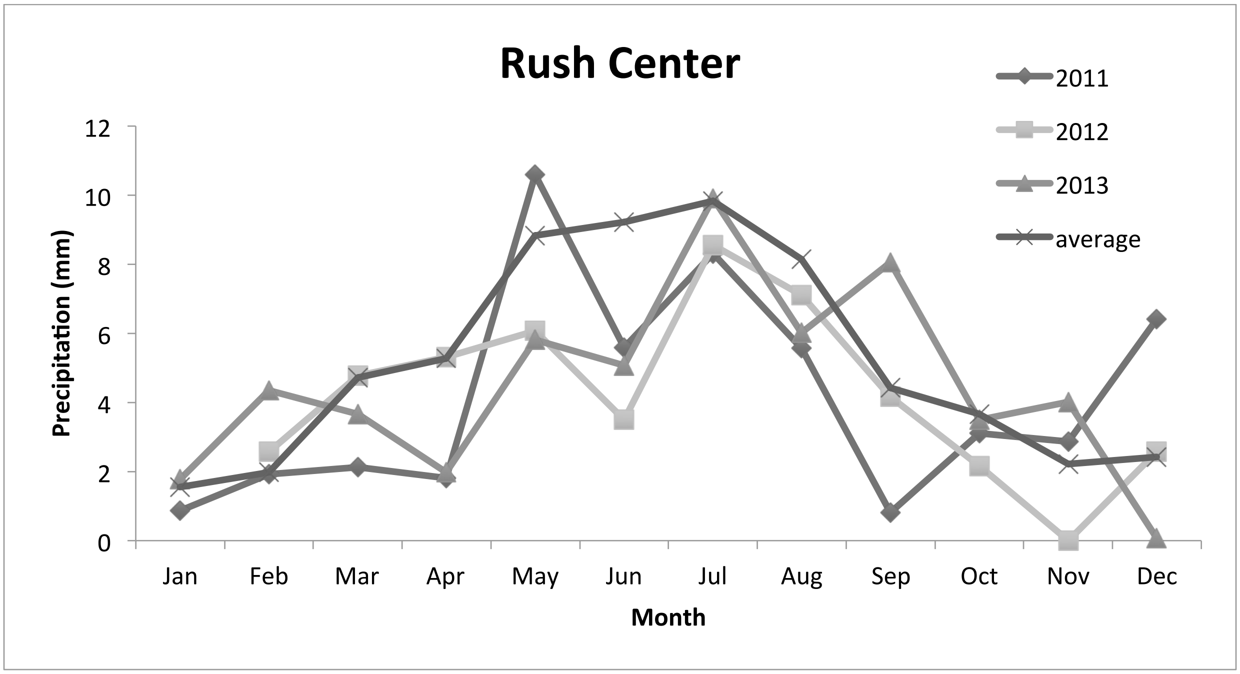


Figure 1.39 Precipitation in 2011, 2012, 2013 and monthly average at the Colby site.

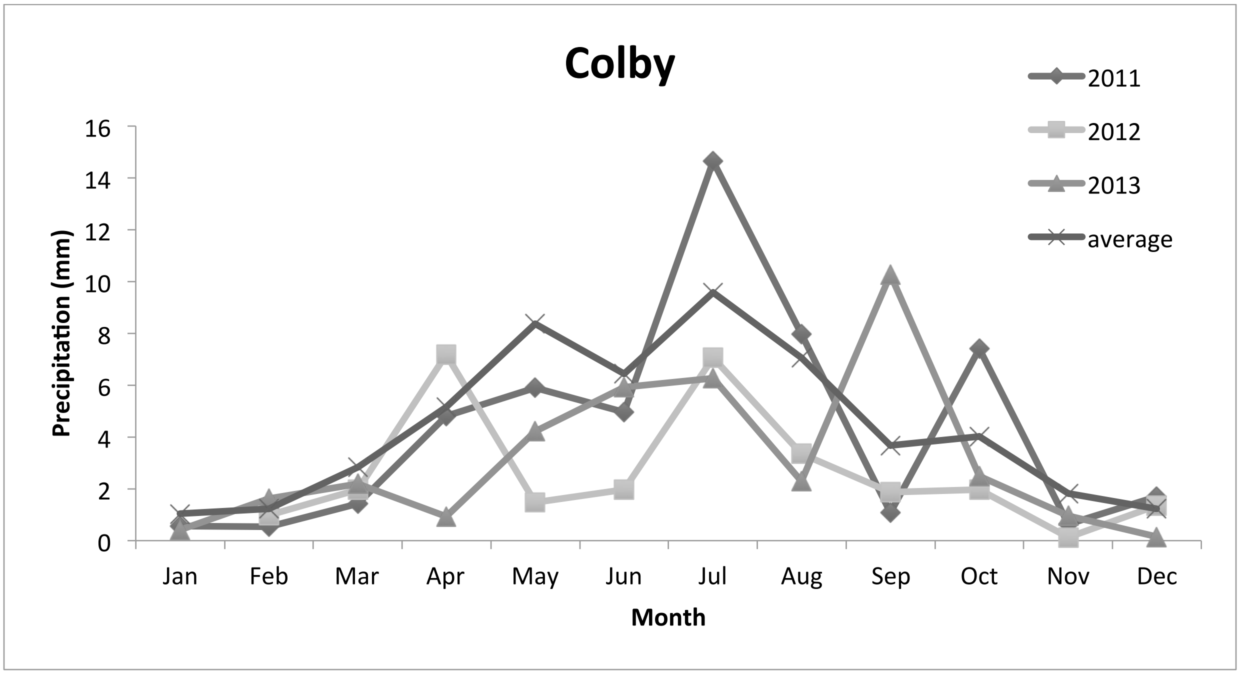


Figure 1.40 Precipitation in 2011, 2012, 2013 and monthly average at the Norcatur site.

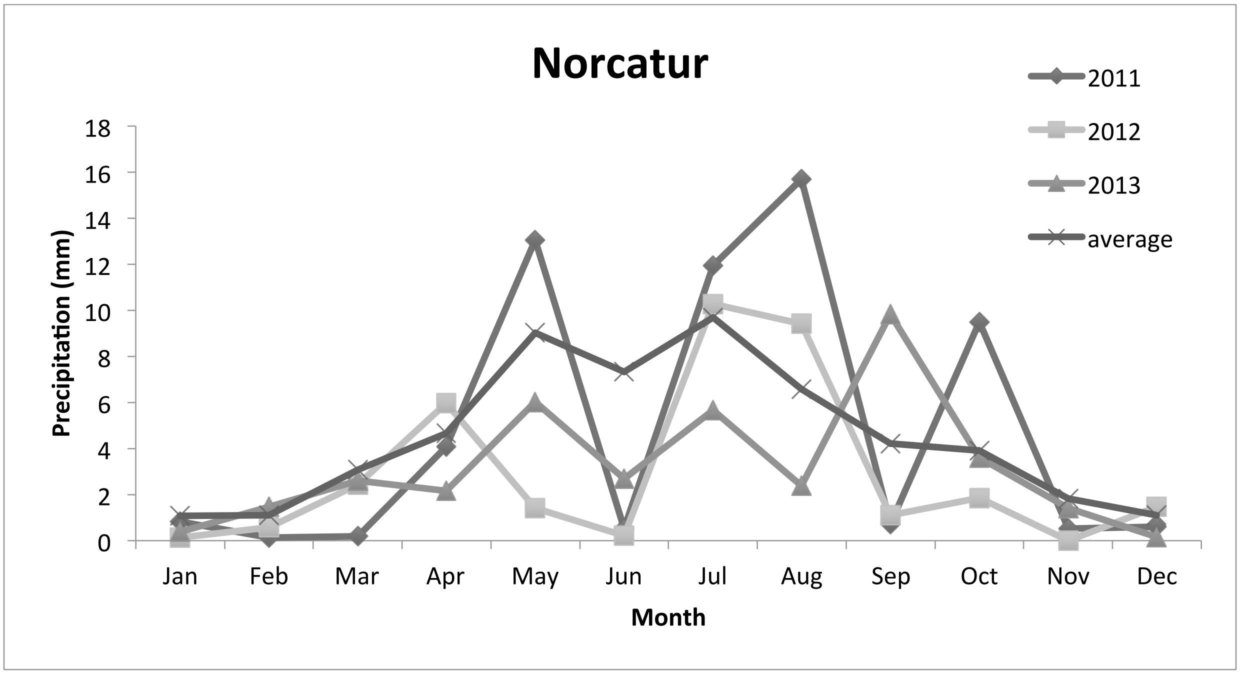


Figure 1.41 Precipitation in 2011, 2012, 2013 and monthly average at the Garden City site.

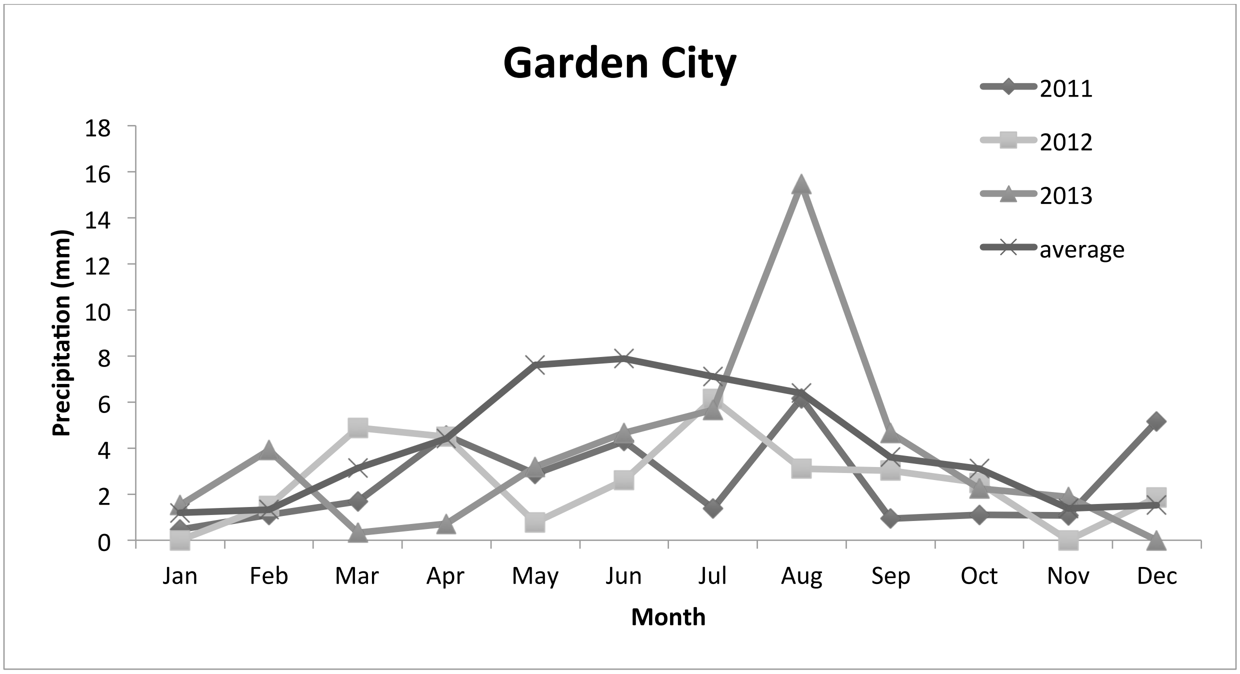


Figure 1.42 Precipitation in 2011, 2012, 2013 and monthly average at the Scott City site.

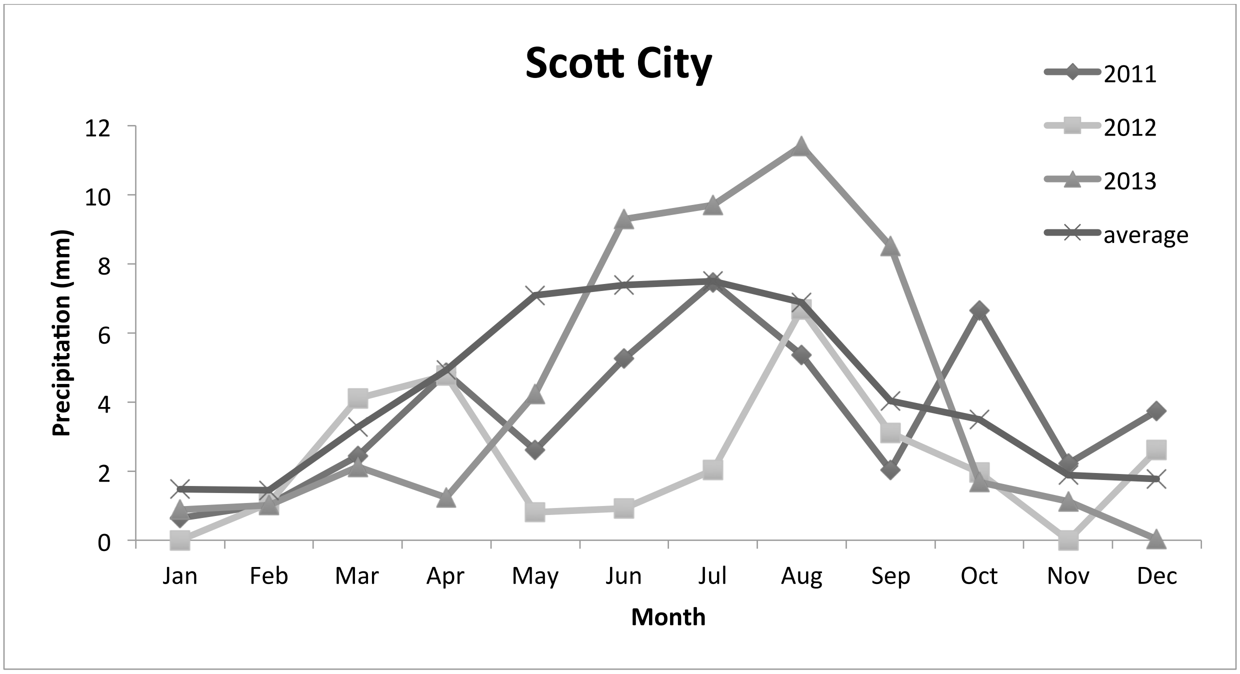


Table 1.1 Soil information, cropping system and management of the six experimental sites. Soil slope is < 1% at all sites.

Experimental Site	Soil series	Cropping system (Spring 2011—Spring 2013	Years NT	Total N (%)	Total C (%)	C:N	Sand (%)	Silt (%)	Clay (%)
La Crosse	Harney silt loam	Wheat-wheat-sorghum-fallow	11	0.24	3.21	13.42	24	62	14
Rush Center	Bridgeport silt loam	Wheat-wheat-fallow	8	0.23	3.26	14.13	22	60	18
Colby	Richfield silt loam	Wheat-corn-fallow	15	0.35	4.83	13.93	28	56	16
Norcatur	Ulysses silt loam	Wheat-corn-fallow	20	0.16	1.62	10.35	30	54	16
Garden City	Ulysses silt loam	Wheat-fallow-wheat	5	0.16	2.07	12.92	28	52	20
Scott City	Richfield silt loam	Wheat-sorghum-sorghum	17	0.18	1.95	10.97	24	58	18

Table 1.2 Sampling time at each research site.

	Initiation Time	Sampling Time			
Site		Fall 2011	Spring 2012	Fall 2012	Spring 2013
La Crosse	June 2011	November	March	November	May
Rush Center					
Colby					March
Norcatur					
Garden City					
Scott City					

Table 1.3 Probability (%) of days when wind speed reaches the wind erosion threshold velocity simulated by SWEEP across six sites among four sampling periods. Treatments with different letters indicate significant differences at the P=0.05 level. Results were separately compared among treatments at every site at each sampling period.

Site	Removal	2011 Fall	2012 Spring	2012 Fall	2013 Spring
La Crosse	100%	9.70a	11.28a	9.63a	17.65a
	75%	1.66b	0.58b	0.34b	0.76b
	50%	0.29c	0.15c	0.14c	0.18c
	25%	0.13c	0.23c	0.07c	0.12c
	0%	0.05c	0.07c	0.02c	0.08c
Rush Center	100%	10.50a	21.98a	15.81a	14.03a
	75%	0.16b	1.06b	0.11b	1.21b
	50%	0.03c	0.28c	0.01c	0.12c
	25%	0.05c	0.25c	0.00c	0.06c
	0%	0.02c	0.07c	0.00c	0.05c
Colby	100%	21.74a	49.98a	25.52a	41.52a
	75%	1.77b	6.49b	6.49b	5.45b
	50%	0.15c	1.06c	1.91c	1.76c
	25%	0.06c	0.57c	1.63c	1.27c
	0%	0.02d	0.33d	1.05d	0.68d
Norcatur	100%	5.22a	26.38a	11.77a	16.16a
	75%	0.25b	1.11b	0.81b	2.06b
	50%	0.04c	0.22c	0.30c	0.26c
	25%	0.04c	0.16c	0.22c	0.22c
	0%	0.02c	0.05d	0.04d	0.13c
Garden City	100%	14.38a	47.88a	31.56a	36.38a
	75%	1.05b	5.37b	4.40b	4.12b
	50%	0.59c	1.51c	1.25c	1.14c
	25%	0.10d	0.87d	0.56d	0.82c
	0%	0.07d	0.49d	0.47d	0.57d
Scott City	100%	25.92a	50.88a	39.42a	47.88a
	75%	0.68b	1.67b	2.41b	4.43b
	50%	0.11c	0.58c	0.74c	1.65c
	25%	0.09c	0.41c	0.46c	1.12c
	0%	0.05c	0.36c	0.24c	0.74d

Table 1.4 Amount of soil loss at 13 m s^{-1} wind speed simulated by SWEEP under 75 and 100% removal levels at each site.

Site	Removal	2011 Fall	2012 Spring	2012 Fall	2013 Spring
La Crosse	100%	0.97	1.69*	1.26*	1.36*
	75%	0.06	0.00	0.00	0.00
Rush Center	100%	0.40	1.14*	1.19*	0.53
	75%	0.00	0.00	0.00	0.00
Colby	100%	0.67	2.70*	1.10	1.00
	75%	0.05	0.29	0.23	0.13
Norcatur	100%	0.48	0.91	0.95	1.55*
	75%	0.00	0.00	0.00	0.03
Garden City	100%	0.66	2.06*	0.95	2.32*
	75%	0.01	0.16	0.17	0.13
Scott City	100%	1.37*	2.38*	1.36*	1.41*
	75%	0.00	0.00	0.08	0.08

* Soil losses are above the NRCS tolerable soil loss limit of 1.12 kg m^{-2} for the study soils.

Table 1.5 Probability (%) of wind speed ≥ 13 m s^{-1} at the nearest weather station from each study site in each month.

Research Site	Nearest Wind Station	County	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
La Crosse & Rush Center	Hays Municipal (AWAS)	Ellis	1.1	1.3	2.8	2.4	0.7	1.0	0.6	0.2	0.7	1.7	1.0	0.6
Colby	Goodland/Renner (AW)	Thomas	1.8	2.2	4.5	4.1	2.5	1.2	0.4	0.3	0.7	1.5	2.0	1.5
Norcatur	US NE McCook	Decatur	1.3	1.7	2.9	3.7	1.7	0.8	0.3	0.2	0.5	1.4	1.6	1.0
Garden City & Scott City	Garden City Municipal	Finney	1.8	2.6	4.9	4.6	2.6	1.9	1.0	0.6	1.2	1.8	2.4	1.9

References

Allmaras, R.R., R.E. Burwell, W.E. Larson, and R.F. Holt. 1966. Total porosity and random roughness of the interrow zone as influenced by tillage. USDA Cons. Res. Rpt. 7.

Arshad, M. A., Franzluebbers, A. J., Azooz, R.H., 1999. Components of surface soil structure under conventional and no-tillage in northwest Canada. *Soil Till Res*. 53: 41-47.

Benyamini, Y. and Unger, P. W. 1984. Crust development under simulated rainfall on four soils. In: *agronomy Abstracts.* P. 243. ASA, Madison, WI.

Bielders, C. L., Michels, K., and J. L. Rajot, 2000. On-farm evaluation of ridging and residue management practices to reduce wind erosion in Niger. *Soil Sci. Soc. Am. J.* 64: 1776-1785.

Bilbro, J. D., and Fryrear, D. W.1988. Plant material for windbarriers in semiarid regions. p. 150- 157. *In* Proc. Wind Erosion Conference, Lubbock, TX. April 11-13, 1988.

Blanco-Canqui, H. 2010. Energy Crops and Their Implications on Soil and Environment. 2010 . *Agron. J.* 102: 403-419.

Blanco-Canqui, H., Lal, R., Post, W. M., Izaurralde, R. C., and Owens, L. B. 2006. Soil structural parameters and organic carbon in no-till corn with variable stover retention rates. *Soil Sci*. 171: 468-482

Blanco-Canqui, H., and Lal, R. 2009a. Crop residue removal effects on soil productivity and environmental quality. *Crit. Rev. Plant Sci*. 28:139–163.

Blanco-Canqui, H., and Lal, R. 2009b. Corn Stover removal for expanded uses reduces soil fertility and structural stability. *Soil Sci. Soc. Am. J.* 73: 943-946.

Boyd, D. W., Skidmore, E. L., and Thompson, J. G., 1983. A soil-aggregate crushing-energy meter. *Soil Sci. Soc. Am. J.* 47: 313-316.

Braida, J. A., Reichert, J. M., da Veiga, M., and Reinert, D. J. 2006. Mulch and soil organic carbon content and their relationship with the maximum soil density obtained in the proctor. *Rev. Brasileira De Cienc. Do Solo* 30: 605–614.

Bullock, M. S., Larney, F. J., Izaurralde, R. C., Feng, Y., 2001. Overwinter changes in wind erodibility of clay loam soils in southern Alberta. Soil Sci. Soc. Am. J. 65, 423–430.

Buschiazzo, D. E. and Zobeck, T.M., 2008. Validation of WEP, RWEQ and WEPS wind erosion for different arable land management systems in the Argentinean Pampas. *Earth Surf. Process. Landforms* 33: 1839-1850.

Chan C. K. and Yao X., 2008. Air pollution in mega cities in China. *Atmospheric Environment* 42: 1-42.

Chepil, W. S., 1945. Dynamics of wind erosion: I. Nature of movement of soil by wind. *Soil Sci*. 60: 305-320.

Chepil, W. S., 1952. Improve rotary sieve for measuring state and stability of dry soil structure. *Soil Sci. Soc. Am. Proc*. 26:4-6.

Chepil, W.S., 1962. A compact rotary sieve and the importance of dry sieving in physical soil analysis. *Soil Sci. Soc. Am. J.* 1962, 26, 4–6, doi:10.2136/sssaj1962.03615995002600010002x.

Colacicco, D., Osborn, T., and Alt, K. 1989. Economic damage from soil erosion. *J. Soil Water Conserv*. 44:35–39.

Colazo, J. C., and Buschiazzo, D. E., 2010. Soil dry aggregate stability and wind erodible fraction in a semiarid environment of Argentina. *Geoderma* 159: 228-236

Dam, R. F., Mehdi, B. B., Burgess, M.S.E., Madramootoo, C.A., Mehuys, G.R., Callum, I.R., 2005. Soil bulk density and crop yield under eleven consecutive years of corn with different tillage and residue practices in a sandy loam soil in central Canada. *Soil Till. Res*. 84: 41–53

Devine, S., Markewitz, D., Hendrix, P., and Coleman, D. 2014. Soil Aggregates and Associated Organic Matter under Conventional Tillage, No-Tillage, and Forest Succession after Three Decades. PLoS ONE 9(1): e84988. doi:10.1371/journal.pone.0084988

Evers, B. J., Blanco-Canqui, H., Staggenborg, S. A., and Tatarko, J. 2013. Dedicated bioenergy crop impacts on soil wind erodibility and organic carbon in Kansas. Agronomy Journal. 105(5): 1271-1276.

Feng, G. and Sharratt, B. 2009. Evaluation of the SWEEP model during high winds on the Columbia Plateau. Earth Surface Processes and Landforms 34:1461-1468. *Earth Surface Processes and Landforms* 34:1461-1468.

Gee, G.W., and Bauder, J.W. 1986. Particle-size analysis. *In*: A. Klute (Editor), Methods of Soil Analysis, Part 1. Agronomy, 9: 399-404.

Graham, R. L., Nelson, R., Sheehan, J., Perlack, R. D., and Wright, L. L. 2007. Current and potential U.S. corn stover supplies. *Agron. J.* 99: 1–11.

Hagen, L. J., 1991. A wind erosion prediction system to meet user needs. *Jour. Soil and Water Comerv*. 46(2): 106- 1 1 1.

Hagen, L.J., Skidmore, E.L., and Saleh, A. 1992. Wind Erosion: Prediction of Aggregate Abrasion Coefficients. *ASAE J.* 35(6):1847-1850.

Hagen, L.J., Wagner, L.E. and E.L. Skidmore. 1999. Analytical solutions and sensitivity analyses for sediment transport in WEPS. Trans. Amer. Soc. Agric, Engin. 42(6):1715-1721.

Hill, R.L., 1990. Long-term conventional and no-tillage effects on selected soil physical properties. *Soil Sci. Soc. Am. J.* 54: 161-166

Hobbs, P.R., 2007. Conservation agriculture: what is it and why is it important for future sustainable food production? *Journal of Agricultural Science*. 145: 127-137

Jia, Q., Al-Ansari, N., Knutsson, S. 2014 Modeling of Wind Erosion of the Aitik Tailings Dam Using SWEEP Model. *Engineering*. 6(7). DOI:10.4236/eng.2014.67038

Kenney, I., Blanco-Canqui, H., Presley, D.R., Rice, C.W., Janssen, K., and Olson, B. 2014. Soil and crop response to stover removal from rainfed and irrigated corn. Global Change Biology Bioenergy, doi:10.1111/gcbb.12128.

Kim, S., and Dale, B.E. 2004. Global potential bioethanol production from wasted crops and crop residues. *Biomass Bioenerg.* 26: 361–375.

Kravchenko, A.N., Robertson, G.P., Hao, X., Bullovk, D.G., 2006. Management practices effects on surface total carbon: differences in spatial variability patterns. *Agron. J.* 98: 1559–1568

Lal, R., 1982. No-till farming: soil and water conservation and management in the humid and subhumid tropics. IITA Monograph No.2, IITA, Ibadan, Nigeria, 64pp.

Lal, R., 2004. Soil carbon sequestration impacts on global climate change and food security. *Science*. 304: 1623–1627.

Lal, R. 2009. Soil quality impacts of cresidue removal for bioethanol production. *Soil & Tillage Research*. 102: 233-241.

Larney, F.J., Bullock, M.S., Janzen, H.H., Ellert, B.H., and Olson, E.C.S. 1998. Wind erosion effects on nutrient redistribution and soil productivity. J. Soil and Water Cons. 53: 133-140.

Layton, J.B., E.L. Skidmore, and C.A. Thompson. 1993. Winter-associated changes in dry-soil aggregation as influenced by management. Soil Sci. Soc. Am. J. 57:1568-1572.

Leys, J. and NcTainsh, G. 1994. Soil loss and nutrient decline by wind erosion –cause for concern. *Aust. J. Soil & Water Conserv.* 7(3): 30-40.

Li, F., Zhao, L., Zhang, H., Zhang, T., Shirato, Y., 2004. Wind erosion and airborne dust deposition in farmland during spring in the Horqin Sandy Land of eastern Inner Mongolia, China. Soil Tillage Res. 75: 121–130.

Lyles, L., Dickerson, J.D., and Disrud, L.A., 1970. Modified rotary sieve for improved accuracy. *Soil Sci*. 190: 207-210.

Lyles, L., and B.E., Allison. 1981. Equivalent wind-erosion protection from selected crop residues. *Trans ASAE.* 24: 405-408.

Mendez, M.J., and Buschiazzo, D.E. 2010. Wind erosion risk in agricultural soils under different tillage systems in the semiarid Pampas of Argentina. *Soil Tillage Res*. 106: 311–316.

Mengel, D.B., Wilson, D.W., Huber, D.M., 1982. Placement of nitrogen fertilizer for no-till and conventional tillage corn. *Agron. J.* 74: 515–518

Nelson, R. G., Walsh, M., Sheehan, J. J., and Graham, R. 2004. Methodology for estimating removable quantities of agricultural residues for bioenergy and bioproduct use. *Applied Biochemistry and Biotechonology* 113: 13-26

Okin, G.S., Mahowald, N., Chadwick, O.A., and Artaxo, P. 2004. Impact of desert dust on the biogeochemistry of phosphorus in terrestrial ecosystems. Global Biogeochemical Cycles, 18, GB2005, doi:10.1029/2003GB002145

Perlack, R.D.; Wright, L.L.; Turnhollow, A.F.; Graham, R.L.; Stokes, B.J.; Erbach, D.C. 2005. Biomass as feedstock for a bioenergy and bioproducts industry: the technical feasibility of a billion-ton annual supply. Oak Ridge, TN: Oak Ridge National Laboratory. 59 p.

Rhoton, F. E. 2000. Influence of Time on Soil Response to No-Till Practices. *Soil Sci. Soc. Am. J.* 64:700-709.

Rhoton, F. E., Shipitalo, M. J., and Lindbo, D. L. 2002. Runoff and soil loss from midwestern and southeastern US silt loam soils as affected by tillage practice and soil organic matter content. *Soil Tillage Res.* 66: 1–11.

Ruan, H. X., Ahuja, L. R., Green, R. R., and Benjamin, J. G. 2001. Residue cover and surface-sealing effects on infiltration: numerical simulations for field applications. *Soil Sci. Soc. Am. J.* 65: 853-861.

Saliba N. A., El Jam F., El Tayar G., Obeid, W., and Roumie M., 2010. *Atmospheric Research* 97: 106-114.

Sarath, G., Mitchell, R. B., Sattler, S. E., Funnell, D., Pedersen, J. F., Graybosch, R. A., and Vogel, K. P. 2008. Opportunities and roadblocks in utilizing forages and small grains for liquid fuels. *J. Ind. Microbiol. Biotechonol*. 35: 343-354.

SAS Institute (2011) Online doc. 9.3. SAS Institute Inc., Gary, NC. Available at http://support.sas.com/documentation/93/index.html (verified 21 Jan. 2015).

Schwanghart W., and Schutt B., 2008. Meteorological causes of Harmattan dust in West Africa. *Geomorphology* 95: 412-428.

Six, J., Elliott, E.T., and Paustian, K. 1999. Aggregate and Soil Organic Matter Dynamics under Conventional and No-Tillage Systems. *Soil Sci. Soc. Am. J.* 63:1350-1358.

Skidmore E.L, Hagen L.J., Armbrust D.V., Durar A.A., Fryrear D.W., Potter K.N., Wagner L.E., and Zobeck T.M. 1994. Methods for investigating basic processes and conditions affecting wind erosion. In *Soil Erosion Research Methods,* La1 R (ed.). Soil and Water Conservation Society: Ankeny, IA; 295-330.

SPSS Science. 1998. SigmaScan Pro 5.0 User's Guide. SPSS Science, Chicago, IL.

Tatarko, J., Wagner, L.E., Boyce, C.A. 2001. Effects of Overwinter Processes on Stability of Dry Soil Aggregates. *Soil Erosion Research for the 21st Century, Proc. Int. Symp. (3-5 January 2001, Honolulu, HI, USA)*: 459-462.

Varvel, G.E., Vogel, K.P., Mitchell, R.B., Follett, R.F., Kimble, J.M., 2008. Comparison of corn and switchgrass on marginal soils for bioneregy. *J Biomass and Bioenergy* 32: 18-21.

Wagner L.E., and Ding, D. 1994. Representing aggregate size distributions as modified lognormal distributions. *Transactions of the ASAE* 37(3): 815-821.

Wagner, L.W. and Yu, Y. 1991. Digitization of profile meter photographs. *Trans. Am. Soc. Agric. Engin.* 34(2): 412-416.

Wagner, L.E. 2013. A history of wind erosion prediction models in the United States Department of Agriculture: The Wind Erosion Prediction System (WEPS). *Aeolian Research*. 10:9-24.

Wang, L., Shi, Z.H., Wu, G.L., and Fang, N.F. 2014. Freeze/thaw and soil moisture effects on wind erosion. Geomorphology. 207: 141-148.

Wilhelm,W.W., Johnson, J. M. F., Hatfield, J. L., Voorhees,W. B., and Linden, D. R. 2004. Crop and soil productivity response to corn residue removal: a literature review. *Agron. J.* 96: 1–17.

Wilhelm, W.W., Johnson, J.M.F., Karlen, D., and Lightle, D. 2007. Corn stover to sustain soil organic carbon further constrains biomass supply. *Agron. J.* 99: 1665-1667.

Wuest, S.B., Caesar-TonThat, T.C., Wright, S.F., Williams, J.D., 2005. Organic matter addition, N, and residue burning effects on infiltration, biological, and physical properties of an intensively tilled silt-loam soil. *Soil Till. Res*. 84 (2): 154–167.

Zobeck, T.M., and Bilbro, J.D. 2001 Crop Productivity and Surface Soil Properties of a Severely Wind-Eroded Soil. In D.E. Stott, R.H. Mohtar and G.C. Steinhardt (eds). Sustaining the Global Farm. 10th International Soil Conservation Organization Conference. May 24-29, 1999. Purdue University and the USDA-ARS National Soil Erosion Research Laboratory. 617-622.

Chapter 2 - Effect of Liquid N and S Fertilizer Solutions on the Mass and Strength of Winter Wheat (*Triticum aestivum*) Residue in No-Till Systems

Abstract

To solve stand establishment issues in high residue situations, application of nitrogen (N) fertilizer as urea ammonium nitrate (UAN) and N plus sulfur (S) fertilizer as ammonium thiosulfate (ATS) by spraying on crop residue to stimulate microbial activity and subsequent decomposition of the residue is often debated. We conducted field experiments to assess winter wheat (*Triticum aestivum*) straw decomposition under different fertilizer rates and application timings at three locations in western Kansas (Hays, Colby, and Garden City) following wheat harvest in 2011 and 2012. The UAN was applied at rates of 0, 22.4, 44.8 and 67.2 kg N ha^{-1} and the ATS was applied at rates of 16.8 and 33.6 kg S ha^{-1}. A double shear box apparatus instrumented with a load cell measured the shear stress required to cut wheat straw. Twenty-five wheat straws from each plot were tested. Photomicrography and image analysis software were used to measure the cross-sectional area of each individual wheat straw after shearing and these data were used to calculate shear stress and specific energy parameters. Total C and N content was measured for bulk wheat straw samples from each plot. Treatment differences were often observed; however, there were few site years that had significant differences in wheat straw decomposition as compared to the no-fertilizer control. For example, fertilizer rate and timing of application during summer 2012 and Fall 2013 at the Hays site had impacts on wheat straw shear stress at break point. Across site years, earlier (fall) fertilizer application generally resulted in lower remaining aboveground biomass as compared to a spring application. Multivariate and

linear regressions suggested that N content and C:N ratio can explain the results observed with respect to treatment effects on winter wheat residue decomposition.

Introduction

The importance of crop residue to soil quality and agronomic sustainability is widely recognized by researchers and farmers. The benefits of no-till (NT) practices include that it maintains high levels of crop residue on the ground, enhances soil structure, conserves soil moisture, maintains soil nutrient pools, protects plant growth, and increases agricultural productivity (Unger, 1994; Hobbs, 2007). Increasingly, producers are switching to NT management in the U.S. (112.8 million hectares NT in 2012), particularly in rain-fed areas where soil moisture is highly dependent on precipitation (USDA, 2014). Compared to conventional-tillage (CT), NT or reduced tillage (RT) may increase surface soil water content (Lal, 1982; Mengel et al., 1982), enhance soil aggregate stability (Dam et al., 2005; Hobbs, 2007), increase soil mechanical resistance (Reichert et al., 2009), and generally have higher bulk density (Hill, 1990; Dam et al., 2005; Kravchenko et al., 2006). Horton et al. (1996) stated that NT systems retaining crop residue could increase the albedo of the soil surface, which has implications for helping mitigate climate change. Using the Consortium for Small-scale Modeling-Climate Limited-area Modeling Regional Climate Model, Davin et al. (2014) found a 2 °C cooling effect due to NT practices.

Global wheat production was expected to reach 690 million tons in 2013, which was a 4.3 percent increase over the previous year (FAO, 2013). Although wheat straw is a potential feedstock for bioenergy production (Sarath et al., 2008), Blanco-Canqui and Lal (2009) concluded that indiscriminate removal of crop residue could drastically reduce the erosion-resisting benefits of NT farming. This is particularly true for semi-arid areas. Therefore, crop residue often remains in the field after harvest to decrease the potential for losses of soil by wind erosion in some regions today (Gao et al., 2014).

One direct effect of NT is that a large amount of crop residue remains on the ground after crops are harvested, particularly in high-yielding environments or in years of abundant rainfall and ideal growing conditions. Farmers may have concerns about establishing a good plant stand in high residue situations due to higher shear stress and energy required to cut through residues by the disk opener on planters or drills (Payton et al. 1985; Doan et al., 2005). Decomposed crop residue tends to have weaker structure (McCalla, 1943; Annoussamy et al., 2000). However, dry regions have a climate that is not as conducive to residue decomposition as more humid regions (Schomberg et al., 1994; Abera et al., 2014). Therefore, increasing the decomposition rate of wheat straw between post-harvest and planting could be an effective way to solve abundant crop residue issues while maintaining the benefits of residue coverage.

Usually, cereal crop residues have high carbon (C) to nitrogen (N) ratio (C:N) (Hadas et al., 2004; Havstad et al., 2010). Significantly higher C:N ratio in wheat straw (up to 55.1) compared to seed was measured by Gan et al. (2011). According to the literature, about 32.5% of the cells in wheat straw are fibers and the remaining 67.5% contains parenchyma, epidermis cells, vessels, and spirals, known as non-fibrous cells (Singh et al., 2011). Li et al. (2009) observed that the structural degradation of wheat straw happened mainly in the parenchyma cells and the surrounding vascular bundles 50 days after a study was initiated. Due to the selection of varieties with better lodging resistance, stiffer and shorter straw wheat is preferred (Travis et al., 1996). Capper et al. (1992) reported that these varieties usually contain high lignin content with low digestibility. Meanwhile, Kriaučiūnienė et al (2012) found that highly decomposed residue had significantly higher concentration of N compared to less decomposed residue. Therefore, adding

N fertilizer to lower the C:N ratio (Melchiori et al., 2014) has the potential to hasten wheat straw decomposition after grain harvest.

During the decomposition process, not only can N content be the limiting factor that restricts the bioactivity of microbiomass, but also may cause N immobilization from soil and additionally decrease the nutrient pool in soil for the next crop (Clapp et al., 2000). Meanwhile, as a secondary nutrient, sulfur (S) can be a limiting factor, especially after harvest of high S demand plants such as alfalfa. Consequently, one thought an agronomist or producer might have is to apply these limiting nutrients (N and/or S) to the residue to stimulate microbial activity and subsequent decomposition of the residue. However, there is no consensus among researchers on the utility of this practice. A recent paper by Guzman and Alkaisi (2013) examined the effects of tillage and adding N fertilizer on the decomposition rates of Bt and non-Bt corn observing no significant differences between Bt and non-Bt isolines under NT management. Also, they did not observe a difference in the decomposition rates between Bt and non-Bt; however, maize residue decomposition rates declined with increasing N rates.

A double shear using shear box is the method that can be used to evaluate shear strength of crop residue. O’Dogherty et al. (1989) reported a range of 5.39 to 6.98 MPa shear stress for winter wheat straw was smaller than spring wheat straw, which was 8.53 MPa. Dernedde (1970) applied this method to test shear strength of forage materials at two different moisture contents. Similarly, Kushaha et al. (1983) found the shear strength of wheat straw had relationship with the moisture content. Tavakoli et al. (2009) tested the barley straw at different internodes and reported the third internode position of barley straw had the maximum shear strength. Taghijarah et al. (2011) applied the double shear method on sugar cane stalk and reported the loading rate and internode position had significant impacts on the shearing characteristics. However, the relationship between wheat straw decomposition due to different fertilizer treatments and its physical strength parameters (i.e. shear stress, specific energy) has not been documented.

The objective of research was to evaluate the effect of application rate and timing of two commercially-available liquid fertilizers (i.e., Urea Ammonium Nitrate (UAN) and Ammonium Thiosulfate (ATS) on the decomposition of wheat straw by measuring physical strength parameters, and analyzing for total C, N, and ash percent of straw after treatment.

Materials and methods

Site description and field experimental protocols

Three research sites were established in western Kansas in 2011 and 2012 after winter wheat harvest. Sites were at Hays (38°52′46″N, 99°19′20″W, elevation 616 m), Colby (39°23′32″N, 101°2′51″W, elevation 963 m), and Garden City (38°01’17”N, 100°49’26”W, elevation 883 m). The experimental design was a randomized complete block design with four replications. All plots were 6.1 m × 6.1 m in size and were placed directly over the center of the grain harvesting equipment path (i.e., between the wheel tracks). The UAN was applied at rates of 0, 22.4, 44.8 and 67.2 kg N ha^{-1} and the ATS was applied at rates of 16.8 and 33.6 kg S ha^{-1}. The ATS also contained 7.7 and 15.5 kg N ha^{-1}. Hereafter the fertilizer rates will be referred to as UAN$_{\text{low/med/high}}$, and ATS$_{\text{low/high}}$ respectively. In addition, there was one treatment that contained a blend of UAN$_{\text{high}}$ and ATS$_{\text{high}}$, referred to as Mixed, which contains 82.7 kg N ha^{-1} and 33.6 kg S ha^{-1}. All fertilizer treatments were applied using a tractor-mounted sprayer using a flat fan spray tip. No water or surfactants were used. The fertilizers were applied at two different times to separate plots, resulting in a total of 13 treatments (Table 2.1). The two application times were

September, after wheat harvest, and February, before temperatures increased and microbial activities resumed.

Residue sampling and analyses

Wheat straw samples were collected from within a portion of each research plot in a 0.61 m × 0.61 m area in summer (July) 2012, summer (June) 2013, and fall (October) 2013 from the Hays and Colby sites. The Garden City site was only sampled in summer 2012 and summer 2013 due to very poor residue conditions from high wind speeds that lodged and blew nearly all of the wheat residue off of the field. The residue sampling periods were selected to simulate the time of year when subsequent crops would normally be planted, e.g., wheat in fall, and row crops such as corn (*Zea mays L.*) in the spring. The wheat straw was sorted by hand to remove any soil material that may have been collected from the field. Straw samples were dried at 56 ℃ for 72 h and weighed to calculate total surface residue. A subsample of 25 wheat straws were randomly selected for the shearing test and the remainder of the straw sample was then ground and analyzed for total C, total N (Bremner and Mulvaney, 1982) and ash percent (Khardiwar et al., 2013).

A double shear using a shear box was used to test the shear stress and specific energy required to cut wheat straw. Dernedde (1970), O'Dogherty et al. (1989), Shinner et al. (1987), and Taghijarah et al. (2011) applied similar method to measure the shear strength of crop residue or plant tissue. This process is intended to simulate the type of force encountered by a disk opener on a drill or planter as it cuts through crop residue. Figure 2.1 shows the design of the shear box. The shear box consists of two parallel aluminum plates (channel) 6 mm apart. Between them, the third plate (blade) can move up and down along the central axis freely. Five holes with diameters ranging from 2 mm to 6 mm were drilled through all three plates to accommodate different wheat straw sizes. The shear box was attached to the Instron MN 44 (Instron, Norwood, MA), a load cell of a tension/compression testing machine (Fig. 2.2). The blade plate was set to move at a rate of 10 mm min^{-1} and the applied force was recorded by a strain-gauge load cell. Integrating the shear force with the respect to the displacement untill the failure force (Fig. 2.3) generates the total energy (TE) used to cut through wheat straw (Chen et al., 2004; Nazari Galedar et al., 2008). The specific energy was then calculated as:

$$SE = \frac{TE}{A}$$

Where

SE is the specific energy (J mm^{-2})

TE is the total energy (J)

A is the wheat straw wall area at failure cross-section (mm^2)

The shear stress was then calculated as:

$$\tau_s = \frac{F}{2A}$$

Where

τ_s is the shear stress (MPa)

F is the shear force at failure (N)

A is the wheat straw wall area at failure cross-section (mm^2)

Sub-samples from each plot were tested for τ_s and SE in this manner. During the shearing test, shear force was recorded by the computer. Shear force change with the center blade movement was then graphed (Fig. 2.3). Figure 2.3 illustrates an example output from the load cell. The highest load was reported by the computer, which is the shearing force (F) at the point of wheat straw failure, as well as TE.

To accurately measure the cross-sectional area at the breaking point of wheat straw, a microscope and camera was utilized to capture images of the cross-sectional area of wheat straw. The pictures were then analyzed with SigmaScan 5 (Systat Software Inc.) image analysis software. Figure 2.4 shows the wheat straw captured by a microscope (left) and then analyzed with the software to determine the area (right).

Statistical analysis

Analysis of variance was conducted using SAS 9.3 (SAS Institute, 2011) software and summarized. MIXED procedure using treatment and time as classification variables for two-way analysis of variance, REG procedure using physical parameters as dependent variable and total C, N, and ash content as independent variables for multivariate stepwise regression, and REG procedure using physical parameters as dependent variable and C:N ratio as independent variable for linear regression were applied to analyze the data.

Results

Results of statistical analysis were shown from Table 2.2 to Table 2.4. The p-values from two-way analysis of variance at $\alpha \leq 0.05$ and $\alpha \leq 0.10$ are presented in Table 2.2. The asterisks indicate properties that had significant treatment differences within a sampling period. Multiple regression results of relationships between physical (i.e. SE and τ_s) and chemical (i.e. total C, N, and ash content) parameters are reported in Table 2.3. Linear regression results between physical parameters and C:N ratio are shown in Table 2.4.

Aboveground biomass

For summer 2012 samples, the fertilizer application timing had significant effects ($p \leq 0.1$) on the aboveground biomass at Colby (Table 2.2). There were no significant treatment differences measured at Hays and Garden City sites for the summer 2012 sampling period. Figure 2.5 shows effects of the treatments on the wheat straw biomass in summer 2012 at the Colby site under different treatments. Besides the spring 2012 treatment, the aboveground biomass that remained in the other plots was not significantly different from the control. The application of UAN_{low} in spring 2012 had significantly greater biomass remaining in the field compared to the fall 2011 application of the same treatment. Also, applications of ATS_{high} and the mixture of the two fertilizers in fall 2011 had significantly less aboveground biomass compared to the UAN_{low} application in spring 2012.

Significant residue biomass differences due to the fertilizer types and rate were also measured at both the Hays and Colby sites during the Summer 2013 sampling period (Fig. 2.5). Although there is no significant difference between the control and any treatment at Hays (Fig. 2.5), the overall biomass of the fall 2012 applied treatments was less than spring 2013 application ($p<0.01$), when averaged across all fertilizer types and rates (Table 2.2). Significantly different biomass between application timings under same amount fertilizer usage was only measured at UAN_{med} treatment at this site. A similar pattern was observed at the Colby site. Timing of the application was significant, and the fall 2012 application led to less remaining biomass than the spring 2012 timing ($p<0.01$). Compared to the control, UAN_{med} and ATS_{high} applied in fall 2012 led to significantly less aboveground biomass. Between different timings with same amount of fertilizer application, UAN_{med} applied in fall 2012 led to significantly less reimagining biomass than when applied in spring 2013.

During the Fall 2013 sampling period, there were no treatment effects measured at either the Hays or Colby sites. For the Garden City site, compared to the control, no significant difference in aboveground biomass was measured for the fall 2012 sampling period.

Physical evaluation of straw strength

Specific Energy (SE)

Significant treatment effects were observed for the SE measurement for the samples taken from Hays in summer 2012 and Fall 2013 and at Garden City in summer 2012. At Hays in the summer of 2012, both fertilizer rate and timing factors contributed to the SE required to cut through the wheat straw. As shown in Figure 2.6, the mean SE required to shear the control group samples was 4.58×10^3 J m^{-2}, while the energy required to cut through UAN_{low} is significantly less, at 3.77×10^3 J m^{-2}. Although a significant timing effect on SE was only measured at Hays during summer 2012 sampling period ($p<0.05$), generally, the spring treatments required lower energy to break wheat straw compared to fall-applied treatments at all sites. However, most of the treatments were not significantly different from the control, except the UAN_{low} treatment. Similar results were found at Garden City, in that UAN_{low} and ATS_{low} treatments led to significantly lower SE compared to the control ($p<0.01$). At Hays in Fall 2013, significantly lower SE was measured under UAN_{low} and UAN_{high} treatments applied in both fall 2012 and spring 2013, and ATS_{high} treatment applied in spring 2013 compared to control group. At the Garden City site, SE measured for the UAN_{low} treatment applied in fall 2011 (6336.5 J m^{-2}) was significantly lower than the control (8045.4 J m^{-2}).

Shear Stress (τ_s)

For the Hays summer 2012 sampling period, the application time was not significant, nor were there any particular treatments that had lower τ_s than the control. There were some minor differences among treatments, however ($p=0.05$), such as the decreasing τ_s with increasing rates of UAN (Fig. 2.7).

For the Fall 2013 sampling period at the Hays location, there were treatments with significantly less τ_s than the control. In particular, the straw sampled from all three of the UAN rate treatments was weaker by 20% than the control. Generally, wheat straw from plots with fall 2012 application required less τ_s to shear the straw ($p<0.05$). There were no differences between the control and either of the ATS treatments, nor the mixed treatment.

As shown in Figure 2.7, at Colby in summer 2012, there was only one treatment that differed from the control. The wheat straw from the fall-applied Mixed treatment required significantly less τ_s (3.58 Mpa) to cut through compared to the control treatment (4.44 Mpa).

Chemical parameters of wheat straw

Total C

Significant differences were not observed between treatments for either the summer 2012 or the Fall 2013 sampling period. However, during the Summer 2013 sampling period, significant treatment effects were detected at all three sites: Hays, Garden City ($p<0.05$), and Colby ($p<0.1$) (Fig. 2.8). The Hays site had a significant treatment*timing interaction ($p=0.09$). Timing was not significant at either the Garden City or Colby sites. The C content was lower for both UAN_{low} and ATS_{low}.

Relative to the control, the C content for Hays 2013 samples was less for both the UAN_{low} and ATS_{low} treatments and for both the fall and spring applications. Among all of the treatments, ATS_{low} with fall 2012 application treatment had least C content of all, which was 394 g kg^{-1} compared to 414 g kg^{-1} measured for the control.

The values from Colby and Garden City (Fig. 2.8) were not different from the control. However, there were treatments that differed from each other. For example, at the Colby site, the least C content was observed for ATS_{high} applied at fall 2012. At the Garden City site, the least C content was for UAN_{low} applied at spring 2013 treatment.

Total N

The results of N concentration of wheat straw are shown in Figure 2.9. For the fall 2012 sampling interval at Hays, there was a significant effect of the timing of liquid fertilizer. All of the fall-applied fertilizer treatments contained the same N concentration as the control, while two of the spring-applied treatments contained more N than the control. For the Hays 2013 experiment, however, there was no timing effect, but rather a treatment effect, with the mid-rate of UAN and high rate of ATS containing more N than the control. Timing was also an important factor for the Garden City summer 2012 site. The fall applied treatments contained less N than the spring applied treatments ($p=0.05$).

C:N Ratio

For the summer 2012 sampling period there were significant application timing effects for both Hays and Garden City (Fig. 2.10), and for both sites, the spring applications had a narrower C:N than treatments applied in the fall. Conversely, in Summer 2013 there was no effect of timing on any of the sites, but there were significant treatment effects at both Hays and Garden City. The UAN_{low} and UAN_{med} had narrower C:N ratio compared to the control at Hays, while at Garden City, there were no differences from the control. Rather, at Garden City, the main differences were between treatments. The $\mathrm{UAN}_{\mathrm{high}}$ fall and spring treatments were among the lowest with C:N values of <40:1, and the ATS fall and spring values were greatest for the $\mathrm{ATS}_{\mathrm{high}}$ treatment.

Ash Content

Significant effects of the fertilizer sources/rates on wheat straw ash content were observed for Colby and Garden City in Summer 2013 (Fig. 2.11). Among them, the Colby site had a treatment*timing interaction as well. At Colby, the ash content of the $\mathrm{ATS}_{\mathrm{high}}$ treatment applied in fall 2012 (15.1%) was significantly greater than the control (10.2%). At Garden City, no statistical difference of ash content was measured between any treatments as compared to the control. However, treatment differences existed.

Multiple regression: Examining relationships between physical and chemical properties

Significant effects of total N content on SE required to cut through wheat straw were found at three out of seven sampling periods (Table 2.3), which were the summer 2012 samples at Hays （$p < 0.1$) and Garden City ($p < 0.05$) (inverse relationship), and Fall 2013 sample at Colby ($p < 0.05$) (positive relationship). The coefficient of determination (R^2) for three sampling periods ranges from 0.08 to 0.22 (Table 2.3). Samples collected in Summer 2013 from Hays were inversely related with respect to total C content and SE required ($P=0.02$). A negative relationship was reported and the coefficient of determination is 0.1.

Significant impacts of total N content on τ_s were measured for six out of seven sampling periods (Table 2.3), all with negative relationships between N and τ_s. Meanwhile, significant effects of total C content on τ_s were found at Hays in Summer 2013 and Garden City in summer

2012 (Table 2.3). Similar to the SE, an inverse relationship was observed between C and τ_s. Additionally, the coefficient of determination ranged from 0.13 to 0.27.

Simple linear regression between physical parameters and C:N ratio

A significant relationship between the C:N ratio and SE required to cut through wheat straw was measured at three out of seven sampling periods. Among them, samples from Hays and Garden City in summer 2012 showed positive relationship. However, sample from Colby in Fall 2013 were negatively related. The coefficients of determination ranged from 0.07 to 0.21.

Five out of seven sampling periods showed significant effects of C:N ratio to τ_s measured to cut through wheat straw. They are Hays and Garden City in summer 2012, Colby in Summer 2013, and Colby and Hays in Fall 2013. All five sampling periods had positive relationships between τ_s and the C:N ratio. The coefficient of determination ranged from 0.10 to 0.27.

Discussion

In situ application of fluid N and N plus S fertilizer had inconsistent effects in this study. Table 2.2 summarizes the inconsistency of the treatment and timing effects for a sum of eight sampling periods over the course of the two-year, three locations, and three sampling periods project (minus the Garden City sampling period that was not completed). For the biomass parameter, there were no significant fertilizer treatment effects; however, timing was significant for three out of the eight data sets. In years with a significant effect of timing, fall application resulted in less remaining biomass than the spring application of liquid fertilizers on wheat straw, which indicates that wheat straw decomposition may be positively correlated to the length of time that has passed since liquid fertilizer was applied.

Annoussamy et al. (2000) studied the change in wheat straw mechanical properties and found a 40% decrease in biomass due to decomposition and also measured a lower physical strength (i.e., shearing force and bending force). In our study, the strength parameters, SE and τ_s, had few instances of treatment or timing difference. Both timing and fertilizer application rate affected SE significantly for one out of the eight site years. However, interaction between these two factors was found as well. Significant effects of fertilizer application rate and timing on wheat straw τ_s were found for two of the eight data sets.

Factors that can affect in situ aboveground biomass include initial post-harvest biomass, local weather condition (i.e., temperature, precipitation, moisture, and wind etc.), and residue decomposition rate (Kriaučiūnienė et al., 2012; Al-Kaisi and Guzman, 2013). In western Kansas, where the study was conducted, wind erosion is a major concern. Wheat straw can be detached and removed from the field by strong wind regardless if it is physically weakened due to the decomposition. At the Garden City site, we had to exclude the Fall 2013 sampling period due to strong winds and physical loss of residue across the entire field. Therefore, when wind velocity is excessively high, impact of the decomposition on residue aboveground biomass may not be clear. In other words, the effects of treatments and our ability to detect differences may be confounded with field conditions such as intense precipitation and strong wind.

To simulate the disk opener of the planter and how it encounters residue during planting, we randomly selected wheat straw internode position (i.e. section from root) for the shearing test. To determine size of the sub-sample needed, we tested 50 straws for physical parameters from two baseline samples and statistically analyzed results for 10, 20, 30, 40 and 50 straws (Table 2.6) and found that there was no difference when more than 20 samples were tested. Therefore, we elected to test 25 wheat straws from each sample. However, averaging the physical strength results of sub-sample from each plot might offset the various degrees of impacts of fertilizer application rates and timings on different section of wheat straw. Huber (1991) stated that different internodes of wheat had different cross-sectional area and mass per unit length. Therefore, different SE and τ_s could be expected to be measured for different internodes of any one wheat straw. Announssamy et al. (2000) found significant effects of mass per unit length or cross-sectional area on wheat straw physical strength. Consequently, the inconsistent decrease of physical strength of wheat straw under different fertilizer management scenarios for sites and sampling periods in our study may be attributed to randomly testing internodes. Future work could eliminate this random variable by consistently selecting a particular internode for physical testing.

Moisture content of the wheat straw specimens at shearing test could also affect the physical strength of those straws. Nazari Galedar et al. (2008) measured the engineering properties of alfalfa stems under different moisture contents and found a positive relationship between moisture content and τ_s and energy. Tavakoli et al. (2009) reported a similar finding after testing the physical parameters of barley straw. In our study, wheat straw samples were oven dried at 56 °C for 72 h. After moving the samples from oven to testing laboratory, they were stored in a cardboard box in the laboratory where the temperature and moisture were not precisely controlled. However, laboratory thermostat was set to 20 °C and humidity was not controlled. Shearing test was operated for two weeks for samples from each site during each sampling period. Therefore, the wheat straw moisture content could gradually increase over the period of time between when it was removed from the oven and when it was sheared, which could cause inconsistent physical strength results.

Compared to the control, effects of liquid fertilizer application on the chemical properties (total C, N, and C:N ratio) of wheat straw were found one, three, and three out of the eight sample sets in our study, respectively. Meanwhile, significant effects on ash content were only found one out of eight sample sets.

Residue C content is highly associated with wheat straw decomposition. Annoussamy et al. (2000) reported a 50% reduction of cellulose and a 30% reduction of hemicellulose in wheat straw after 25 days of incubation. In our study, the only difference between control group and fertilizer applied plots in C content was measured at Hays in Summer 2013. UAN$_{low}$ and ATS$_{low}$ showed the potential ability to speed the decomposition rate by decreasing the C concentration compared to the control group. However, reduction of C content was not measured in samples from high fertilizer application rate treatments at this site. Furthermore, N content was expected to increase with increase in N fertilizer application rate. This increasing trend was observed at all three sites during the first sampling period. Also, the samples from spring-applied plots generally had higher N content than those from fall-applied plots. This difference can be attributed to the interval between treatment application time and sampling time. Shorter intervals may have less evaporation, leaching, and chemical reaction and results in higher remaining N content. However, this phenomenon was not observed at other sampling periods, so it is not possible to make a conclusion.

Commonly, the C:N ratio can partially explain the decomposition rate. Since we assume that N content is the limiting factor for wheat straw decomposition, a smaller C:N ratio is desired if rapid decomposition is the objective. Similar conclusions were drawn by Melchiori et al. (2014). We did measure smaller C:N ratio at Hays and Garden City, particularly for UAN$_{high}$ and Mixed treatments. Therefore, larger N application rates could decrease C:N ratio, indicating the possibility for quicker straw decomposition. However, we did not consistently measure lower physical strength of wheat straw from high N rate treatments, indicating some other factors (e.g., wheat variety) may have affected the results. Shorter and stiffer wheat varieties planted today have low digestibility (Capper et al., 1992; Travis et al., 1996), which might lead to slow and less response of physical strength of wheat straw to liquid fertilizer application. Furthermore, the influence of N on C mineralization remains unclear. Contradictory findings about N addition and consistent effects on C mineralization have been reported (Fog, 1988; Green et al., 1995; Moran et al., 2005; Al-Kaisi et al., 2013).

According to the multiple and linear regression results (Table 2.3 and 2.4), there is a generally negative pattern of relationship between physical and chemical parameters. Negative relationships between total N content and τ_s were measured at six sampling periods and additionally, two sampling periods showed negative relationship between SE and total N content. This indicates that the higher N content of crop residue might have potentially advanced decomposition. However, an opposite result was found at the Colby site in Fall 2013, which showed a positive relationship between SE and N content. Berg and McClaugherty (2007) stated that N might have a negative effect on the lignin component of crop residue decomposition over time due to the barrier formed by chemical bonds between lignin and N during de novo synthesis of lignin. This may explain the opposite findings at Colby in Fall 2013 at which greater N content resulted in less τ_s, however, greater SE. Shear stress (τ_s) describes the shear force resistibility at the breaking point. Decomposed crop residue usually has fragile structure. However, the de novo synthesis of lignin can cause weaker, yet elastic structure due to the chemical bounds. Since the effects of total C on physical parameters were only observed a few times and ash content was not selected by the multivariate stepwise regression model, we cannot suggest using total C and ash content as indicators to evaluate crop residue decomposition.

In the linear regression, C:N ratio showed positive relationship with τ_s at five out of eight sampling periods. Meanwhile, two sampling periods have positive relationship between SE and C:N ratio. One sampling period had the opposite result. Wider C:N ratio usually suggests a slow decomposition situation. Baldock (2007) found plant residues with C:N ratio greater than 40 had significantly slower mineralization process than residue with C:N ratio less than 40. The opposite result was measured at Colby in Fall 2013 again.

Setting drying temperature at 56 ℃ may result in further decomposition of wheat straw. Cone et al. (1996) reported that different chemical compound contents and physical properties of grass and maize during degradation could be attributed to temperature choice. Therefore, multiple drying temperatures could be evaluated in the future studies. A chamber study that would control the environmental factors (i.e., soil moisture content, temperature, and wind) and precisely apply fertilizer to crop residue accordingly would be an excellent follow-up study.

Conclusions

Physical parameters (i.e., aboveground biomass, τ_s, and SE) and chemical parameters (i.e., total C and N content, C:N ratio, and ash content) of wheat straw were evaluated to assess the impacts of fertilizer application rates and timing on its decomposition. Overall, there were no consistent results to reveal any predictable relationship between fertilizer application rates and wheat straw decomposition. However, smaller remaining biomass, less SE and τ_s, and narrower C:N ratio were measured at different sites during different sampling periods indicating some, albeit inconsistent, potential of applying fertilizer to hasten wheat straw decomposition. Longer application periods tended to reduce the wheat straw physical strength at some sites (Summer 2012 and Fall 2013 at Hays). Multivariate and linear regression analysis suggested that N and C:N ratio may be practical indicators to assess crop residue decomposition.

Figures and tables

Figure 2.1 Design of the shear box and photograph of the manufactured shear box.

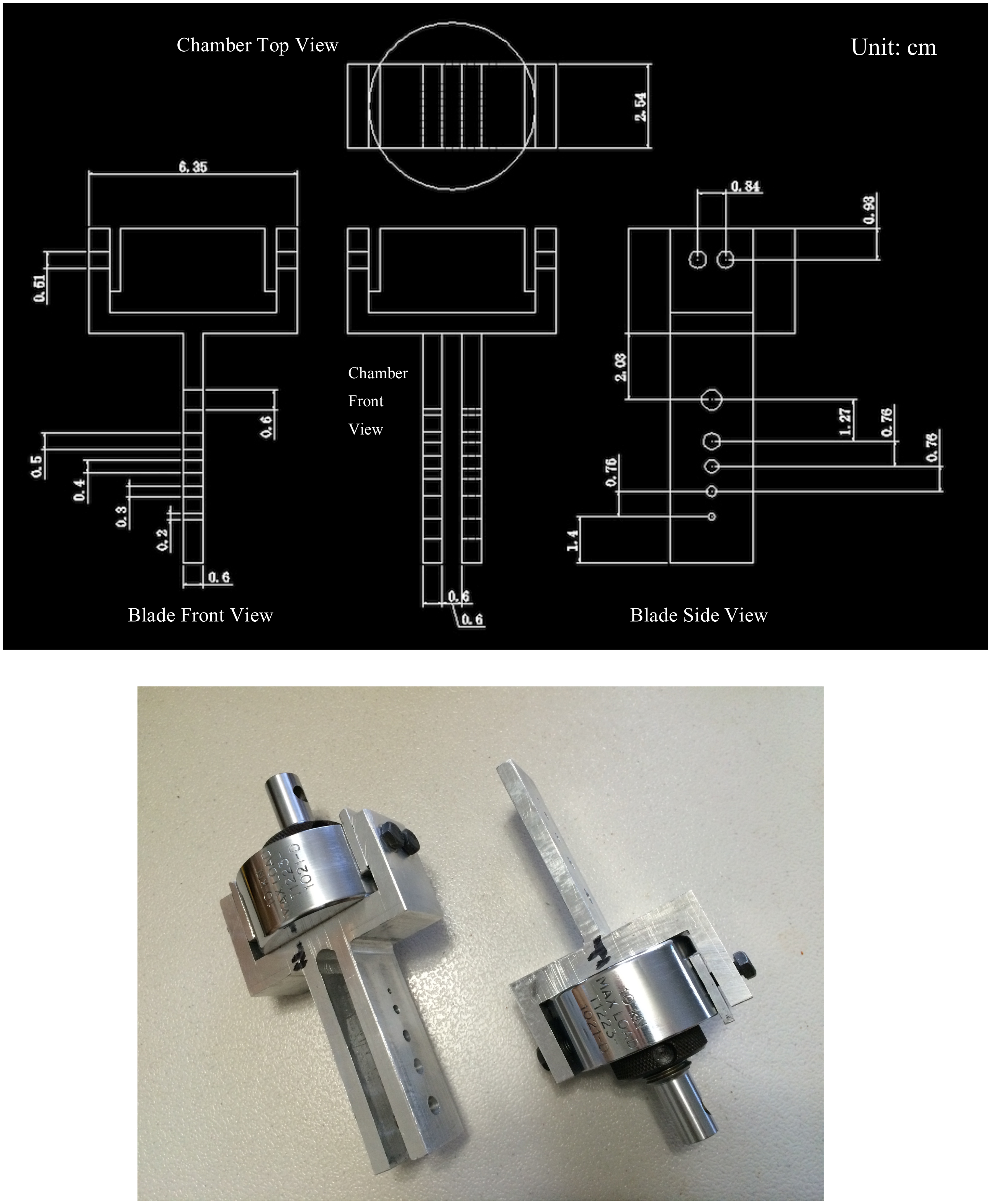


Figure 2.2 Testing wheat straw physical strength using a shear box attached with load cell Instron MN 44 (Instron, Norwood, MA) that is connected to a computer.

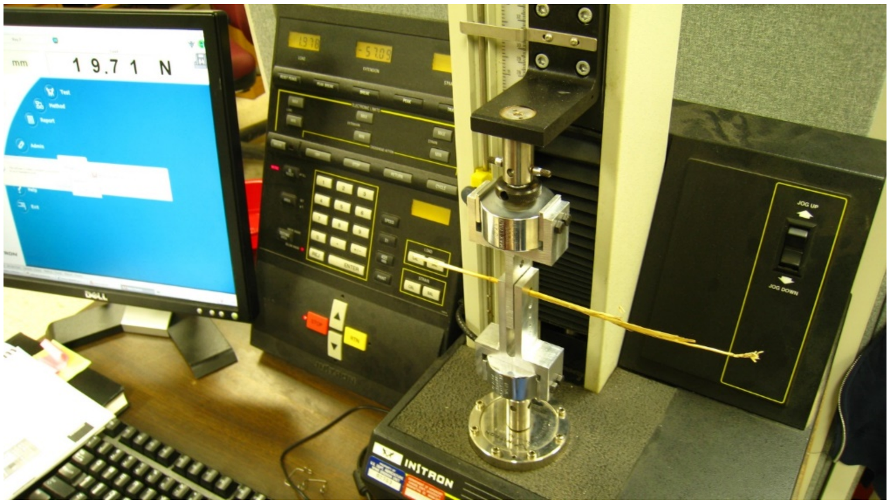


Figure 2.3 Shear force along blade movement recorded by computer with different colors showing different shearing stages.

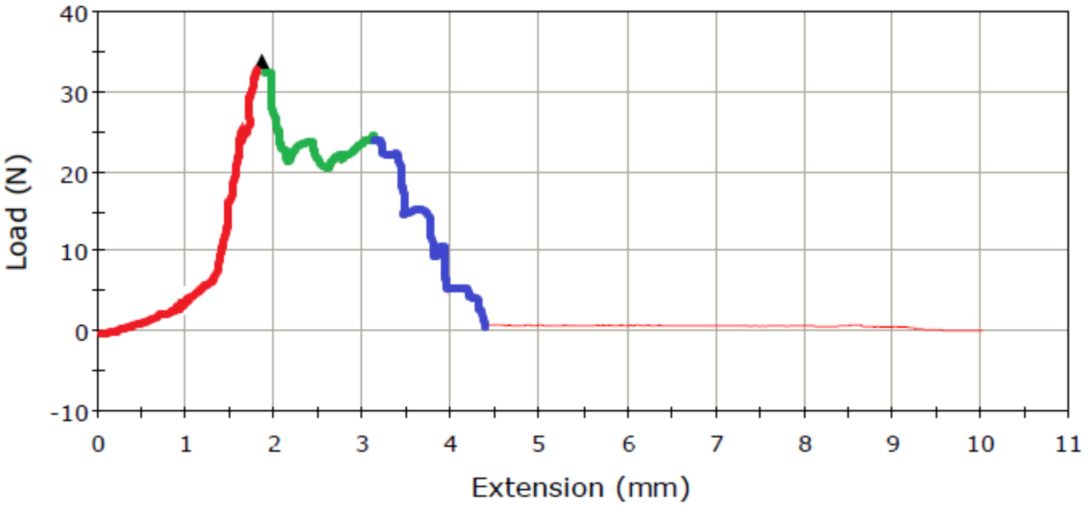


Figure 2.4 Image of cross section of wheat straw at the breaking point under microscope (left) and being analyzed by the image analysis software package SigmaScan 5 (Systat Software Inc.) (right).

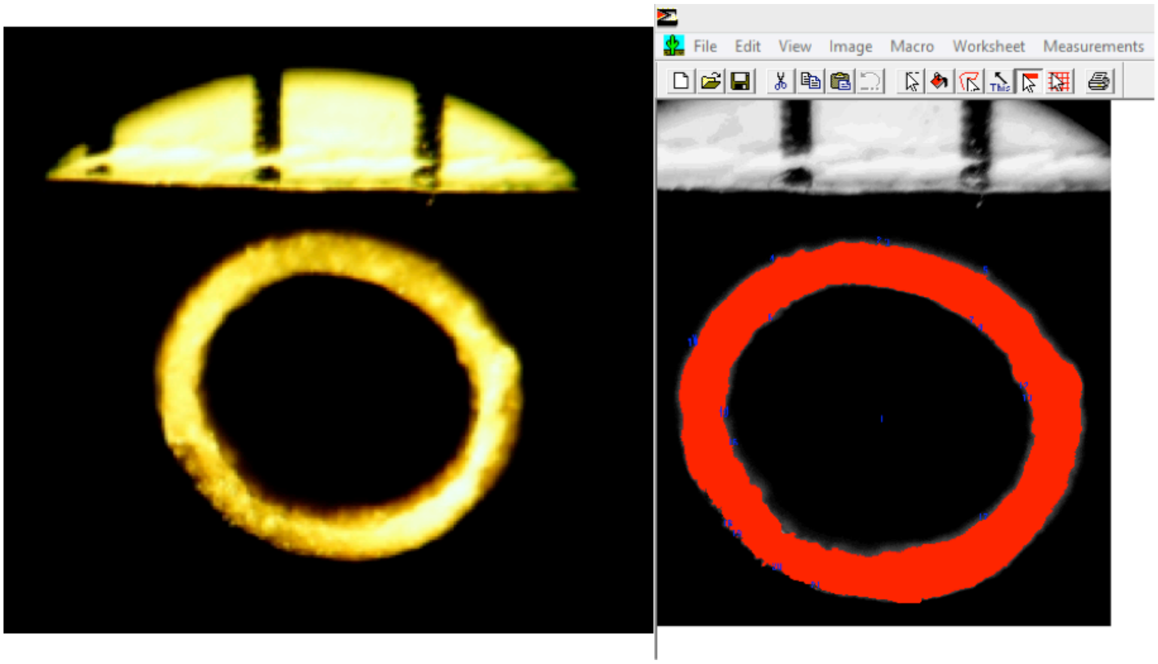


Figure 2.5 Aboveground biomass at Hays site of Summer 2013, Colby site of summer 2012 and Summer 2013 sampling periods. Bars with the same letter are not significantly different (p<0.05).

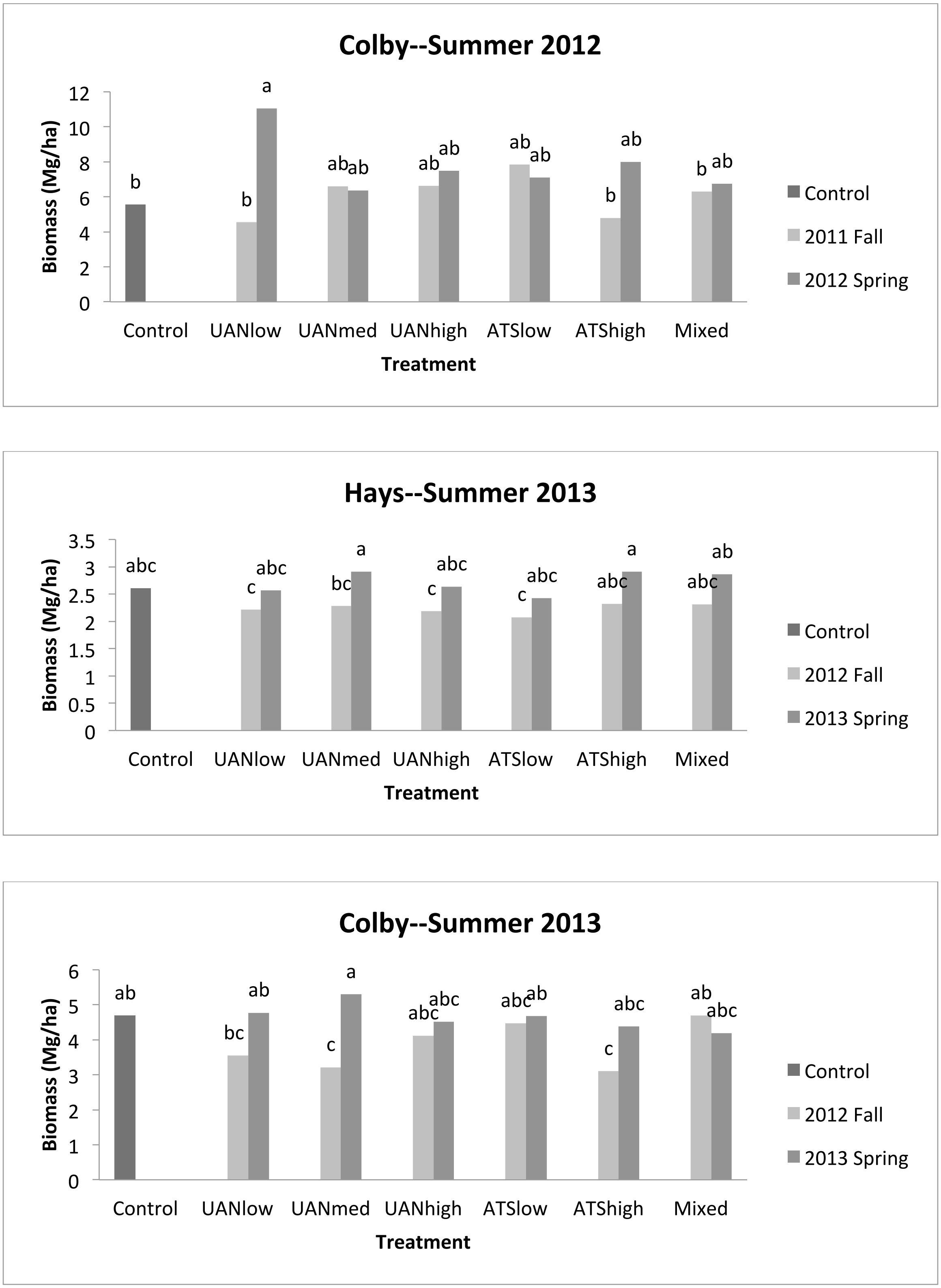
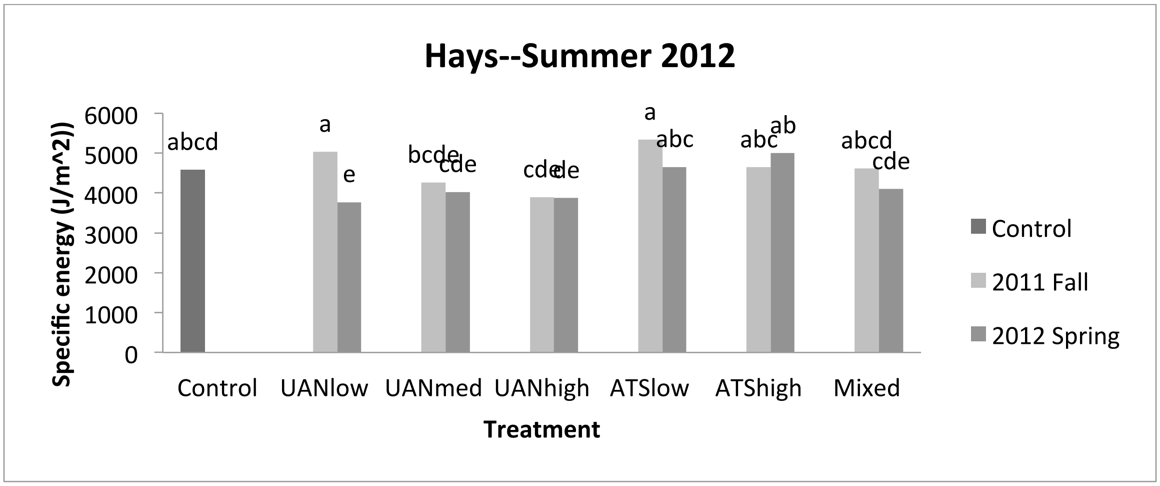
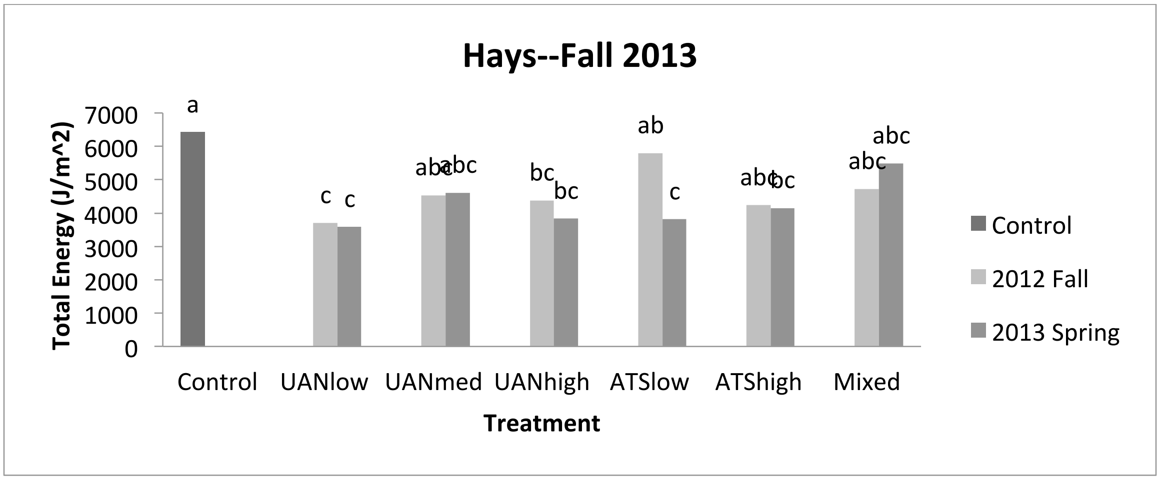


Figure 2.6 Specific energy measured at Hays and Garden City in summer 2012 and at Hays in Fall 2013. Bars with the same letter are not significantly different (p<0.05).





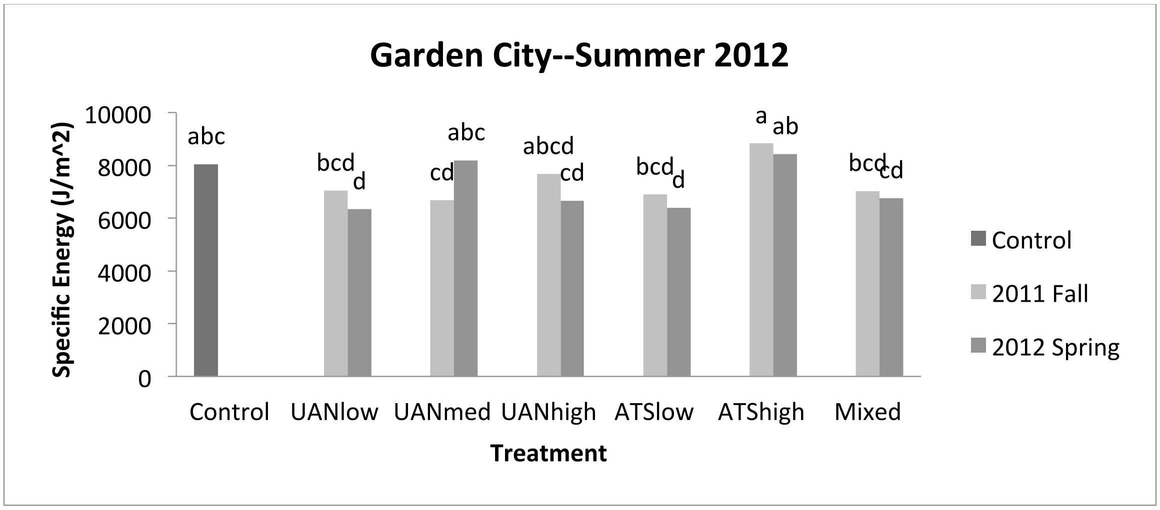


Figure 2.7 Measured shear stress at Hays and Colby during summer 2012 and Fall 2013 sampling periods. Bars with the same letter are not significantly different (p<0.05).

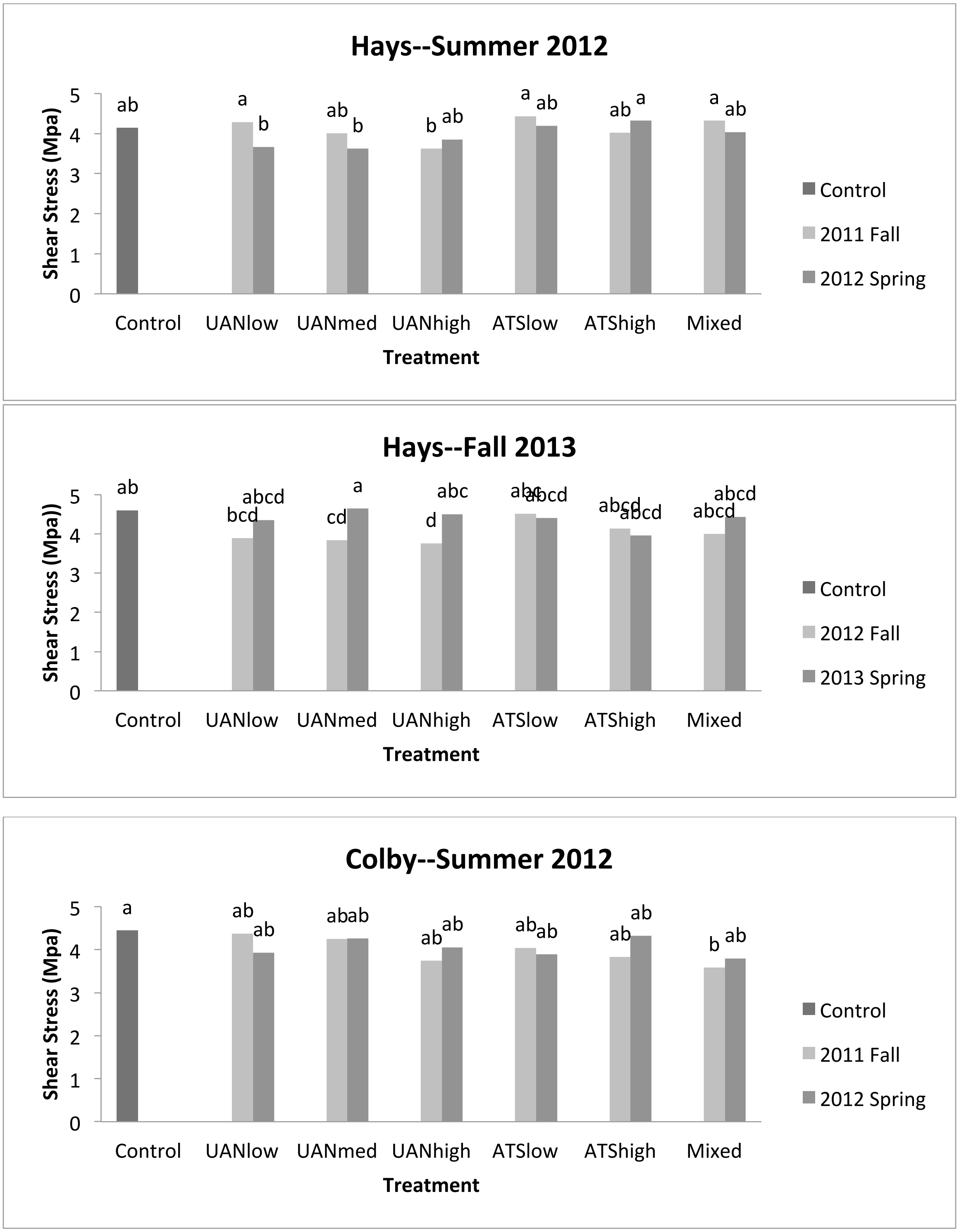


Figure 2.8 Total C content measured at the Hays, Colby, and Garden City sites in Summer 2013.

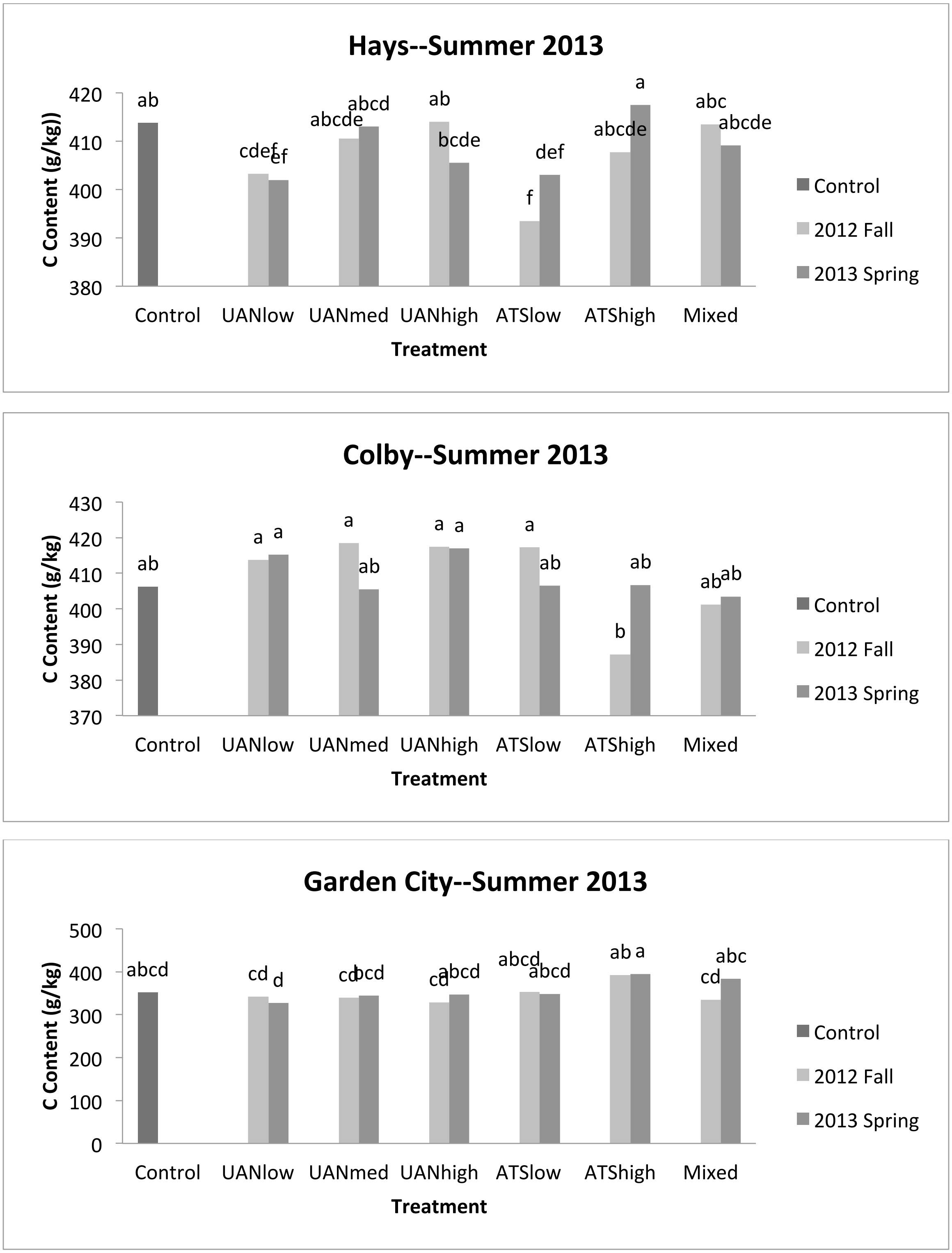


Figure 2.9 Wheat straw N contents at Hays in summer 2012, Summer 2013, and Garden City in summer 2012. Data is not shown for the other site years.

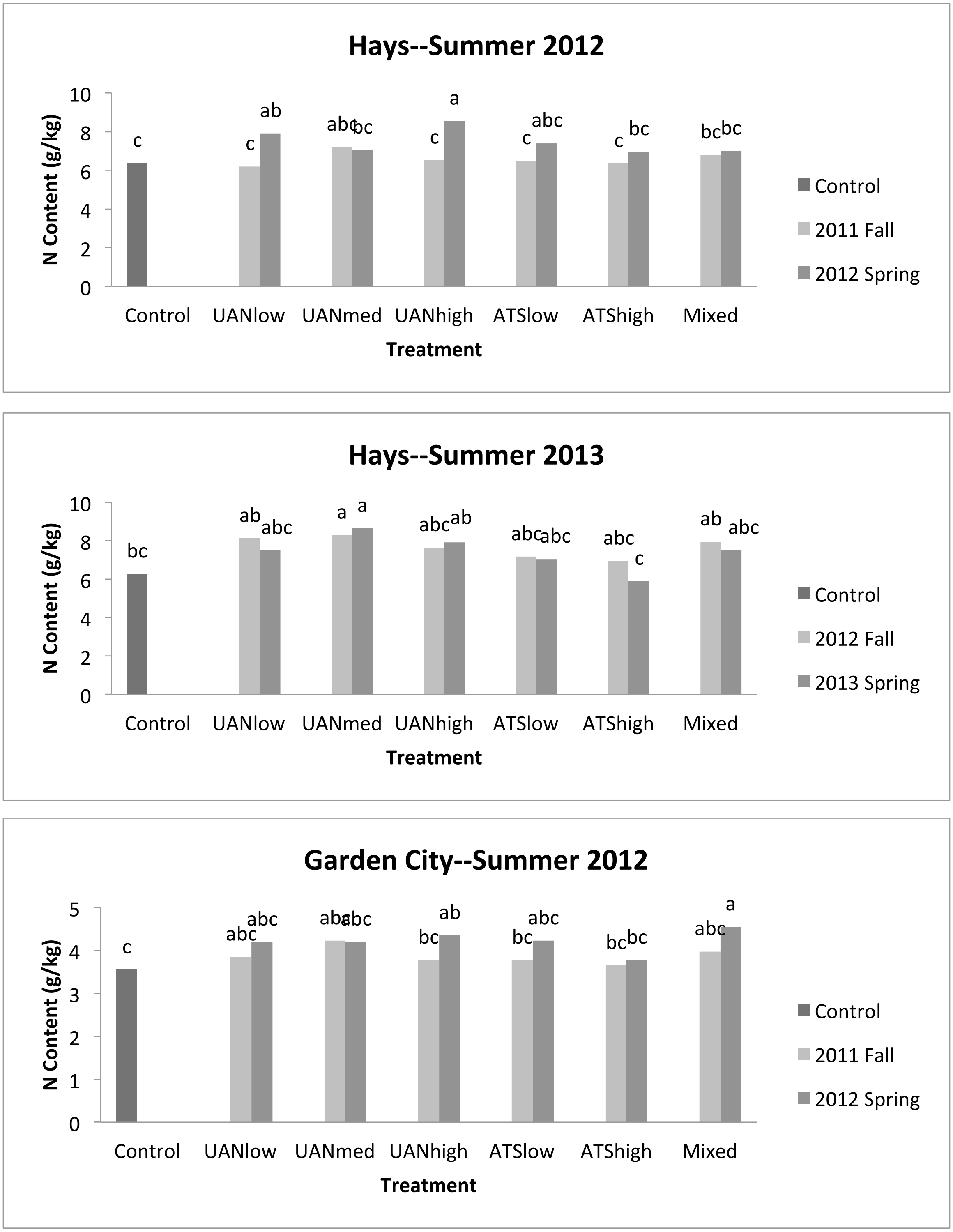
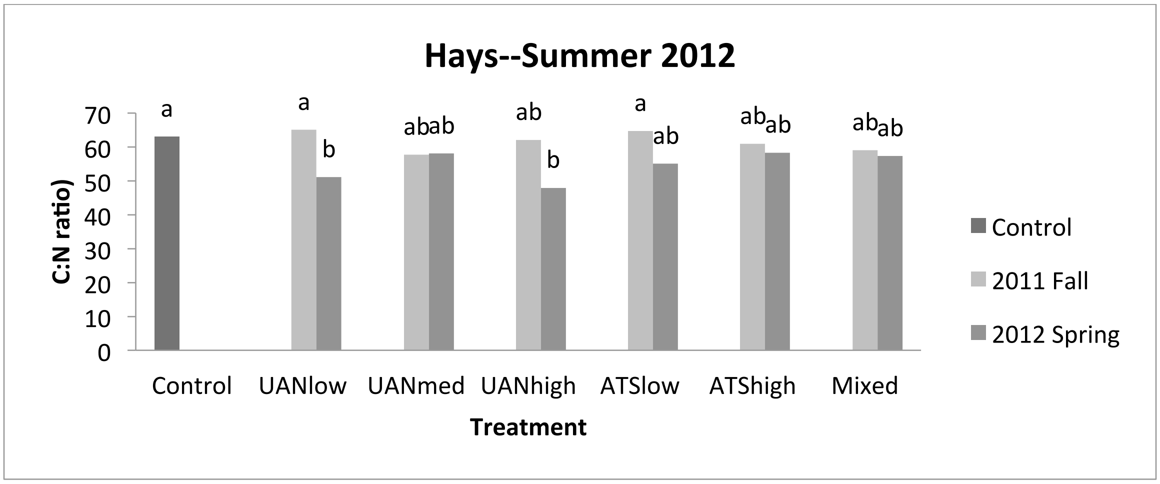
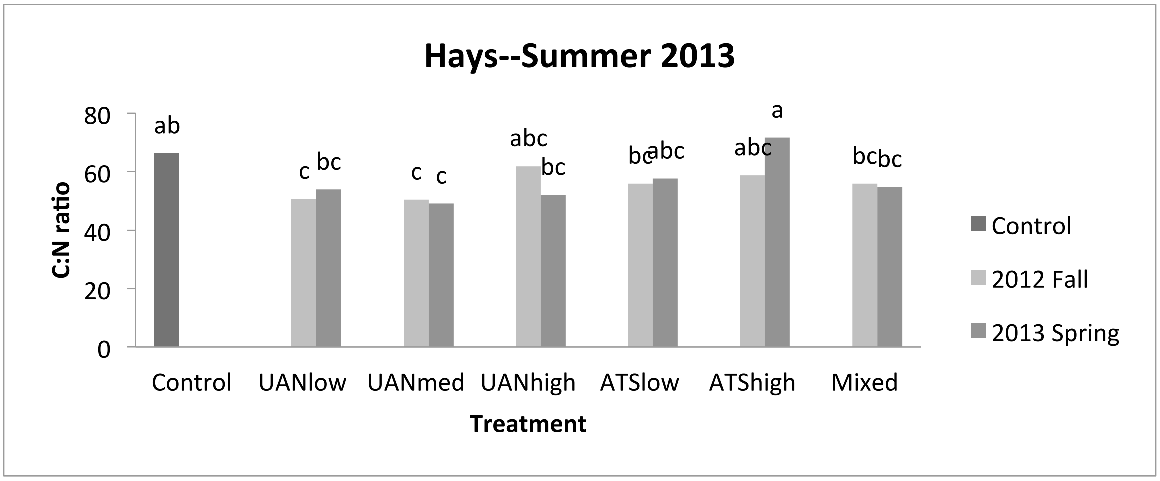
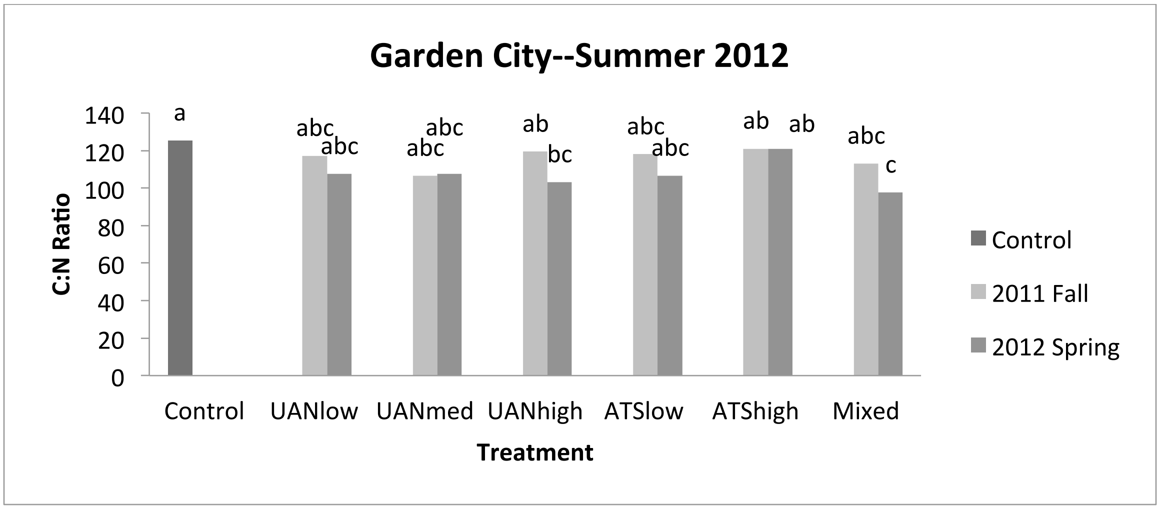


Figure 2.10 C:N ratios measured at Hays and Garden City in summer 2012 and Summer 2013. Data is not shown for the other site years.







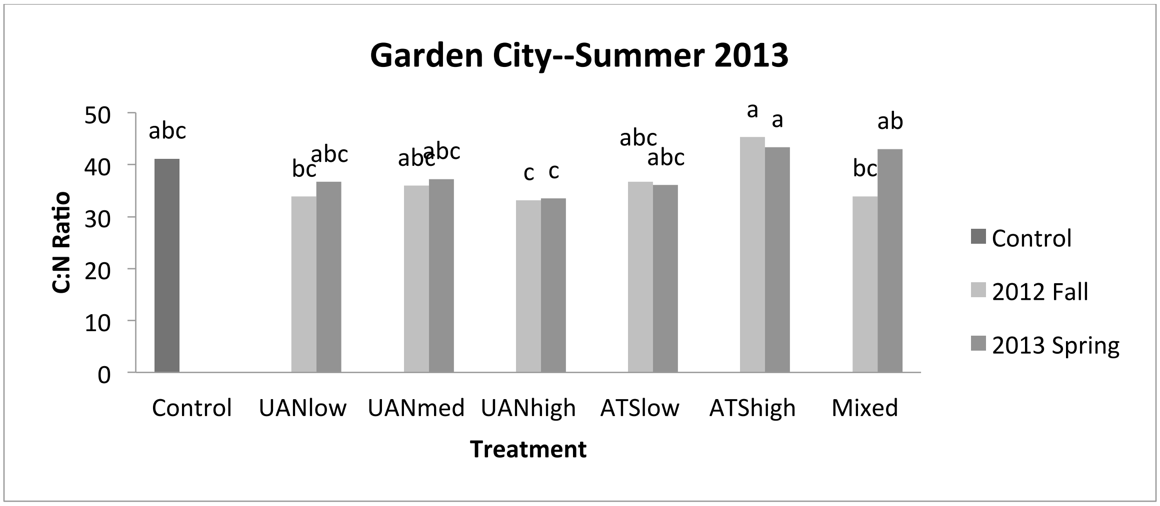

Garden City--Summer 2013
C:N Ratio
50
40
30
20
10
0
abc
bc
abc
abc
abc
c
c
abc
abc
a
a
bc
ab
Control
UANlow
UANmed
UANhigh
ATSlow
ATShigh
Mixed
Treatment
Control
2012 Fall
2013 Spring

Figure 2.11 Ash contents measured at Colby and Garden City in Summer 2013. Data is not shown for the other site years.

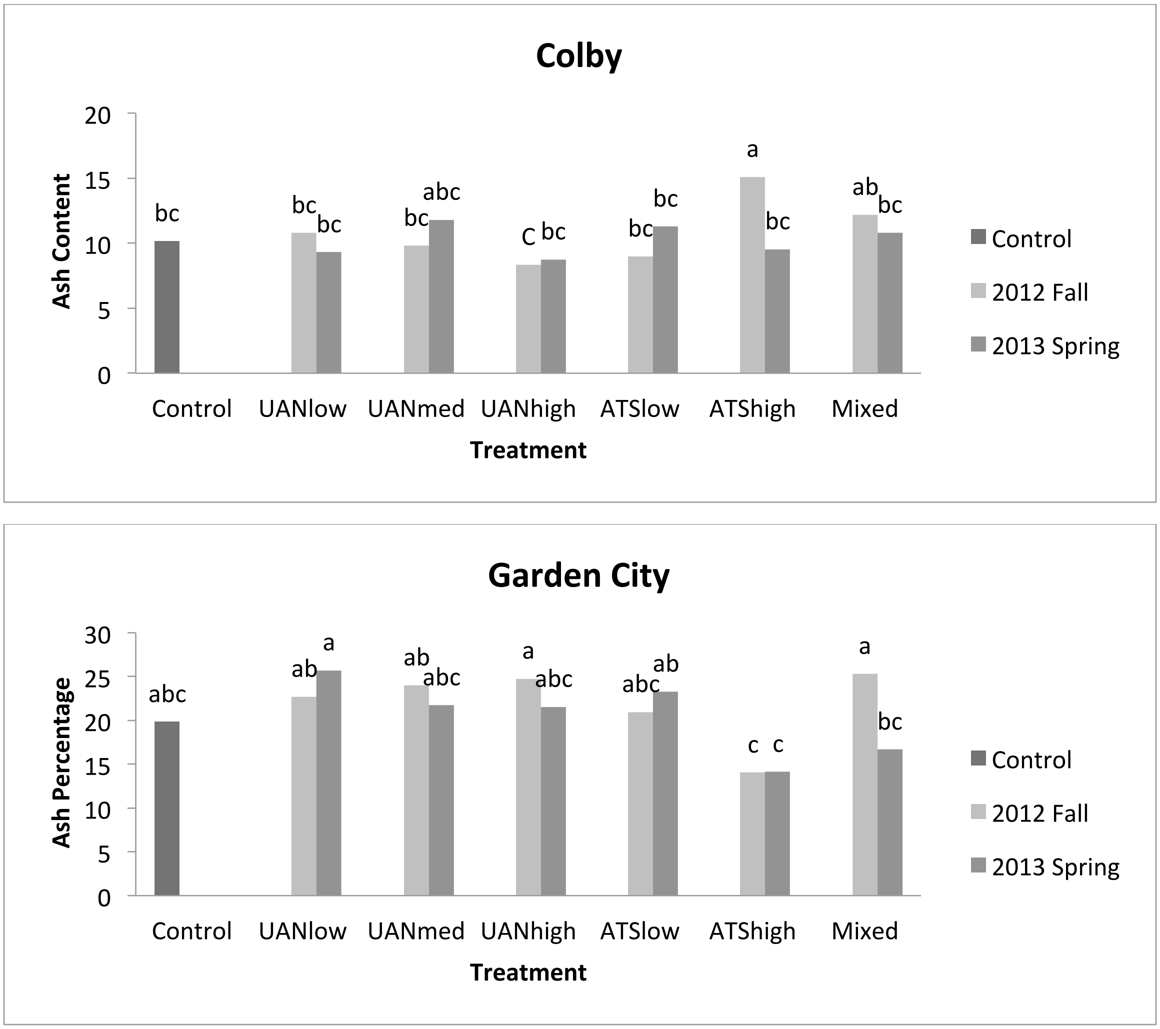


Table 2.1 Fertilizer rates for each treatment and their application time.

	Treatment	N rate (kg/ha)	S rate (kg/ha)	Fertilizer application timing	
1	Control	0	0	Sept. 2011	Sept. 2012
2	$\mathrm{UAN}_{\mathrm{low}}$	22.4	0		
3	$\mathrm{UAN}_{\mathrm{med}}$	44.6	0		
4	$\mathrm{UAN}_{\mathrm{high}}$	67.2	0		
5	$\mathrm{ATS}_{\mathrm{low}}$	7.7	16.8		
6	$\mathrm{ATS}_{\mathrm{high}}$	15.5	33.6		
7	Mixed	82.7	33.6		
8	$\mathrm{UAN}_{\mathrm{low}}$	22.4	0	Feb. 2012	Feb. 2013
9	$\mathrm{UAN}_{\mathrm{med}}$	44.6	0		
10	$\mathrm{UAN}_{\mathrm{high}}$	67.2	0		
11	$\mathrm{ATS}_{\mathrm{low}}$	7.7	16.8		
12	$\mathrm{ATS}_{\mathrm{high}}$	15.5	33.6		
13	Mixed	82.7	33.6		

Table 2.2 Results of analysis of variance.

Summer 2012								
		Biomass	Specific Energy	Shear Stress	Total C	Total N	C:N	Ash%
Hays	Trt	--	**	*	--	--	--	--
	Time	--	**	--	--	**	**	--
	Trt*Time	--	*	--	--	--	--	--
Colby†	Trt	--	--	--	NA	NA	NA	--
	Time	*	--	--	NA	NA	NA	--
	Trt*Time	--	--	--	NA	NA	NA	--
Garden City	Trt	--	--	--	--	--	--	--
	Time	--	--	--	--	**	*	--
	Trt*Time	--	--	--	--	--	--	--

Summer 2013								
		Biomass	Specific Energy	Shear Stress	Total C	Total N	C:N	Ash%
Hays	Trt	--	--	--	**	*	*	--
	Time	**	--	--	--	--	--	--
	Trt*Time	--	--	--	**	--	--	--
Colby	Trt	--	--	--	*	--	--	*
	Time	**	--	--	--	--	--	--
	Trt*Time	--	--	--	--	--	--	**
Garden City	Trt	--	NA	NA	**	--	**	**
	Time	--	NA	NA	--	--	--	--
	Trt*Time	--	NA	NA	--	--	--	--

Fall 2013‡								
		Biomass	Specific Energy	Shear Stress	Total C	Total N	C:N	Ash%
Hays	Trt	--	--	--	--	--	--	--
	Time	--	--	**	--	--	--	--

	Trt*Time	--	--	--	--	--	--	--
Colby	Trt	--	--	--	--	--	--	--
	Time	--	--	--	--	--	--	--
	Trt*Time	--	--	--	--	--	--	--

-- no significance

* significant at 0.1 level

** significant at 0.05 level

NA measurement incomplete

† Total C and N values are not available for the Colby Summer 2012 samples, due to laboratory error.

‡No samples were collected from the Garden City site in Fall 2013 due to wind damage to the site.

Table 2.3 Stepwise multivariate regression parameters for specific energy and shear stress as dependent variables and total N, C and ash content as independent variables.

Specific Energy vs. C, N, and ash								
		Stepwise Selection			Model			
Site	Sampling Period	N	C	ash	R^2	C(p)	F value	Pr>F
Hays	Summer 2012	-0.00244		NA	0.0783	0.4169	2.97	0.09
	Summer 2013		-0.00013787	NA	0.1024	2.218	5.7	0.02
Colby	Fall 2013	0.00361		NA	0.1019	0.4286	5.67	0.02
Garden City	Summer 2012	-0.01136		NA	0.2216	0.0282	14.23	<0.01
Shear Stress vs. C, N, and ash								
		Stepwise Selection			Model			
Site	Sampling Period	N	C	ash	R^2	C(p)	F value	Pr>F
Hays	Summer 2012	-2.17348		NA	0.1344	1.1313	5.43	0.03
	Summer 2013	-1.12782	-0.21503	NA	0.1419	2.0629	4.57	0.04
	Fall 2013	-1.65897		NA	0.1061	0.2314	5.93	0.02
Colby	Summer 2013	-3.68532		NA	0.2718	1.6396	18.66	<0.01
	Fall 2013	-2.50634		NA	0.2058	0.0256	12.96	<0.01
Garden City	Summer 2012	-7.77231	-0.16522	NA	0.2556	2.0014	2.88	0.096

Table 2.4 Linear regression between physical parameters and C:N ratio.

Specific Energy vs. C:N					
		Parameter Estimated	Model		
Site	Sampling Period	C:N	R^2	t value	Pr>F
Hays	Summer 2012	0.000026	0.0728	1.66	0.1064
Colby	Fall 2013	-0.000027	0.0906	-2.23	0.0302
Garden City	Summer 2012	0.000037	0.2109	3.66	0.0006
Shear Stress vs. C:N					
			Model		
Site	Sampling Period	C:N	R^2	t value	Pr>F
Hays	Summer 2012	0.020600	0.0985	1.96	0.0586
	Fall 2013	0.012340	0.0972	2.32	0.0245
Colby	Summer 2013	0.026020	0.2689	4.29	<0.0001
	Fall 2013	0.018080	0.1716	3.22	0.0023
Garden City	Summer 2012	0.019450	0.1709	3.21	0.0023

Table 2.5 Analysis of variance result of pre-test to determine the number of straw used.

test 1		test 2		test 3		test 4	
Shear Stress	Straw tested	Peak Energy	Straw tested	Peak Energy	Straw tested	SE	Straw tested
3.94	50	0.0099	40	0.0115_{a}	50	0.009_{a}	50
3.88	30	0.0098	30	0.0095_{ab}	40	0.0074_{a}	40
3.84	40	0.0096	50	0.008_{ab}	30	0.0055_{ab}	30
3.46	20	0.0093	20	0.0047_{b}	10	0.0035_{b}	10
3.41	10	0.0086	10	0.0043_{b}	20	0.0034_{b}	20

References

Abera, G., Wolde-Meskel, E., and Bakken, L.R. 2014. Unexpected high decomposition of legume residues in dry season soils from tropical coffee plantations and crop lands. Agronomy for Sustainable Development. 34(3): 667-676

Al-Kaisi, M.M., Guzman, J.G. 2013. Effects of tillage and nitrogen rate on decomposition of transgenic Bt and near-isogenic non-Bt maize residue. Soil & Tillage Research. 129: 32-39.

Annoussamy, M., Richard, G., Recous, S., Guerif, J. 2000. Change in Mechanical Properties of Wheat Straw Due to Decomposition and Moisture. Applied Engineering in Agriculture. 16(6):657-664

Baldock, J.A. 2007. Composition and cycling of organic carbon in soil. In: Marschner, P., Rengel, Z. (Eds.), Nutrient Cycling in Terrestrial Ecosystems. Springer Verlag, Berlin Heidelberg, pp. 1–35.

Berg, B. and C. McClaugherty. 2007. Plant litter: decomposition, humus formation, carbon sequestration. Springer

Blanco-Canqui, H., and Lal, R. 2009. Crop residue removal impacts on soil productivity and environmental quality. Critical Reviews in Plant Science. 28: 139-163.

Bremner, J.M., and Mulvaney, C.S. 1982. Nitrogen-total. In:Page, A.L., Miller, R.H., Keeney, D.R. (Eds.). Methods of Soil Analysis, Part II. Chemical and Microbiological Properties. Second ed. Am. Soc. Agron, Madison, WI, USA, pp, 595-624.

Capper, B.S., Sage G., Hanson P.R., Adamson A. H. 1992. Influence of variety, row type and time of sowing on the morphology, chemical composition and in vitro digestibility of barley straw. Jornual of Agricultural Science, Cambridge. 118: 165-173.

Chen, Y., Gratton, J.L., Liu, J. 2004. Power requirements of hempcutting and conditioning. Biosystems Engineering, 87(4), 417–424.

Clapp, C.E., Allmaras, R.R., Layese, M.F., Linden, D.R. and Dowdy, R.H. 2000. Soil organic carbon and 13C abundance as related to tillage, crop residue, and nitrogen fertilization under continuous corn management in Minnesota. Soil and Tillage Research 55: 127-142.

Cone, J. W., A. H. Van Gelder, and H. J. P. Marvin. 1996. Influence of drying method and aging on chemical and physical properties and in vitro degradation characteristics of grass and maize samples. J. Agric. Sci. 126: 7-14.

Dam, R.F., Mehdi, B.B., Burgess, M.S.E., Madramootoo, C.A., Mehuys, G.R., Callum, I.R., 2005. Soil bulk density and crop yield under eleven consecutive years of corn with different tillage and residue practices in a sandy loam soil in central Canada. *Soil Till. Res*. 84: 41–53

Davin, E.L., Seneviratne, S.I., Ciaic, P., Olioso, A., Wang, T. 2014. Preferential cooling of hot extremes from cropland albedo management. PNAS. 111(27):9757-9761

Dernedde, W. 1970. Die technologischen eigenschaften von grasund deren einfluss den schneidvorgang (Technological properties of grass and their influence on the cutting process). “Zerkleinern Von Halmfutter” LandbForseh-V.lkenrode. Sondern 8: 53-57.

Doan, G., Chen, T., and Irvine, B. 2005. Effect of oat stubble height on the performace of no-till seeder openers. Canadian Biosystems Engineering. 47:237-244.

Fog, K. 1988. The effect of added nitrogen on the rate of decomposition of organic matter. Biological Reviews of the Cambridge Philosophical Society 63, 433–462.

Gao, F., Feng, G., Sharratt, B., and Zhang, M. 2014. Tillage and straw management affect PM10 emission potential in subarctic Alaska. Soil and Tillage Research. 114:1-7.

Green, C.J., Blackmer, A.M., Horton, R. 1995. Nitrogen effects on conservation of carbon during corn residue decomposition in the soil. Soil Science Society of America Journal 59, 453–459.

Hadas, A., Larissa, K., Goek, M., and Kara, E.E. 2004. Rates of decomposition of plant residues and available nitrogen in soil, related to residue composition through simulation of carbon and nitrogen turnover. Soil Biology and Biochemistry. 36: 255-266.

Havstad, L.T., Aamlid, T.S., and Henriksen, T.M. 2010. Decomposition of straw from herbage seed production: Effects of species, nutrient amendment and straw placement on C and N net mineralization. Soil and Plant Science. 60: 57-68

Hill, R. L., 1990. Long-term converntional and no-tillage effects on selected soil physical properties. *Soil Sci. Soc. Am. J.* 54: 161-166

Hobbs, P.R. 2007. Conservation agriculture: what is it and why is it important for future sustainable food production? J. Agric. Sci. 145 (2): 127–137

Horton, R., K. L. Bristow, G. J. Kluitenberg, and T. J. Sauer. 1996. Crop residue effects on surface radiation and energy balance - Review. Theor. and Applied Climatology 54(1-2): 27-37.

Huber, J. A. 1991. A study of the physical properties of wheat straw. M.Phil. Silsoe, U.K.: Cranfield Institute of Technology, Silsoe College.

Khardiwar, M.S., Dubey, A.K., Mahalle, D.M., and Kumar, S. 2013. Study on Physical and Chemical Properties of Crop Residues briquettes for gasification. International Journal of Renewable Energy Technology Research. 2(11): 237-248.

Kravchenko, A.N., Robertson, G.P., Hao, X., Bullovk, D.G., 2006. Management practices effects on surface total carbon: differences in spatial variability patterns. *Agron. J.* 98: 1559–1568

Kriaučiūnienė, Z., Velička, R., and Raudonius, S. 2012. The influence of crop residues type on their decomposition rate in the soil: a litterbag study. Žemdirbystė=Agriculture. 99(3): 227-236.

Kushaha, R. L., A. S. Vashnav, and G. C. Zoerb. 1983. Shear strength of wheat straw. Canadian Agric. Eng. 25(2): 163-166.

Lal, R., 1982. No-till farming: soil and water conservation and management in the humid and subhumid tropics. IITA Monograph No.2, IITA, Ibadan, Nigeria, 64pp.

Li, R., Fei, J., Cai, Y., Li, Y., Feng, J., and Yao, J. 2009. Cellulose Whisker Extracted from Mulberry: A Novel Biomass Production. Carbohydr. Polym. 76(1):94-99.

McCalla, T. M. 1943. Changes in the physical properties of straw during the early stages of decomposition. Soil Sci. Soc. Proc., 258-262.

Melchiori, R.J.M., Novelli, L.E., Gregorutti, V.C., and Caviglia, O.P. 2014. Stover Quality and Soil Organic Carbon in Long-Term Nitrogen-Fertilized Maize. Agronomy J.

Mengel, D.B., Wilson, D.W., Huber, D.M., 1982. Placement of nitrogen fertilizer for no-till and conventional tillage corn. *Agron. J.* 74: 515–518

Moran, K.K., Six, J., Horwath, W.R., van Kessel, C. 2005. Role of mineral-nitrogen in residue decomposition and stable soil organic matter formation. Soil Science Society of America Journal 69, 1730–1736.106:1709-1716.

Nazari Galedar, M., Jafari, A., Mohtasebi, S.S., Tabatabaeefar, A., Sharifi, A., O'Dogherty, M.J., Rafiee, S., Richard, G. 2008. Effects of Moisture Content and Level in The Crop on The Engineering Properties of Alfalfa Stems. Biosystems Engineering 101:199-208.

O'Dogherty M.J., Gilbertson H.G., Gale G.E.1989. Measurements of the physical and mechanical properties of wheat straw. Fourth International Conference on the Physical Properties of Agricultural Materials, Rostock, German Democratic Republic, 4-8 September: 608–613

Payton, D.M., Hyde, G.M., and Simpson, J.B. 1985. Equipment and methods for no-tillage wheat planting. Transaction of the ASAE. 28(5):1419-1424.

Reichert, J.M., Suzuki, L.E.A.S., and Reinert, D.J. 2009. Reference bulk density and critical degree-of-compactness for no-till crop production in subtropical highly weathered soils. Soil & Tillage Research. 102:242-254.

Sarath, G., Mitchell, R. B., Sattler, S. E., Funnell, D., Pedersen, J. F., Graybosch, R. A., and Vogel, K. P. 2008. Opportunities and roadblocks in utilizing forages and small grains for liquid fuels. J. Ind. Microbiol. Biotechonol. 35: 343-354.

Schomberg, H.H., Steiner J.L., and Unger, P.W. 1994. Decomposition and Nitrogen Dynamics of Crop Residues: Residue Quality and Water Effects. Soil Science Scciety of America Journal. 58(2): 372-381

Singh S., Dutt D., and Tyagi C.H., 2011. Complete characterization of wheat straw (triticum aestivum PBW-343 L. Emend. Fiori & Paol.) – A renewable source of fibers for pulp and paper making. BioResources 6(1): 154-177

Shinners, K. J., R. G. Koegel, G. P. Barrington, and R. J. Straub. 1987. Evaluating longitudinal shear as a forage maceration technique. Transactions of the ASAE, 30(1), 18–22.

Taghijarah, H., Ahmadi, H., Ghahderijani, M., and Tavakoli, M. 2011. Shearing characterstics of sugar can (*Saccharum officinarum* L.) stalks as a function of the rate of the applied force. Australian Journal of Crop Science 5(6): 630-634.

Tavakoli H, Mohtasebi SS, Jafari A, Nazari Galedar M (2009b) Some engineering properties of barley straw. Appl Eng Agric 25(4): 627–633.

Travis A.J., Murison S.D., Hirst D.J., Walker K.C., Chesson A. 1996. Comparison of the anatomy and degradability of straw from varieties of wheat and barley that differ in susceptibility to lodging. Journal of Agricultural Science, Cambridge. 127: 1-10

Unger, P. W. [ed.]. 1994. Managing agricultural residues. Lewis Publ., Boca Raton, Florida

Appendix A - On-farm Assessment of Crop Residue Removal Impacts on Wind Erosion in the Central Great Plains

Raw data

Table A.1 Soil EF, GMD and GSD at La Crosse in fall 2011

Removal rate	Plot #	EF	GMD	GSD
100%	101	38.61	1.05	16.14
	203	38.55	1.13	17.09
	304	53.87	0.44	15.15
	402	41.75	0.97	18.25
75%	104	45.80	0.68	14.76
	201	53.63	0.53	16.90
	305	51.22	0.54	16.11
	403	36.96	1.33	15.58
50%	102	33.69	1.63	15.77
	204	51.64	0.50	14.44
	302	39.74	1.12	15.42
	405	36.63	1.37	14.39
25%	105	45.43	0.65	13.17
	202	31.62	1.62	13.47
	303	23.99	2.97	11.97
	401	54.02	0.44	14.86
0%	103	40.89	1.06	17.92
	205	39.28	1.17	16.98
	301	48.07	0.65	14.66
	404	27.79	2.50	14.28

Table A.2 Soil EF, GMD and GSD at Rush Center in fall 2011

Removal rate	Plot #	EF	GMD	GSD
100%	104	28.48	2.23	13.32
	202	47.38	0.66	10.42
	303	42.10	0.81	11.16
	401	36.21	0.91	10.67
75%	103	25.98	2.25	9.68
	204	32.77	1.79	14.79
	301	33.39	1.55	11.98
	405	23.26	3.84	12.69
50%	101	17.73	4.23	8.52
	205	16.82	5.09	8.81
	302	36.85	1.32	13.88
	403	19.45	5.55	12.19
25%	105	26.34	2.25	9.18
	201	25.39	2.67	10.52
	304	21.16	3.12	9.45
	402	40.19	1.00	10.25
0%	102	16.11	4.30	8.34
	203	26.76	2.44	11.21
	305	15.03	6.80	11.01
	404	17.69	6.00	12.70

Table A.3 Soil EF, GMD and GSD at Colby in fall 2011

Removal rate	Plot #	EF	GMD	GSD
100%	104	30.72	1.84	14.98
	202	32.39	1.55	13.45
	303	35.75	1.30	14.38
	401	20.86	4.31	14.12
75%	103	46.97	0.74	14.40
	204	45.78	0.64	14.44
	301	30.91	1.82	14.45
	405	42.48	0.91	15.47
50%	101	34.58	1.24	10.61
	205	31.63	1.49	13.32
	302	44.66	0.79	16.56
	403	29.62	2.06	12.81
25%	105	25.54	2.35	11.21
	201	33.34	1.60	11.99
	304	16.61	4.47	5.06
	402	30.82	2.01	14.06
0%	102	27.59	3.14	18.30
	203	36.32	1.26	12.29
	305	29.55	2.03	14.88
	404	30.33	2.29	14.25

Table A.4 Soil EF, GMD and GSD at Norcatur in fall 2011

Removal rate	Plot #	EF	GMD	GSD
100%	101	23.97	5.70	26.80
	203	13.12	7.08	10.92
	304	17.13	4.97	12.59
	402	20.15	3.17	11.08
75%	104	17.58	5.97	13.23
	201	20.90	2.73	10.22
	305	14.67	7.14	10.66
	403	13.62	9.33	13.07
50%	102	8.34	16.21	9.71
	204	9.07	14.67	9.64
	302	8.50	21.09	11.47
	405	19.39	3.50	10.49
25%	105	16.05	7.22	13.03
	202	13.28	8.40	10.91
	303	7.87	13.68	8.06
	401	17.66	5.30	11.90
0%	103	17.14	5.26	11.68
	205	8.39	12.95	8.56
	301	15.04	5.40	8.81
	404	24.63	2.88	13.42

Table A.5 Soil EF, GMD and GSD at Garden City in fall 2011

Removal rate	Plot #	EF	GMD	GSD
100%	101	39.17	1.03	15.97
	203	26.66	2.81	16.33
	304	32.87	1.80	16.09
	402	28.10	2.10	12.86
75%	104	50.64	0.51	11.70
	201	41.95	0.98	14.30
	305	34.80	1.67	16.40
	403	29.68	2.25	15.88
50%	102	44.83	0.83	16.33
	204	27.90	2.29	14.17
	302	36.02	1.13	12.17
	405	36.94	1.05	12.00
25%	105	42.54	0.85	16.33
	202	26.62	2.46	12.86
	303	25.59	4.41	20.54
	401	31.21	1.82	13.26
0%	103	39.00	1.20	14.64
	205	41.94	1.04	16.65
	301	20.10	4.71	13.66
	404	28.15	2.54	16.24

Table A.6 Soil EF, GMD and GSD at Scott City in fall 2011

Removal rate	Plot #	EF	GMD	GSD
100%	101	36.91	1.24	15.62
	203	62.79	0.29	13.73
	304	68.17	0.24	12.52
	402	54.16	0.43	13.26
75%	104	45.12	0.72	10.91
	201	32.29	1.81	14.13
	305	52.87	0.63	14.88
	403	41.63	0.77	12.87
50%	102	26.44	3.31	15.91
	204	55.71	0.56	13.97
	302	23.22	3.58	12.80
	405	63.71	0.32	11.29
25%	105	35.15	1.75	14.30
	202	31.42	1.84	14.98
	303	46.33	0.77	14.04
	401	32.06	1.76	13.18
0%	103	36.33	1.23	11.19
	205	38.23	1.31	13.86
	301	31.51	1.78	12.77
	404	36.68	1.36	14.09

Table A.7 Soil crushing test results and random roughness at La Crosse in fall 2011

Removal rate	Plot #	Break Force	Stability	Roughness
100%	101	6.46	2.86	6.46
	203	6.86	3.53	3.87
	304	6.67	3.24	3.05
	402	6.70	3.16	2.64
75%	104	6.05	2.66	6.29
	201	6.63	2.95	3.94
	305	6.31	2.86	3.48
	403	6.47	2.96	4.17
50%	102	6.70	3.04	6.06
	204	6.83	3.30	8.76
	302	6.67	3.07	3.08
	405	6.46	2.90	4.91
25%	105	6.64	3.14	5.90
	202	6.86	3.07	5.36
	303	6.16	2.82	6.72
	401	6.58	3.40	5.17
0%	103	6.70	3.41	4.39
	205	6.81	3.12	4.39
	301	6.17	2.57	7.40
	404	6.73	3.41	8.25

Table A.8 Soil crushing test results and random roughness at Rush Center in fall 2011

Removal rate	Plot #	Break Force	Stability	Roughness
100%	101	7.49	4.12	7.72
	203	7.22	3.89	7.61
	304	7.26	3.85	14.90
	402	7.26	3.65	1.07
75%	104	7.11	3.49	10.23
	201	7.23	3.77	10.32
	305	7.50	4.07	16.13
	403	7.46	3.91	8.08
50%	102	7.18	3.67	6.75
	204	7.62	4.07	8.43
	302	7.19	3.85	8.19
	405	7.24	3.78	9.42
25%	105	7.65	4.27	12.96
	202	7.50	3.95	9.63
	303	7.53	4.18	10.32
	401	6.79	3.51	6.22
0%	103	7.89	4.44	7.06
	205	7.60	4.20	9.83
	301	7.27	3.73	12.66
	404	7.68	4.10	12.31

Table A.9 Soil crushing test results and random roughness at Colby in fall 2011

Removal rate	Plot #	Break Force	Stability	Roughness
100%	101	6.52	3.23	1.71
	203	6.69	3.43	1.74
	304	7.13	3.89	1.74
	402	7.32	4.00	1.82
75%	104	6.71	3.47	3.00
	201	6.68	3.24	5.21
	305	6.62	3.28	1.87
	403	5.89	2.63	5.20
50%	102	6.19	2.86	9.46
	204	5.91	2.57	7.31
	302	6.25	2.98	8.25
	405	6.76	3.29	10.27
25%	105	6.33	2.77	4.81
	202	6.79	3.38	11.32
	303	6.88	3.54	5.06
	401	6.79	3.21	7.55
0%	103	6.37	2.97	12.12
	205	7.03	3.75	9.27
	301	7.00	3.52	12.77
	404	7.05	3.72	9.26

Table A.10 Soil crushing test results and random roughness at Norcatur in fall 2011

Removal rate	Plot #	Break Force	Stability	Roughness
100%	101	7.24	3.96	2.46
	203	7.52	3.91	4.73
	304	7.04	3.73	8.14
	402	6.89	3.06	4.01
75%	104	7.69	4.16	7.47
	201	7.04	3.78	6.37
	305	7.30	3.85	8.14
	403	6.85	3.70	4.01
50%	102	7.84	4.45	9.71
	204	7.62	4.25	10.01
	302	6.97	3.54	7.72
	405	6.61	3.37	5.64
25%	105	7.32	3.72	6.56
	202	7.58	4.23	8.47
	303	6.74	3.36	8.11
	401	7.02	3.38	4.01
0%	103	7.32	4.01	9.78
	205	7.34	3.63	3.91
	301	7.41	3.90	8.44
	404	6.88	3.35	9.07

Table A.11 Soil crushing test results and random roughness at Garden City in fall 2011

Removal rate	Plot #	Break Force	Stability	Roughness
100%	101	6.14	2.67	5.34
	203	7.45	4.09	3.59
	304	7.20	3.75	3.57
	402	7.52	4.09	1.56
75%	104	7.01	3.54	8.77
	201	6.66	3.38	3.75
	305	7.29	3.85	5.16
	403	7.35	3.56	5.82
50%	102	6.64	3.07	7.77
	204	6.71	3.22	4.92
	302	7.15	3.74	4.60
	405	7.64	4.14	6.84
25%	105	6.22	2.85	6.31
	202	6.69	3.43	7.09
	303	7.11	3.95	6.24
	401	7.12	3.74	9.71
0%	103	6.83	3.63	8.15
	205	7.13	3.45	5.24
	301	7.17	3.75	8.98
	404	7.40	4.09	5.70

Table A.12 Soil crushing test results and random roughness at Scott City in fall 2011

Removal rate	Plot #	Break Force	Stability	Roughness
100%	101	6.40	2.99	7.03
	203	5.80	2.34	3.12
	304	5.49	2.13	3.97
	402	6.36	2.98	5.46
75%	104	5.80	2.39	6.58
	201	6.05	2.70	7.88
	305	6.29	2.88	9.58
	403	6.30	2.60	7.59
50%	102	6.24	3.03	8.90
	204	5.45	1.94	8.63
	302	6.63	3.28	10.42
	405	6.46	2.92	16.01
25%	105	6.66	3.31	12.25
	202	6.50	3.13	11.95
	303	6.19	2.75	5.98
	401	6.94	3.61	10.81
0%	103	6.10	2.68	9.44
	205	5.57	2.18	10.93
	301	6.47	3.13	11.02
	404	6.48	3.04	9.66

Table A.13 Soil wind erosion modeling (SWEEP) results at La Crosse in fall 2011

Removal rate	Plot #	Initial wind	Probability%	Soil loss (kg m^{-2})
100%	101	10	8.63	1.0978
	203	10	8.63	0.7002
	304	10	8.63	1.0586
	402	9	12.89	1.0124
75%	104	14	0.99	0
	201	13	1.69	0.1153
	305	12	2.97	0.1383
	403	14	0.99	0
50%	102	17	0.14	0
	204	17	0.14	0
	302	15	0.56	0
	405	16	0.3	0
25%	105	17	0.14	0
	202	18	0.06	0
	303	19	0.03	0
	401	16	0.3	0
0%	103	18	0.06	0
	205	18	0.06	0
	301	18	0.06	0
	404	20	0.01	0

Table A.14 Soil wind erosion modeling (SWEEP) results at Rush Center in fall 2011

Removal rate	Plot #	Initial wind	Probability%	Soil loss (kg m^{-2})
100%	101	11	5.23	0.2647
	203	10	8.63	0.4443
	304	12	2.97	0.2595
	402	6	25.15	0.6454
75%	104	17	0.14	0
	201	16	0.3	0
	305	18	0.06	0
	403	17	0.14	0
50%	102	19	0.03	0
	204	20	0.01	0
	302	18	0.06	0
	405	19	0.03	0
25%	105	20	0.01	0
	202	19	0.03	0
	303	20	0.01	0
	401	17	0.14	0
0%	103	19	0.03	0
	205	19	0.03	0
	301	21	0	0
	404	21	0	0

Table A.15 Soil wind erosion modeling (SWEEP) results at Colby in fall 2011

Removal rate	Plot #	Initial wind	Probability%	Soil loss (kg m^{-2})
100%	101	7	25.63	0.9299
	203	7	25.63	0.789
	304	7	25.63	0.5402
	402	9	10.06	0.408
75%	104	12	2.38	0.0941
	201	13	1.47	0.0371
	305	12	2.38	0.0552
	403	14	0.85	0
50%	102	18	0.12	0
	204	17	0.21	0
	302	17	0.21	0
	405	19	0.06	0
25%	105	18	0.12	0
	202	20	0.03	0
	303	20	0.03	0
	401	19	0.06	0
0%	103	21	0.01	0
	205	20	0.03	0
	301	21	0.01	0
	404	20	0.03	0

Table A.16 Soil wind erosion modeling (SWEEP) results at Norcatur in fall 2011

Removal rate	Plot #	Initial wind	Probability%	Soil loss (kg m^{-2})
100%	101	9	9.97	0.4073
	203	12	2.25	0.3272
	304	13	1.37	0.2644
	402	10	7.28	0.9194
75%	104	17	0.21	0
	201	16	0.33	0
	305	18	0.14	0
	403	16	0.33	0
50%	102	21	0.01	0
	204	21	0.01	0
	302	21	0.01	0
	405	18	0.12	0
25%	105	20	0.03	0
	202	21	0.01	0
	303	22	0	0
	401	18	0.12	0
0%	103	22	0	0
	205	20	0.03	0
	301	21	0.01	0
	404	20	0.03	0

Table A.17 Soil wind erosion modeling (SWEEP) results at Garden City in fall 2011

Removal rate	Plot #	Initial wind	Probability%	Soil loss (kg m^{-2})
100%	101	9	13.59	1.3485
	203	10	9.41	0.3524
	304	9	13.59	0.5463
	402	8	20.91	0.3957
75%	104	14	0.96	0
	201	13	1.81	0.0502
	305	14	0.96	0
	403	15	0.47	0
50%	102	15	0.47	0
	204	15	0.47	0
	302	14	0.96	0
	405	15	0.47	0
25%	105	17	0.19	0
	202	19	0.07	0
	303	19	0.07	0
	401	19	0.07	0
0%	103	19	0.07	0
	205	18	0.11	0
	301	21	0.02	0
	404	19	0.07	0

Table A.18 Soil wind erosion modeling (SWEEP) results at Scott City in fall 2011

Removal rate	Plot #	Initial wind	Probability%	Soil loss (kg m^{-2})
100%	101	10	9.41	0.8173
	203	6	42.68	1.7501
	304	7	30.69	1.926
	402	8	20.91	1.0039
75%	104	14	0.96	0
	201	16	0.32	0
	305	15	0.47	0
	403	14	0.96	0
50%	102	19	0.07	0
	204	17	0.19	0
	302	20	0.05	0
	405	18	0.11	0
25%	105	20	0.05	0
	202	20	0.05	0
	303	17	0.19	0
	401	20	0.05	0
0%	103	20	0.05	0
	205	20	0.05	0
	301	20	0.05	0
	404	20	0.05	0

Table A.19 Soil EF, GMD and GSD at La Crosse in spring 2012

Removal rate	Plot #	EF	GMD	GSD
100%	101	33.03	1.74	15.11
	203	37.10	1.25	14.44
	304	35.63	1.45	14.97
	402	39.19	1.46	20.25
75%	104	27.09	2.48	14.05
	201	21.45	4.96	14.57
	305	30.88	1.98	14.95
	403	25.82	3.67	15.89
50%	102	24.59	3.70	14.47
	204	35.00	1.78	17.94
	302	26.34	3.36	17.94
	405	21.08	4.58	13.79
25%	105	33.39	1.52	13.53
	202	33.79	1.81	17.40
	303	22.79	3.78	13.36
	401	37.34	1.28	15.11
0%	103	35.75	1.55	16.46
	205	28.19	2.91	16.97
	301	33.86	1.54	14.42
	404	21.71	5.50	16.10

Table A.20 Soil EF, GMD and GSD at Rush Center in spring 2011

Removal rate	Plot #	EF	GMD	GSD
100%	104	45.83	0.88	11.48
	202	53.16	0.74	15.30
	303	66.83	0.34	8.69
	401	52.90	0.52	8.80
75%	103	21.57	2.98	9.16
	204	55.75	0.51	9.31
	301	70.70	0.35	8.00
	405	28.40	1.88	8.96
50%	101	44.57	0.92	10.76
	205	23.97	1.85	7.42
	302	43.45	0.74	8.11
	403	39.76	1.12	10.25
25%	105	26.88	2.50	11.10
	201	28.91	2.70	14.23
	304	35.47	1.15	9.31
	402	35.18	1.46	11.42
0%	102	17.42	3.88	9.24
	203	31.19	1.52	8.89
	305	23.54	1.80	7.48
	404	23.17	1.99	7.25

Table A.21 Soil EF, GMD and GSD at Colby in spring 2012

Removal rate	Plot #	EF	GMD	GSD
100%	104	74.27	0.18	10.08
	202	66.54	0.27	10.09
	303	69.56	0.24	10.23
	401	88.72	0.09	7.40
75%	103	77.78	0.15	10.91
	204	69.05	0.27	10.89
	301	78.30	0.16	10.73
	405	58.04	0.50	11.03
50%	101	46.84	0.90	16.49
	205	40.74	1.27	19.51
	302	42.70	1.01	12.39
	403	66.71	0.31	12.97
25%	105	27.25	3.41	17.04
	201	55.71	0.51	13.56
	304	30.43	2.58	16.10
	402	38.07	1.26	12.11
0%	102	17.73	5.42	11.44
	203	45.15	0.99	15.39
	305	51.67	0.61	14.13
	404	46.11	0.97	15.10

Table A.22 Soil EF, GMD and GSD at Norcatur in spring 2012

Removal rate	Plot #	EF	GMD	GSD
100%	101	47.89	0.93	23.50
	203	39.31	1.21	14.05
	304	63.07	0.26	11.38
	402	61.86	0.31	13.87
75%	104	26.67	2.43	12.34
	201	30.93	1.80	13.96
	305	27.61	2.63	15.66
	403	24.24	2.71	12.10
50%	102	29.36	2.74	17.08
	204	17.00	5.20	10.35
	302	26.12	2.73	12.74
	405	35.09	1.37	14.73
25%	105	31.91	1.87	16.07
	202	26.13	2.73	14.32
	303	15.47	6.04	10.26
	401	33.24	1.48	13.67
0%	103	22.52	4.17	14.15
	205	20.82	3.70	11.69
	301	22.66	3.56	12.89
	404	29.86	2.09	13.62

Table A.23 Soil EF, GMD and GSD at Garden City in spring 2012

Removal rate	Plot #	EF	GMD	GSD
100%	101	66.32	0.28	10.53
	203	69.76	0.25	8.15
	304	75.64	0.20	9.56
	402	62.16	0.31	8.77
75%	104	76.28	0.19	8.21
	201	27.34	2.06	10.64
	305	52.80	0.50	9.38
	403	52.90	0.54	12.24
50%	102	63.51	0.34	11.27
	204	44.69	0.84	12.79
	302	36.74	1.16	10.08
	405	42.36	0.84	8.60
25%	105	51.85	0.61	14.26
	202	40.26	0.94	11.00
	303	45.66	0.81	12.83
	401	54.70	0.60	12.21
0%	103	37.22	1.20	11.78
	205	44.54	0.87	12.25
	301	26.49	2.15	10.57
	404	41.44	0.87	8.96

Table A.24 Soil EF, GMD and GSD at Scott City in spring 2012

Removal rate	Plot #	EF	GMD	GSD
100%	101	52.58	0.56	14.90
	203	62.05	0.35	11.37
	304	75.20	0.19	9.43
	402	69.91	0.26	11.47
75%	104	31.14	2.09	14.03
	201	40.15	1.07	13.13
	305	36.11	1.56	14.70
	403	38.35	1.21	12.90
50%	102	18.87	4.65	10.44
	204	45.92	0.95	13.26
	302	14.92	8.64	12.61
	405	42.13	1.05	13.78
25%	105	37.95	1.28	12.72
	202	33.74	1.70	13.30
	303	25.18	2.54	11.18
	401	31.87	1.99	13.95
0%	103	42.64	0.99	12.49
	205	33.36	1.72	12.77
	301	33.79	1.65	11.76
	404	45.45	0.77	10.65

Table A.25 Soil crushing test results and random roughness at La Crosse in spring 2012

Removal rate	Plot #	Break Force	Stability	Roughness
100%	101	5.63	2.27	
	203	5.24	1.80	
	304	6.17	2.85	
	402	5.50	2.03	
75%	104	5.72	2.25	
	201	5.99	2.48	
	305	6.17	2.60	
	403	6.07	2.66	
50%	102	5.79	2.30	
	204	6.60	3.01	
	302	6.66	2.96	
	405	6.50	3.13	
25%	105	5.86	2.52	
	202	6.17	2.64	
	303	6.12	2.67	
	401	6.09	2.64	
0%	103	6.08	2.85	
	205	6.71	3.38	
	301	6.07	2.73	
	404	6.87	3.36	

Table A.26 Soil crushing test results and random roughness at Rush Center in spring 2012

Removal rate	Plot #	Break Force	Stability	Roughness
100%	101	6.73	3.51	
	203	6.02	2.79	
	304	5.67	2.37	
	402	6.39	3.04	
75%	104	7.12	3.89	
	201	6.63	3.05	
	305	6.61	3.31	
	403	6.73	3.37	
50%	102	6.98	3.56	
	204	6.10	2.70	
	302	6.37	3.03	
	405	7.05	3.90	
25%	105	7.23	3.86	
	202	6.25	2.96	
	303	6.82	3.40	
	401	7.07	3.63	
0%	103	7.16	3.86	
	205	6.59	3.29	
	301	6.48	3.09	
	404	6.78	3.53	

Table A.27 Soil crushing test results and random roughness at Colby in spring 2012

Removal rate	Plot #	Break Force	Stability	Roughness
100%	101	5.64	2.05	2.13
	203	5.91	2.20	1.35
	304	5.73	2.16	1.76
	402	5.21	1.75	2.81
75%	104	4.63	1.59	3.71
	201	6.26	2.78	3.46
	305	5.06	1.70	4.58
	403	5.98	2.53	2.58
50%	102	5.47	2.08	10.14
	204	6.11	2.78	10.14
	302	5.24	1.88	7.76
	405	4.81	1.49	5.86
25%	105	6.32	3.10	7.38
	202	6.05	2.75	8.34
	303	6.19	2.99	8.27
	401	5.34	2.11	4.26
0%	103	6.38	2.96	11.47
	205	5.89	2.62	5.74
	301	5.16	1.73	8.30
	404	5.93	2.71	9.32

Table A.28 Soil crushing test results and random roughness at Norcatur in spring 2012

Removal rate	Plot #	Break Force	Stability	Roughness
100%	101	6.58	3.20	1.97
	203	5.84	2.60	2.96
	304	6.19	3.05	5.58
	402	6.42	2.97	5.58
75%	104	6.38	3.18	5.10
	201	5.90	2.70	4.23
	305	5.78	2.66	5.13
	403	6.49	3.09	4.26
50%	102	6.44	3.11	9.14
	204	7.23	3.96	7.60
	302	6.13	2.95	9.64
	405	5.67	2.43	3.93
25%	105	5.88	2.66	6.04
	202	6.46	3.20	6.20
	303	6.37	2.88	6.68
	401	6.13	2.76	4.33
0%	103	6.29	3.12	9.24
	205	5.94	2.59	5.28
	301	6.16	3.09	5.82
	404	6.00	2.65	7.60

Table A.29 Soil crushing test results and random roughness at Garden City in spring 2012

Removal rate	Plot #	Break Force	Stability	Roughness
100%	101	6.01	2.67	2.58
	203	5.72	2.20	4.58
	304	5.54	2.36	4.10
	402	6.21	2.61	2.71
75%	104	5.08	1.76	3.90
	201	6.33	3.12	4.05
	305	6.27	3.09	4.62
	403	5.88	2.39	3.16
50%	102	5.35	1.99	4.95
	204	5.20	1.79	5.22
	302	6.30	2.78	4.06
	405	6.47	3.10	5.22
25%	105	5.45	2.14	5.82
	202	5.67	2.20	4.11
	303	6.63	3.33	6.03
	401	6.32	3.05	7.24
0%	103	6.33	3.16	3.98
	205	6.56	3.20	6.61
	301	6.34	3.08	6.76
	404	6.24	2.84	5.58

Table A.30 Soil crushing test results and random roughness at Scott City in spring 2012

Removal rate	Plot #	Break Force	Stability	Roughness
100%	101	4.63	1.49	1.47
	203	5.10	1.60	3.11
	304	4.96	1.72	3.18
	402	4.97	1.70	3.06
75%	104	6.27	2.85	10.62
	201	6.55	3.32	6.71
	305	5.60	2.22	7.19
	403	5.56	1.95	6.69
50%	102	6.07	2.83	7.12
	204	5.60	2.37	7.85
	302	6.19	2.74	8.33
	405	6.32	3.21	8.37
25%	105	6.66	3.39	8.29
	202	6.19	2.92	12.49
	303	6.10	2.78	7.64
	401	6.34	2.99	6.71
0%	103	6.02	2.39	6.13
	205	6.16	2.98	7.03
	301	6.45	3.09	8.55
	404	6.45	3.15	8.54

Table A.31 Soil wind erosion modeling (SWEEP) results at La Crosse in spring 2012

Removal rate	Plot #	Initial wind	Probability%	Soil loss (kg m^{-2})
100%	101	10	11.28	1.62
	203	10	11.28	2.127
	304	10	11.28	1.1034
	402	10	11.28	1.8921
75%	104	16	0.53	0
	201	17	0.31	0
	305	15	0.95	0
	403	16	0.53	0
50%	102	19	0.11	0
	204	18	0.19	0
	302	18	0.19	0
	405	19	0.11	0
25%	105	17	0.31	0
	202	18	0.19	0
	303	19	0.11	0
	401	17	0.31	0
0%	103	19	0.11	0
	205	20	0.06	0
	301	19	0.11	0
	404	21	0.01	0

Table A.32 Soil wind erosion modeling (SWEEP) results at Rush Center in spring 2012

Removal rate	Plot #	Initial wind	Probability%	Soil loss (kg m^{-2})
100%	101	6	33.49	0.7272
	203	9	16.18	1.1515
	304	8	22.06	1.6658
	402	9	16.18	1.0064
75%	104	17	0.31	0
	201	14	1.7	0
	305	14	1.7	0
	403	16	0.53	0
50%	102	17	0.31	0
	204	18	0.19	0
	302	17	0.31	0
	405	17	0.31	0
25%	105	18	0.19	0
	202	18	0.19	0
	303	17	0.31	0
	401	17	0.31	0
0%	103	21	0.01	0
	205	19	0.11	0
	301	19	0.11	0
	404	20	0.06	0

Table A.33 Soil wind erosion modeling (SWEEP) results at Colby in spring 2012

Removal rate	Plot #	Initial wind	Probability%	Soil loss (kg m^{-2})
100%	101	6	49.98	2.6914
	203	6	49.98	2.3593
	304	6	49.98	2.4399
	402	6	49.98	3.3095
75%	104	12	6.49	0.3823
	201	12	6.49	0.2389
	305	12	6.49	0.3149
	403	12	6.49	0.2279
50%	102	18	0.6	0
	204	18	0.6	0
	302	17	0.96	0
	405	15	2.06	0
25%	105	19	0.35	0
	202	18	0.6	0
	303	19	0.35	0
	401	17	0.96	0
0%	103	22	0	0
	205	18	0.6	0
	301	19	0.35	0
	404	19	0.35	0

Table A.34 Soil wind erosion modeling (SWEEP) results at Norcatur in spring 2012

Removal rate	Plot #	Initial wind	Probability%	Soil loss (kg m^{-2})
100%	101	7	33.2	0.9615
	203	8	24.1	0.2769
	304	8	24.1	1.2067
	402	8	24.1	1.1975
75%	104	15	0.97	0
	201	14	1.51	0
	305	15	0.97	0
	403	15	0.97	0
50%	102	19	0.1	0
	204	19	0.1	0
	302	19	0.1	0
	405	16	0.56	0
25%	105	18	0.2	0
	202	19	0.1	0
	303	20	0.04	0
	401	17	0.31	0
0%	103	21	0.03	0
	205	19	0.1	0
	301	20	0.04	0
	404	20	0.04	0

Table A.35 Soil wind erosion modeling (SWEEP) results at Garden City in spring 2012

Removal rate	Plot #	Initial wind	Probability%	Soil loss (kg m^{-2})
100%	101	6	53.88	1.7704
	203	7	41.87	2.2154
	304	7	41.87	2.1556
	402	6	53.88	2.0908
75%	104	12	6.73	0.3542
	201	14	3.17	0
	305	13	4.85	0.1025
	403	12	6.73	0.1929
50%	102	15	1.94	0
	204	16	1.36	0
	302	16	1.36	0
	405	16	1.36	0
25%	105	17	0.87	0
	202	17	0.87	0
	303	17	0.87	0
	401	17	0.87	0
0%	103	18	0.53	0
	205	18	0.53	0
	301	19	0.35	0
	404	18	0.53	0

Table A.36 Soil wind erosion modeling (SWEEP) results at Scott City in spring 2012

Removal rate	Plot #	Initial wind	Probability%	Soil loss (kg m^{-2})
100%	101	6	53.88	2.3545
	203	7	41.87	2.3244
	304	6	53.88	2.4858
	402	6	53.88	2.3605
75%	104	17	0.87	0
	201	15	1.94	0
	305	15	1.94	0
	403	15	1.94	0
50%	102	19	0.35	0
	204	17	0.87	0
	302	20	0.22	0
	405	17	0.87	0
25%	105	18	0.53	0
	202	20	0.22	0
	303	19	0.35	0
	401	18	0.53	0
0%	103	18	0.53	0
	205	19	0.35	0
	301	20	0.22	0
	404	19	0.35	0

Table A.37 Soil EF, GMD and GSD at La Crosse in fall 2012

Removal rate	Plot #	EF	GMD	GSD
100%	101	54.17	0.48	14.47
	203	33.29	2.01	19.39
	304	42.57	1.11	17.24
	402	47.08	0.78	17.21
75%	104	22.03	4.23	14.12
	201	19.75	6.78	17.21
	305	26.50	2.90	16.65
	403	31.84	2.59	21.46
50%	102	29.08	2.38	15.12
	204	34.94	1.83	18.97
	302	21.88	7.65	22.63
	405	26.54	2.90	14.54
25%	105	26.09	2.64	13.82
	202	33.93	1.60	15.36
	303	20.49	8.71	21.25
	401	28.16	3.12	17.16
0%	103	24.16	3.45	15.55
	205	34.93	1.68	15.76
	301	21.85	6.17	19.91
	404	14.91	10.14	14.94

Table A.38 Soil EF, GMD and GSD at Rush Center in fall 2012

Removal rate	Plot #	EF	GMD	GSD
100%	104	47.24	0.67	9.88
	202	61.16	0.39	9.41
	303	67.72	0.28	8.55
	401	45.89	0.82	12.90
75%	103	20.36	4.90	12.82
	204	31.92	1.90	10.24
	301	29.33	2.11	10.31
	405	39.94	0.87	8.99
50%	101	27.75	3.37	14.85
	205	26.07	2.26	7.92
	302	30.91	1.85	10.37
	403	30.83	2.50	15.17
25%	105	28.18	1.91	8.88
	201	33.67	2.08	13.46
	304	23.20	3.70	11.14
	402	28.05	2.52	11.58
0%	102	24.06	4.66	13.25
	203	19.22	3.57	8.06
	305	28.68	2.53	10.83
	404	29.19	2.30	10.27

Table A.39 Soil EF, GMD and GSD at Colby in fall 2012

Removal rate	Plot #	EF	GMD	GSD
100%	104	69.40	0.18	11.03
	202	53.34	0.43	13.06
	303	73.34	0.29	14.39
	401	47.32	0.66	11.44
75%	103	77.55	0.18	9.21
	204	81.56	0.11	9.01
	301	63.11	0.32	10.44
	405	51.04	0.26	11.33
50%	101	30.01	1.96	13.41
	205	68.79	0.27	11.77
	302	69.50	0.26	14.30
	403	61.22	0.36	11.90
25%	105	59.26	0.37	12.46
	201	56.27	0.45	13.92
	304	57.49	0.49	13.93
	402	68.77	0.24	13.42
0%	102	48.50	0.62	16.29
	203	81.09	0.16	8.88
	305	46.06	0.79	15.11
	404	69.88	0.22	9.76

Table A.40 Soil EF, GMD and GSD at Norcatur in fall 2012

Removal rate	Plot #	EF	GMD	GSD
100%	101	52.21	0.55	11.73
	203	46.95	0.58	9.67
	304	32.81	1.76	16.22
	402	50.95	0.55	16.71
75%	104	46.42	0.74	13.84
	201	23.99	2.60	11.05
	305	38.50	1.22	15.13
	403	25.49	2.70	14.00
50%	102	35.11	1.25	12.82
	204	24.81	2.29	11.34
	302	38.02	1.71	21.35
	405	29.60	2.89	22.20
25%	105	33.54	1.58	14.40
	202	35.99	1.33	14.17
	303	38.74	1.40	16.23
	401	36.16	1.22	15.23
0%	103	22.03	4.41	13.51
	205	34.68	1.60	16.86
	301	20.08	3.51	11.29
	404	30.83	1.50	12.42

Table A.41 Soil EF, GMD and GSD at Garden City in fall 2012

Removal rate	Plot #	EF	GMD	GSD
100%	101	73.33	0.20	9.11
	203	64.94	0.31	10.11
	304	62.34	0.31	14.17
	402	61.01	0.33	9.26
75%	104	64.04	0.31	11.49
	201	63.71	0.31	10.26
	305	80.75	0.12	8.36
	403	52.15	0.45	10.59
50%	102	56.66	0.45	13.46
	204	52.91	0.50	13.19
	302	65.04	0.33	10.60
	405	55.30	0.54	15.02
25%	105	64.13	0.32	14.36
	202	52.05	0.61	13.62
	303	67.02	0.22	11.27
	401	61.82	0.37	9.32
0%	103	59.06	0.39	12.76
	205	49.82	0.59	14.17
	301	62.52	0.31	10.31
	404	54.97	0.50	14.46

Table A.42 Soil EF, GMD and GSD at Scott City in fall 2012

Removal rate	Plot #	EF	GMD	GSD
100%	101	46.39	0.85	15.25
	203	55.78	0.47	10.62
	304	72.17	0.23	10.06
	402	80.05	0.20	8.72
75%	104	73.19	0.21	8.05
	201	53.06	0.58	12.34
	305	61.01	0.39	13.23
	403	57.54	0.50	16.40
50%	102	46.45	0.75	12.60
	204	68.09	0.38	9.41
	302	58.81	0.41	14.11
	405	57.29	0.44	11.65
25%	105	57.56	0.41	10.63
	202	38.31	1.19	12.28
	303	55.98	0.56	12.55
	401	41.58	1.25	18.05
0%	103	44.41	0.47	7.52
	205	42.39	0.78	9.15
	301	38.25	1.26	12.10
	404	44.98	0.46	8.29

Table A.43 Soil crushing test results and random roughness at La Crosse in fall 2012

Removal rate	Plot #	Break Force	Stability	Roughness
100%	101	5.87	2.37	8.66
	203	5.82	2.66	9.64
	304	5.93	2.66	7.20
	402	5.69	2.57	7.48
75%	104	6.41	3.17	6.22
	201	6.22	2.98	8.34
	305	6.16	2.75	12.58
	403	6.63	3.37	9.69
50%	102	6.27	3.27	7.39
	204	6.60	3.23	9.80
	302	6.16	3.07	6.54
	405	6.92	3.74	14.05
25%	105	6.15	2.79	11.01
	202	6.09	2.70	9.50
	303	7.00	3.75	9.39
	401	6.11	2.89	8.31
0%	103	6.28	2.79	12.58
	205	6.41	3.32	10.10
	301	6.34	3.21	7.49
	404	6.84	3.52	5.72

Table A.44 Soil crushing test results and random roughness at Rush Center in fall 2012

Removal rate	Plot #	Break Force	Stability	Roughness
100%	101	6.37	3.03	4.24
	203	5.84	2.39	3.26
	304	6.37	3.23	6.61
	402	6.21	3.06	5.92
75%	104	6.60	3.56	5.38
	201	6.55	3.24	10.47
	305	6.61	3.30	5.85
	403	6.17	2.70	10.55
50%	102	6.89	3.66	18.61
	204	7.06	3.80	10.75
	302	6.18	2.94	7.41
	405	6.62	3.43	7.74
25%	105	6.79	3.71	15.43
	202	6.78	3.58	8.99
	303	7.09	3.92	8.76
	401	6.73	3.47	12.95
0%	103	6.79	3.52	9.97
	205	6.84	3.68	10.03
	301	6.86	3.53	7.05
	404	6.87	3.61	15.34

Table A.45 Soil crushing test results and random roughness at Colby in fall 2012

Removal rate	Plot #	Break Force	Stability	Roughness
100%	101	6.56	3.28	2.79
	203	6.62	3.52	2.81
	304	6.21	3.04	3.34
	402	6.76	3.32	5.19
75%	104	6.01	2.77	4.98
	201	5.77	2.70	4.22
	305	6.25	2.80	4.79
	403	5.64	2.20	4.94
50%	102	6.03	2.56	3.66
	204	5.58	2.39	4.41
	302	6.44	3.14	5.17
	405	5.65	2.38	1.70
25%	105	6.20	2.87	3.79
	202	5.78	2.62	6.20
	303	5.78	2.60	2.86
	401	5.56	2.17	3.37
0%	103	6.26	3.05	8.37
	205	5.70	2.52	4.49
	301	6.03	2.73	2.75
	404	5.64	2.27	3.21

Table A.46 Soil crushing test results and random roughness at Norcatur in fall 2012

Removal rate	Plot #	Break Force	Stability	Roughness
100%	101	6.09	2.83	6.10
	203	5.83	2.62	5.29
	304	6.88	3.52	6.49
	402	7.43	3.85	2.53
75%	104	6.56	3.35	8.53
	201	7.02	3.26	11.14
	305	6.12	2.83	8.51
	403	6.62	3.24	5.81
50%	102	6.64	3.30	8.57
	204	6.49	3.26	1.32
	302	6.48	2.97	4.03
	405	6.36	2.83	4.99
25%	105	6.26	2.81	6.83
	202	6.43	3.14	4.72
	303	6.57	2.98	7.95
	401	6.50	3.10	4.91
0%	103	6.10	2.96	4.96
	205	5.56	2.41	9.55
	301	6.89	3.58	4.58
	404	6.20	2.71	4.00

Table A.47 Soil crushing test results and random roughness at Garden City in fall 2012

Removal rate	Plot #	Break Force	Stability	Roughness
100%	101	6.11	2.73	3.66
	203	6.98	3.73	5.86
	304	6.96	3.83	6.14
	402	7.48	4.12	0.39
75%	104	6.15	2.76	3.46
	201	7.22	3.78	2.58
	305	7.15	3.59	3.59
	403	6.65	3.19	6.46
50%	102	6.92	3.38	1.73
	204	6.41	3.21	11.88
	302	6.71	2.85	3.15
	405	7.09	3.40	6.60
25%	105	6.54	3.00	7.02
	202	6.37	3.30	4.42
	303	7.05	3.81	5.05
	401	7.04	3.67	7.59
0%	103	6.64	3.13	4.18
	205	6.34	2.83	3.84
	301	6.78	3.47	8.85
	404	6.59	3.26	3.35

Table A.48 Soil crushing test results and random roughness at Scott City in fall 2012

Removal rate	Plot #	Break Force	Stability	Roughness
100%	101	5.45	1.94	2.56
	203	6.62	3.43	2.38
	304	6.51	3.15	1.86
	402	6.37	2.78	1.92
75%	104	6.35	3.07	6.47
	201	5.90	2.62	6.31
	305	6.42	3.06	3.97
	403	6.03	2.75	5.75
50%	102	6.58	3.49	8.36
	204	5.38	2.00	4.86
	302	6.48	2.98	5.19
	405	6.31	2.93	5.86
25%	105	6.95	3.65	10.87
	202	6.60	3.24	4.23
	303	5.85	2.62	3.83
	401	6.09	2.90	4.33
0%	103	6.17	2.83	4.54
	205	5.98	2.70	6.07
	301	6.31	2.94	4.36
	404	6.05	2.77	9.76

Table A.49 Soil wind erosion modeling (SWEEP) results at La Crosse in fall 2012

Removal rate	Plot #	Initial wind	Probability%	Soil loss (kg m^{-2})
100%	101	10	11.28	1.4853
	203	12	4.67	0.9954
	304	10	11.28	1.2315
	402	10	11.28	1.3371
75%	104	16	0.53	0
	201	17	0.31	0
	305	18	0.19	0
	403	17	0.31	0
50%	102	18	0.19	0
	204	18	0.19	0
	302	19	0.11	0
	405	20	0.06	0
25%	105	20	0.06	0
	202	19	0.11	0
	303	21	0.01	0
	401	19	0.11	0
0%	103	22	0	0
	205	20	0.06	0
	301	21	0.01	0
	404	21	0.01	0

Table A.50 Soil wind erosion modeling (SWEEP) results at Rush Center in fall 2012

Removal rate	Plot #	Initial wind	Probability%	Soil loss (kg m^{-2})
100%	101	8	15.23	1.0408
	203	7	22.58	1.7969
	304	8	15.23	0.9848
	402	9	10.18	0.9252
75%	104	16	0.1	0
	201	17	0.03	0
	305	15	0.2	0
	403	16	0.1	0
50%	102	21	0	0
	204	19	0	0
	302	18	0.01	0
	405	18	0.01	0
25%	105	21	0	0
	202	19	0	0
	303	20	0	0
	401	21	0	0
0%	103	21	0	0
	205	21	0	0
	301	20	0	0
	404	22	0	0

Table A.51 Soil wind erosion modeling (SWEEP) results at Colby in fall 2012

Removal rate	Plot #	Initial wind	Probability%	Soil loss (kg m^{-2})
100%	101	6	38.09	1.2975
	203	7	26.32	0.8773
	304	7	26.32	1.3445
	402	9	11.33	0.874
75%	104	12	6.49	0.2229
	201	12	6.49	0.3174
	305	12	6.49	0.1613
	403	12	6.49	0.2121
50%	102	16	1.45	0
	204	15	2.06	0
	302	15	2.06	0
	405	15	2.06	0
25%	105	16	1.45	0
	202	17	0.96	0
	303	15	2.06	0
	401	15	2.06	0
0%	103	19	0.35	0
	205	16	1.45	0
	301	17	0.96	0
	404	16	1.45	0

Table A.52 Soil wind erosion modeling (SWEEP) results at Norcatur in fall 2012

Removal rate	Plot #	Initial wind	Probability%	Soil loss (kg m^{-2})
100%	101	9	8.87	1.1929
	203	8	13.5	1.4206
	304	11	4.32	0.5646
	402	7	20.4	0.632
75%	104	15	0.97	0
	201	17	0.31	0
	305	15	0.97	0
	403	15	0.97	0
50%	102	19	0.03	0
	204	16	0.56	0
	302	17	0.31	0
	405	17	0.31	0
25%	105	18	0.06	0
	202	17	0.31	0
	303	18	0.2	0
	401	17	0.31	0
0%	103	19	0.03	0
	205	20	0.02	0
	301	19	0.03	0
	404	18	0.06	0

Table A.53 Soil wind erosion modeling (SWEEP) results at Garden City in fall 2012

Removal rate	Plot #	Initial wind	Probability%	Soil loss (kg m^{-2})
100%	101	6	42.41	1.7823
	203	8	20.71	0.7269
	304	8	20.71	0.662
	402	6	42.41	0.6481
75%	104	12	3.41	0.2225
	201	11	5.91	0.1794
	305	11	5.91	0.2642
	403	13	2.35	0.0313
50%	102	13	2.35	0.0175
	204	17	0.46	0
	302	14	1.54	0
	405	16	0.65	0
25%	105	17	0.46	0
	202	16	0.65	0
	303	16	0.65	0
	401	17	0.46	0
0%	103	17	0.46	0
	205	17	0.46	0
	301	18	0.31	0
	404	16	0.65	0

Table A.54 Soil wind erosion modeling (SWEEP) results at Scott City in fall 2012

Removal rate	Plot #	Initial wind	Probability%	Soil loss (kg m^{-2})
100%	101	7	30.43	1.9186
	203	6	42.41	0.8092
	304	6	42.41	1.1802
	402	6	42.41	1.5367
75%	104	13	2.35	0.1354
	201	14	1.54	0
	305	12	3.41	0.1426
	403	13	2.35	0.0571
50%	102	17	0.46	0
	204	15	0.93	0
	302	15	0.93	0
	405	16	0.65	0
25%	105	17	0.46	0
	202	17	0.46	0
	303	17	0.46	0
	401	17	0.46	0
0%	103	19	0.24	0
	205	19	0.24	0
	301	19	0.24	0
	404	19	0.24	0

Table A.55 Soil EF, GMD and GSD at La Crosse in spring 2013

Removal rate	Plot #	EF	GMD	GSD
100%	101	43.62	0.85	17.08
	203	41.97	0.90	15.53
	304	40.07	1.10	19.51
	402	38.47	1.26	17.33
75%	104	18.23	5.46	13.75
	201	11.56	16.56	14.93
	305	32.22	1.70	15.52
	403	25.86	2.64	13.46
50%	102	23.48	2.57	11.39
	204	14.90	9.13	13.96
	302	18.41	4.78	12.37
	405	10.92	8.75	8.88
25%	105	22.65	3.95	16.31
	202	18.10	4.71	11.03
	303	16.57	5.37	11.44
	401	16.79	5.07	10.84
0%	103	20.58	3.81	12.29
	205	19.77	3.74	10.82
	301	28.65	2.57	17.37
	404	16.86	6.21	12.35

Table A.56 Soil EF, GMD and GSD at Rush Center in spring 2013

Removal rate	Plot #	EF	GMD	GSD
100%	104	50.17	0.66	16.80
	202	12.95	15.87	15.89
	303	43.50	0.94	14.85
	401	42.90	0.98	15.54
75%	103	25.23	1.96	7.80
	204	23.56	2.78	11.49
	301	35.30	1.66	18.38
	405	48.65	0.76	12.94
50%	101	9.93	12.24	9.98
	205	13.94	7.01	10.86
	302	9.95	8.04	7.32
	403	10.59	12.54	10.36
25%	105	16.17	6.99	13.06
	201	14.35	11.67	14.71
	304	7.19	21.33	10.87
	402	9.87	11.83	9.56
0%	102	13.62	9.61	11.85
	203	29.19	2.19	10.99
	305	16.18	5.26	8.39
	404	28.33	3.36	18.33

Table A.57 Soil EF, GMD and GSD at Colby in spring 2013

Removal rate	Plot #	EF	GMD	GSD
100%	104	62.99	0.26	11.26
	202	48.93	0.49	11.47
	303	52.70	0.50	12.56
	401	53.28	0.54	10.13
75%	103	40.67	0.84	12.87
	204	73.88	0.16	11.36
	301	55.58	0.40	11.34
	405	59.69	0.39	14.30
50%	101	64.57	0.28	9.94
	205	74.04	0.19	11.21
	302	45.48	0.66	11.51
	403	62.85	0.28	8.98
25%	105	57.58	0.46	11.64
	201	59.15	0.39	11.87
	304	63.82	0.31	15.97
	402	29.10	1.71	12.24
0%	102	44.34	0.85	14.28
	203	37.59	1.03	10.54
	305	45.06	0.68	11.93
	404	47.83	0.64	11.81

Table A.58 Soil EF, GMD and GSD at Norcatur in spring 2013

Removal rate	Plot #	EF	GMD	GSD
100%	101	52.87	0.57	12.51
	203	31.29	1.55	11.62
	304	38.99	1.05	12.57
	402	35.02	1.37	12.92
75%	104	33.33	2.04	17.02
	201	35.88	1.58	18.28
	305	28.25	2.11	12.44
	403	38.37	0.99	12.07
50%	102	20.64	4.09	13.19
	204	22.84	2.87	10.69
	302	17.39	8.05	16.18
	405	38.88	0.98	12.63
25%	105	33.67	1.90	16.95
	202	30.52	1.58	11.22
	303	21.28	7.80	15.45
	401	21.17	4.16	14.60
0%	103	20.71	4.84	13.33
	205	21.70	2.45	9.77
	301	26.25	2.56	14.44
	404	42.50	0.81	12.92

Table A.59 Soil EF, GMD and GSD at Garden City in spring 2013

Removal rate	Plot #	EF	GMD	GSD
100%	101	76.86	0.19	8.86
	203	56.55	0.41	10.45
	304	64.10	0.30	9.87
	402	54.52	0.42	8.79
75%	104	63.94	0.32	13.40
	201	52.74	0.59	13.00
	305	65.03	0.26	9.92
	403	51.74	0.49	10.97
50%	102	66.10	0.26	11.18
	204	62.77	0.31	10.72
	302	58.84	0.38	8.35
	405	50.60	0.51	10.47
25%	105	58.22	0.37	16.99
	202	52.49	0.48	9.22
	303	53.66	0.47	10.85
	401	54.17	0.48	9.86
0%	103	59.69	0.35	11.53
	205	49.42	0.53	10.34
	301	38.16	1.04	11.72
	404	48.21	0.61	11.73

Table A.60 Soil EF, GMD and GSD at Scott City in spring 2013

Removal rate	Plot #	EF	GMD	GSD
100%	101	58.02	0.34	9.16
	203	68.32	0.27	7.86
	304	74.89	0.18	8.03
	402	64.77	0.28	9.87
75%	104	61.52	0.39	10.04
	201	54.75	0.42	10.79
	305	43.44	0.70	10.64
	403	41.90	0.83	11.26
50%	102	52.68	0.45	11.17
	204	49.43	0.59	9.22
	302	52.97	0.54	13.05
	405	53.28	0.41	8.44
25%	105	57.01	0.47	10.82
	202	69.65	0.25	8.79
	303	44.74	0.78	12.74
	401	58.26	0.33	8.60
0%	103	45.62	0.68	10.22
	205	65.21	0.30	9.03
	301	36.10	1.03	9.20
	404	48.96	0.58	10.78

Table A.61 Soil crushing test results and random roughness at La Crosse in spring 2013

Removal rate	Plot #	Break Force	Stability	Roughness
100%	101	6.10	2.81	5.13
	203	6.29	2.87	3.88
	304	5.94	2.60	4.48
	402	6.10	2.48	4.50
75%	104	6.24	2.95	4.36
	201	6.47	2.97	6.48
	305	6.02	2.62	7.47
	403	6.46	3.00	5.64
50%	102	5.90	2.37	4.80
	204	6.78	3.52	11.99
	302	6.93	3.56	6.12
	405	7.29	3.62	3.55
25%	105	5.85	2.28	5.81
	202	6.66	3.28	8.66
	303	6.36	3.11	4.62
	401	5.74	2.44	4.05
0%	103	6.38	3.24	7.94
	205	6.55	3.35	9.09
	301	6.27	2.83	4.78
	404	6.66	3.39	9.42

Table A.62 Soil crushing test results and random roughness at Rush Center in spring 2013

Removal rate	Plot #	Break Force	Stability	Roughness
100%	101	6.99	3.58	4.05
	203	7.44	4.14	8.34
	304	7.27	3.60	4.72
	402	6.88	3.23	5.35
75%	104	7.26	3.99	3.33
	201	6.56	3.17	9.36
	305	7.52	3.79	3.41
	403	6.82	3.49	5.89
50%	102	7.33	4.27	4.01
	204	7.22	3.81	3.83
	302	7.48	4.06	6.31
	405	7.41	4.25	4.11
25%	105	7.39	4.16	4.60
	202	7.33	3.76	8.17
	303	7.54	4.07	7.43
	401	7.54	4.09	2.75
0%	103	7.35	3.75	8.07
	205	7.24	4.10	7.11
	301	7.53	4.06	4.22
	404	7.40	3.80	6.34

Table A.63 Soil crushing test results and random roughness at Colby in spring 2013

Removal rate	Plot #	Break Force	Stability	Roughness
100%	101	5.88	2.60	2.53
	203	7.13	3.75	2.09
	304	7.00	3.57	5.44
	402	7.05	3.90	3.08
75%	104	5.62	2.05	11.64
	201	6.57	3.14	3.06
	305	7.07	3.81	5.81
	403	6.41	2.94	2.83
50%	102	5.94	2.53	6.74
	204	4.51	1.50	4.49
	302	7.18	3.37	5.07
	405	5.57	2.15	4.40
25%	105	5.20	1.67	10.82
	202	5.59	2.40	4.16
	303	4.99	1.53	2.84
	401	6.57	3.10	2.96
0%	103	5.23	1.93	3.83
	205	6.38	3.12	4.94
	301	5.08	1.62	15.66
	404	5.79	2.55	4.38

Table A.64 Soil crushing test results and random roughness at Norcatur in spring 2013

Removal rate	Plot #	Break Force	Stability	Roughness
100%	101	5.98	2.58	5.61
	203	5.86	2.64	5.27
	304	5.31	1.96	4.56
	402	6.25	2.61	3.61
75%	104	6.01	2.77	6.15
	201	6.57	3.26	7.25
	305	5.87	2.65	4.01
	403	5.94	2.58	2.61
50%	102	5.97	2.82	3.60
	204	6.51	3.26	6.60
	302	6.45	3.07	5.49
	405	5.74	2.25	7.90
25%	105	5.91	2.85	4.75
	202	6.25	2.92	3.90
	303	6.62	3.19	6.29
	401	6.18	3.03	4.05
0%	103	6.37	2.82	4.78
	205	6.55	2.98	4.97
	301	5.95	2.64	5.27
	404	5.66	2.19	5.09

Table A.65 Soil crushing test results and random roughness at Garden City in spring 2013

Removal rate	Plot #	Break Force	Stability	Roughness
100%	101	4.51	1.35	4.05
	203	5.69	2.57	3.57
	304	5.11	1.90	5.40
	402	5.64	2.11	6.35
75%	104	4.74	1.36	4.78
	201	5.42	2.01	8.89
	305	4.76	1.68	6.07
	403	6.02	2.53	5.15
50%	102	5.02	1.78	5.47
	204	5.13	1.90	10.49
	302	5.99	2.35	10.48
	405	5.57	2.34	9.95
25%	105	4.47	1.39	9.19
	202	5.30	1.93	7.66
	303	4.93	1.67	3.54
	401	5.57	2.08	10.64
0%	103	5.48	2.28	8.93
	205	4.75	1.50	12.56
	301	6.04	2.66	4.94
	404	5.23	2.29	4.58

Table A.66 Soil crushing test results and random roughness at Scott City in spring 2013

Removal rate	Plot #	Break Force	Stability	Roughness
100%	101	6.22	2.85	3.99
	203	6.41	2.98	4.64
	304	5.57	2.16	2.00
	402	6.93	3.22	0.33
75%	104	5.56	2.13	4.69
	201	6.70	3.21	4.87
	305	6.50	3.12	5.41
	403	6.13	2.85	6.05
50%	102	5.62	2.31	4.29
	204	5.55	2.36	6.57
	302	4.91	1.53	3.49
	405	5.13	1.59	6.53
25%	105	4.75	1.49	7.15
	202	6.50	3.16	5.24
	303	5.54	2.27	6.34
	401	4.97	1.63	6.06
0%	103	6.00	2.51	4.51
	205	4.83	1.56	5.59
	301	6.34	2.76	7.01
	404	6.05	2.81	4.84

Table A.67 Soil wind erosion modeling (SWEEP) results at La Crosse in spring 2013

Removal rate	Plot #	Initial wind	Probability%	Soil loss (kg m^{-2})
100%	101	9	16.18	1.2375
	203	8	22.06	1.218
	304	9	16.18	1.4485
	402	9	16.18	1.5525
75%	104	15	0.95	0
	201	18	0.19	0
	305	15	0.95	0
	403	15	0.95	0
50%	102	17	0.31	0
	204	21	0.01	0
	302	18	0.19	0
	405	18	0.19	0
25%	105	19	0.11	0
	202	20	0.06	0
	303	19	0.11	0
	401	18	0.19	0
0%	103	20	0.06	0
	205	20	0.06	0
	301	18	0.19	0
	404	21	0.01	0

Table A.68 Soil wind erosion modeling (SWEEP) results at Rush Center in spring 2013

Removal rate	Plot #	Initial wind	Probability%	Soil loss (kg m^{-2})
100%	101	8	22.06	0.6811
	203	14	1.7	0
	304	9	16.18	0.6191
	402	9	16.18	0.8116
75%	104	14	1.7	0
	201	17	0.31	0
	305	13	1.12	0.0191
	403	14	1.7	0
50%	102	19	0.11	0
	204	18	0.19	0
	302	20	0.06	0
	405	19	0.11	0
25%	105	19	0.11	0
	202	21	0.01	0
	303	21	0.01	0
	401	19	0.11	0
0%	103	22	0	0
	205	20	0.06	0
	301	20	0.06	0
	404	20	0.06	0

Table A.69 Soil wind erosion modeling (SWEEP) results at Colby in spring 2013

Removal rate	Plot #	Initial wind	Probability%	Soil loss (kg m^{-2})
100%	101	6	49.98	1.8837
	203	6	49.98	0.7373
	304	8	27.92	0.7403
	402	7	38.19	0.6236
75%	104	16	1.45	0
	201	11	9.35	0.2764
	305	13	4.51	0.0591
	403	12	6.49	0.2023
50%	102	16	1.45	0
	204	15	2.06	0
	302	16	1.45	0
	405	15	2.06	0
25%	105	18	0.6	0
	202	16	1.45	0
	303	15	2.06	0
	401	17	0.96	0
0%	103	17	0.96	0
	205	18	0.6	0
	301	20	0.19	0
	404	17	0.96	0

Table A.70 Soil wind erosion modeling (SWEEP) results at Norcatur in spring 2013

Removal rate	Plot #	Initial wind	Probability%	Soil loss (kg m^{-2})
100%	101	9	17.19	1.4419
	203	10	13.08	1.2893
	304	9	17.19	2.0458
	402	9	17.19	1.4208
75%	104	15	0.97	0
	201	15	0.97	0
	305	14	1.51	0
	403	12	4.77	0.1286
50%	102	17	0.31	0
	204	18	0.2	0
	302	18	0.2	0
	405	17	0.31	0
25%	105	17	0.31	0
	202	17	0.31	0
	303	20	0.04	0
	401	18	0.2	0
0%	103	19	0.1	0
	205	19	0.1	0
	301	19	0.1	0
	404	18	0.2	0

Table A.71 Soil wind erosion modeling (SWEEP) results at Garden City in spring 2013

Removal rate	Plot #	Initial wind	Probability%	Soil loss (kg m^{-2})
100%	101	7	41.87	3.2434
	203	7	41.87	1.7018
	304	8	30.89	2.356
	402	8	30.89	1.9938
75%	104	13	4.85	0.2167
	201	15	1.94	0
	305	13	4.85	0.1866
	403	13	4.85	0.1024
50%	102	15	1.94	0
	204	17	0.87	0
	302	17	0.87	0
	405	17	0.87	0
25%	105	18	0.53	0
	202	17	0.87	0
	303	16	1.36	0
	401	18	0.53	0
0%	103	18	0.53	0
	205	19	0.35	0
	301	18	0.53	0
	404	17	0.87	0

Table A.72 Soil wind erosion modeling (SWEEP) results at Scott City in spring 2013

Removal rate	Plot #	Initial wind	Probability%	Soil loss (kg m^{-2})
100%	101	7	41.87	1.2212
	203	7	41.87	1.1695
	304	6	53.88	2.1721
	402	6	53.88	1.0739
75%	104	13	4.85	0.1803
	201	13	4.85	0.1012
	305	13	4.85	0.0341
	403	14	3.17	0
50%	102	15	1.94	0
	204	16	1.36	0
	302	15	1.94	0
	405	16	1.36	0
25%	105	17	0.87	0
	202	16	1.36	0
	303	17	0.87	0
	401	16	1.36	0
0%	103	17	0.87	0
	205	17	0.87	0
	301	19	0.35	0
	404	17	0.87	0

Appendix B - Effect of Liquid N and S Fertilizer Solutions on the Mass and Strength of Winter Wheat (*Triticum aestivum*) Residue in No-Till Systems

Raw data

Table B.1 Aboveground biomass, total N content, ash content, total C content, C:N ratio, SE and SS at Hays in summer 2012 sampling period

Plot #	Trt	Biomass	Total-N	Ash	Total-C	C:N	SE	SS
102	1	23.76	0.69	10.4	39.4	57.1	4.97E-03	4.26
209	1	31.89	0.59	13.4	39.7	67.3	4.83E-03	4.47
309	1	46.46	0.63	15.9	40.8	64.8	4.52E-03	3.72
410	1	29.21	.	.	.	.	4.00E-03	4.11
112	2	50.59	0.63	14.0	42.0	66.7	5.64E-03	4.86
207	2	24.59	.	.	.	.	4.99E-03	3.77
301	2	42.23	0.63	18.0	38.4	61.0	5.04E-03	4.45
403	2	23.51	0.60	13.6	40.5	67.5	4.47E-03	4.09
108	3	41.28	.	.	.	.	4.19E-03	4.02
208	3	25.13	0.58	15.2	39.9	68.8	5.18E-03	4.22
305	3	39.71	0.86	15.0	40.1	46.6	3.55E-03	3.40
402	3	31.53	.	.	.	.	4.12E-03	4.39
101	4	40.41	0.56	18.5	41.4	73.9	3.06E-03	2.75
203	4	37.45	0.68	11.4	40.2	59.1	3.64E-03	3.67
310	4	29.41	.	.	.	.	4.55E-03	3.95
404	4	20.01	0.72	17.7	38.3	53.2	4.32E-03	4.12
104	5	13.44	0.69	17.8	40.6	58.8	6.45E-03	4.48
204	5	22.68	0.54	12.8	42.0	77.8	5.54E-03	4.67
308	5	45.83	0.66	10.9	41.1	62.3	4.63E-03	4.67
405	5	22.65	0.71	14.9	42.6	60.0	4.72E-03	3.93
113	6	33.43	.	.	.	.	4.36E-03	4.30
213	6	40.63	0.68	14.3	41.1	60.4	5.67E-03	4.25
304	6	51.02	.	.	.	.	4.07E-03	3.68
401	6	33.13	0.59	19.6	36.2	61.4	4.47E-03	3.85
103	7	21.69	0.77	17.7	36.5	47.4	4.62E-03	4.03
210	7	49.75	0.63	11.0	40.6	64.4	.	.
303	7	27.12	0.63	13.5	41.0	65.1	4.81E-03	4.51
412	7	33.22	0.69	19.3	40.9	59.3	4.42E-03	4.44
105	2	40.41	0.81	17.8	39.0	48.1	3.53E-03	3.88
202	2	27.79	0.93	13.4	38.1	41.0	4.28E-03	3.82
306	2	30.3	0.71	10.0	42.3	59.6	3.59E-03	3.30
406	2	42.08	0.71	16.5	39.5	55.6	3.69E-03	3.67
106	3	26.53	0.84	12.1	40.4	48.1	4.15E-03	2.87

212	3	45.14	0.71	14.1	39.9	56.2	3.67E-03	3.61
302	3	34.94	0.61	10.7	40.4	66.2	4.17E-03	4.17
411	3	41.51	0.66	17.3	40.7	61.7	4.11E-03	3.85
110	4	45.15	.	.	.	.	3.77E-03	4.10
201	4	25.43	0.81	17.9	39.9	49.3	4.06E-03	3.64
307	4	41.33		.	.	.	3.61E-03	3.68
409	4	29.81	0.90	11.5	42.0	46.7	4.04E-03	4.00
109	5	22.26	0.78	13.7	40.6	52.1	5.02E-03	4.00
211	5	37.7	.	.	.	.	4.47E-03	4.15
312	5	34.32	0.70	11.4	40.6	58.0	4.98E-03	4.27
407	5	30.76	.	.	.	.	4.14E-03	4.35
107	6	32.35	.	.	.	.	4.11E-03	3.83
205	6	44.37	0.73	16.0	38.5	52.7	5.25E-03	4.56
311	6	22.66	0.65	11.2	41.3	63.5	6.02E-03	5.13
413	6	25.92	0.71	12.5	41.7	58.7	4.60E-03	3.78
111	7	33.41	0.67	15.6	39.0	58.2	4.16E-03	4.02
206	7	34.06	.	.	.	.	4.00E-03	4.26
313	7	33.37	0.68	15.1	40.5	59.6	4.31E-03	4.33
408	7	33.38	0.75	13.6	40.6	54.1	3.92E-03	3.54

Table B.2 Aboveground biomass, total N content, ash content, total C content, C:N ratio, SE and SS at Hays in Summer 2013 sampling period

Plot #	Trt	Biomass	Total-N	Ash	Total-C	C:N	SE	SS
102	1	50.9	0.63	10.0	41.0	65.1	3.50E-03	5.16
209	1	40.29	0.56	9.8	41.7	74.5	3.57E-03	4.87
309	1	50.07	0.68	8.0	42.0	61.8	2.91E-03	3.78
410	1	52.4	0.64	10	40.8	63.8	4.02E-03	4.39
112	2	36.64	0.74	13.2	39.9	53.9	3.77E-03	5.34
207	2	49.02	0.67	10.9	40.7	60.7	3.61E-03	4.75
301	2	27.49	0.84	11.3	39.8	47.4	3.89E-03	4.58
403	2	51.41	1.00	10.5	40.9	40.9	3.59E-03	3.78
108	3	54.86	0.69	11.1	40.9	59.3	3.78E-03	4.82
208	3	45.23	0.82	8.2	41.7	50.9	3.79E-03	3.70
305	3	37.31	1.02	11.6	40.5	39.7	3.48E-03	4.51
402	3	31.89	0.79	9.6	41.1	52.0	3.90E-03	4.90
101	4	32.44	0.47	8.9	42.6	90.6	3.89E-03	4.98
203	4	39.27	0.54	6.9	42.0	77.8	3.75E-03	4.85
310	4	55.86	0.98	12	40.5	41.3	3.73E-03	3.51
404	4	34.92	1.07	10.8	40.5	37.9	3.21E-03	3.50
104	5	38.73	0.70	15.2	38.7	55.3	3.85E-03	5.25
204	5	30.85	0.57	8.2	39.3	68.9	4.29E-03	4.87
308	5	45.36	0.76	13.2	39.1	51.4	4.10E-03	4.51
405	5	39.47	0.84	10.3	40.3	48.0	3.39E-03	3.79
113	6	48.06	0.74	9.8	40.9	55.3	3.58E-03	3.93
213	6	49.03	0.69	10.2	40.4	58.6	3.79E-03	3.75
304	6	39.97	0.66	11.1	40.3	61.1	3.24E-03	4.52
401	6	35.35	0.69	9.9	41.5	60.1	3.41E-03	4.55
103	7	46.13	0.56	8.1	42.2	75.4	3.53E-03	4.65
210	7	46.99	0.65	7.8	41.8	64.3	3.69E-03	5.12
303	7	42.64	1.09	12.9	40.6	37.2	3.35E-03	4.12
412	7	36.22	0.88	11.8	40.8	46.4	3.72E-03	4.52
105	2	63.57	0.82	10.1	40.1	48.9	4.92E-03	7.23
202	2	39.56	0.67	13.5	39.2	58.5	3.89E-03	5.67
306	2	45.18	0.76	10.4	41.0	53.9	3.39E-03	4.58
406	2	42.21	0.75	10.4	40.5	54.0	2.89E-03	4.07
106	3	53.4	0.79	9.8	41.4	52.4	3.93E-03	5.18
212	3	59.23	0.97	10.4	40.7	42.0	3.85E-03	4.74
302	3	43.84	1.02	10.0	41.3	40.5	3.66E-03	4.40
411	3	59.98	0.68	8.3	41.8	61.5	2.79E-03	3.67
110	4	56.36	0.79	9	41.1	52.0	3.46E-03	4.54
201	4	41.18	0.68	11.2	40.1	59.0	4.10E-03	5.18
307	4	52.18	0.97	10.8	40.5	41.8	2.90E-03	3.95
409	4	46.19	0.73	10.4	40.5	55.5	3.85E-03	4.59
109	5	56.22	0.66	11.6	40.3	61.1	3.98E-03	5.22

211	5	39.57	0.7	12.8	39.3	56.1	3.48E-03	4.00
312	5	45.5	0.64	12.2	40.4	63.1	3.57E-03	4.56
407	5	38.85	0.82	10.6	41.2	50.2	3.42E-03	4.58
107	6	55.27	0.59	9.8	41.4	70.2	2.96E-03	3.95
205	6	55.42	0.56	8.9	43.7	78.0	3.62E-03	4.49
311	6	51.04	0.69	11.3	40.3	58.4	4.01E-03	5.31
413	6	54.85	0.52	10.7	41.6	80.0	3.02E-03	3.76
111	7	67.03	0.76	11.0	40.7	53.6	4.14E-03	5.29
206	7	55.06	0.773	10.8	40.95	53.0	3.60E-03	4.62
313	7	41.57	0.67	10.4	41.0	61.2	3.51E-03	4.45
408	7	49.23	0.80	10.3	41.0	51.3	3.43E-03	3.86

Table B.3 Aboveground biomass, total N content, ash content, total C content, C:N ratio, SE and SS at Hays in Fall 2013 sampling period

Plot #	Trt	Reside Biomass	Total-N	Ash	Total-C	C:N	SE	SS
102	1	38.5	0.61	11.5	40.7	66.7	4.41E-03	4.89
209	1	28.52	0.56	10.6	39.6	70.7	3.27E-03	3.89
309	1	20.2	0.68	15.2	37.3	54.9	1.01E-02	4.79
410	1	46.9	0.81	13.94	38.8	47.9	7.89E-03	4.83
112	2	30.12	0.76	18.2	35.3	46.4	3.90E-03	3.83
207	2	21.4	0.58	16.12	40.1	69.1	3.68E-03	4.19
301	2	25.15	0.72	13.6	37.5	52.1	3.56E-03	3.78
403	2	27.59	0.56	8.5	42.0	75.0	3.65E-03	3.77
108	3	34.42	0.65	9.66	38.4	59.1	4.72E-03	4.65
208	3	30.33	0.57	7.2	42.0	73.7	5.32E-03	3.17
305	3	21	0.67	17.4	38.1	56.9	4.26E-03	3.24
402	3	34.87	0.59	11.03	40.5	68.6	3.85E-03	4.31
101	4	25.3	0.83	26.8	34.7	41.8	3.42E-03	3.71
203	4	16.3	0.49	12.3	40.3	82.2	3.99E-03	4.84
310	4	38.6	0.71	16.79	38.6	54.4	4.45E-03	3.07
404	4	31.77	0.80	12.7	40.2	50.3	5.65E-03	3.41
104	5	54.97	0.44	11.2	41.0	93.2	4.11E-03	5.08
204	5	66.7	0.53	11.4	42.0	79.2	9.63E-03	5.30
308	5	19.8	0.68	13.1	40.4	59.4	3.56E-03	3.90
405	5	73.4	0.73	12.9	39.4	54.0	5.88E-03	3.77
113	6	41.65	0.82	25.58	31	37.8	5.14E-03	3.39
213	6	20.6	0.52	13.1	41.3	79.4	3.40E-03	4.45
304	6	30.3	0.6	13.29	39.7	66.2	3.86E-03	4.42
401	6	46.92	0.52	11.0	42.0	80.8	4.53E-03	4.31
103	7	65.2	0.46	12.7	42.9	93.3	3.45E-03	3.63
210	7	15.2	0.62	13.9	40.0	64.5	5.86E-03	4.83
303	7	29.06	0.60	14.6	38.6	64.3	4.11E-03	3.56
412	7	8	0.56	9.7	42.5	75.9	5.47E-03	3.96
105	2	17.3	0.85	20.1	36.7	43.2	3.64E-03	3.85
202	2	46.99	0.44	10.4	41.2	93.6	3.59E-03	4.41
306	2	17.6	0.62	15.0	39.5	63.7	3.50E-03	4.28
406	2	46.79	0.68	13.0	41.5	61.0	3.60E-03	4.88
106	3	41.6	0.68	15.0	39.1	57.5	4.24E-03	4.76
212	3	46.7	0.56	14.1	39.6	70.7	4.02E-03	4.31
302	3	35	0.50	15.9	39.6	79.2	4.63E-03	5.18
411	3	23.8	0.63	15.2	40.9	64.9	5.56E-03	4.34
110	4	37.8	0.62	11.45	41	66.1	4.15E-03	4.80
201	4	28.7	0.47	13.0	41.1	87.4	4.00E-03	4.70
307	4	37.21	0.54	11.99	41	75.9	3.79E-03	4.06
409	4	35	0.72	9.4	41.9	58.2	3.37E-03	4.47
109	5	38	0.62	16.1	37.8	61.0	4.12E-03	4.92

211	5	24	0.64	14.58	40.2	62.8	3.65E-03	4.14
312	5	32	0.46	7.6	42.7	92.8	3.32E-03	4.26
407	5	36.17	0.64	17.56	40.9	63.9	4.16E-03	4.31
107	6	24.65	0.61	13.55	40.3	66.1	3.51E-03	4.36
205	6	15.68	0.62	11.4	40.5	65.3	3.32E-03	3.70
311	6	48.2	0.54	14.4	39.5	73.1	5.81E-03	3.99
413	6	17.9	0.67	18.0	39.3	58.7	3.96E-03	3.78
111	7	36	0.78	20.8	33.8	43.3	5.74E-03	4.21
206	7	25.4	0.65	11.54	40.1	61.7	3.34E-03	4.45
313	7	43.8	0.83	15.6	38.2	46.0	5.45E-03	4.06
408	7	30.1	0.63	11.2	40.9	64.9	7.41E-03	5.03

Table B.4 Aboveground biomass, total N content, ash content, total C content, C:N ratio, SE and SS at Colby in summer 2012 sampling period

Plot #	Trt	Reside Biomass	Total-N	Ash	Total-C	C:N	SE	SS
102	1	.	.	.	.	.	.	.
209	1	147.33	0.57	28.3	.	.	4.07E-03	3.67
309	1	105.09	0.50	19.4	.	.	5.52E-03	5.20
410	1	120.49	0.65	8.44	.	.	4.35E-03	4.46
112	2	86.57	0.68	16.0	.	.	5.76E-03	4.37
207	2	151.72	0.6	14.67	.	.	4.90E-03	4.60
301	2	.	.	.	.	.	.	.
403	2	64.13	0.65	23.3	.	.	4.72E-03	4.15
108	3	87.59	0.73	13.41	.	.	4.48E-03	4.65
208	3	179.11	0.79	22.2	.	.	5.53E-03	4.40
305	3	143.87	0.71	17.4	.	.	4.20E-03	3.70
402	3	.	.	.	.	.	.	.
101	4	.	.	.	.	.	.	.
203	4	167.58	0.84	15.0	.	.	6.01E-03	2.86
310	4	117.98	0.6	14.14	.	.	6.10E-03	4.86
404	4	147.18	0.63	16.3	.	.	3.73E-03	3.51
104	5	169.59	0.56	21.6	.	.	4.21E-03	4.35
204	5	158.29	0.83	19.9	.	.	5.05E-03	4.13
308	5	177.68	0.74	17.9	.	.	4.20E-03	3.56
405	5	147.52	0.67	12.7	.	.	4.19E-03	4.14
113	6	128.41	0.68	17.41	.	.	3.83E-03	4.23
213	6	94.36	0.56	10.8	.	.	5.29E-03	3.90
304	6	86.84	0.79	16.16	.	.	4.23E-03	3.36
401	6	.	.	.	.	.	.	.
103	7	164.58	0.92	17.4	.	.	4.21E-03	3.13
210	7	109.73	0.64	23.3	.	.	6.76E-03	4.67
303	7	58.92	0.87	31.6	.	.	3.81E-03	2.83
412	7	205.59	0.78	17.5	.	.	3.47E-03	3.70
105	2	197.29	0.76	14.2	.	.	5.45E-03	4.11
202	2	.	.	.	.	.	.	.
306	2	313.06	0.79	13.4	.	.	3.64E-03	3.61
406	2	162.57	0.59	21.9	.	.	4.57E-03	4.08
106	3	164.15	0.63	15.3	.	.	5.28E-03	4.37
212	3	74.66	0.66	14.4	.	.	4.73E-03	4.02
302	3	.	.	.	.	.	.	.
411	3	166.03	0.68	16.2	.	.	4.46E-03	4.38
110	4	90.71	0.8	12.74	.	.	4.82E-03	4.16
201	4	.	.	.	.	.	.	.
307	4	192.62	0.72	12.58	.	.	4.22E-03	3.58
409	4	190.07	0.75	19.4	.	.	5.49E-03	4.44
109	5	54.89	0.66	17.4	.	.	4.38E-03	3.63

211	5	150.45	0.7	22.31	.	.	5.23E-03	4.75
312	5	174.48	0.79	18.3	.	.	3.38E-03	3.72
407	5	218.32	0.78	14.5	.	.	4.04E-03	3.46
107	6	137.63	0.54	10.47	.	.	4.44E-03	4.37
205	6	87.28	0.78	23.1	.	.	6.78E-03	4.40
311	6	294.79	0.58	18.4	.	.	4.57E-03	4.28
413	6	145.08	0.71	16.4	.	.	4.20E-03	4.24
111	7	98.89	0.58	20.9	.	.	4.48E-03	4.05
206	7	142.41	0.81	14.65	.	.	4.37E-03	3.30
313	7	157.37	0.86	26.0	.	.	3.86E-03	3.87
408	7	172.84	0.75	13.0	.	.	4.45E-03	3.96

Table B.5 Aboveground biomass, total N content, ash content, total C content, C:N ratio, SE and SS at Colby in Summer 2013 sampling period

Plot #	Trt	Reside Biomass	Total-N	Ash	Total-C	C:N	SE	SS
102	1	74.83	0.57	9.5	40.3	70.7	5.55E-03	3.91
209	1	75.94	0.51	11.1	40.3	79.0	8.79E-03	4.81
309	1	82.86	0.53	8.2	42.2	79.6	5.32E-03	4.75
410	1	115	0.52	11.8	39.7	76.3	4.60E-03	4.52
112	2	37.55	0.53	7.8	42.4	80.0	5.20E-03	4.10
207	2	73.72	0.6	7.5	41.4	69	5.20E-03	3.43
301	2	88.49	0.73	14.1	40.8	55.9	8.65E-03	4.75
403	2	64.15	0.69	13.7	40.9	59.3	5.96E-03	2.92
108	3	68.43	0.47	6.2	43.5	92.5	4.85E-03	4.62
208	3	65.9	0.52	11.9	39.5	76.0	6.52E-03	4.64
305	3	49.17	0.67	8.2	42.2	63.0	5.57E-03	4.15
402	3	55.62	0.58	12.9	42.2	72.8	1.56E-02	5.57
101	4	65.29	0.55	8.4	41.8	76.0	4.87E-03	3.89
203	4	79.93	0.42	8.6	41.5	98.8	5.11E-03	4.71
310	4	100.4	0.48	6.7	43.1	89.8	5.83E-03	4.11
404	4	60.68	0.74	9.6	40.6	54.9	7.04E-03	4.27
104	5	60.17	0.42	5.7	43.6	103.8	5.70E-03	4.56
204	5	95.91	0.55	11.3	40.5	73.6	4.87E-03	4.72
308	5	90.91	0.64	9.2	41.6	65	5.08E-03	3.93
405	5	85.62	0.64	9.7	41.2	64.4	5.09E-03	3.71
113	6	52.5	0.49	12.3	40.1	81.8	5.33E-03	4.33
213	6	64	0.43	12.4	40.7	94.6	6.96E-03	5.72
304	6	73.51	0.61	21.4	33.4	54.8	6.08E-03	4.19
401	6	40.68	0.55	14.3	40.7	74.0	4.39E-03	3.14
103	7	77.08	0.45	8.4	41.7	92.7	4.99E-03	5.27
210	7	107.59	0.46	11.9	40.7	88.5	5.62E-03	5.32
303	7	89.11	0.70	16.8	38.0	54.3	5.10E-03	4.38
412	7	75.38	0.54	11.6	40.1	74.3	6.36E-03	4.77
105	2	95.88	0.68	10.1	40.9	60.1	4.71E-03	4.10
202	2	84.78	0.54	8.4	41.9	77.5	5.26E-03	4.56
306	2	82.49	0.66	8.3	41.7	63.2	3.99E-03	3.34
406	2	91.75	0.55	10.4	41.6	75.6	4.80E-03	3.86
106	3	106.36	0.58	9.3	42.0	72.4	4.42E-03	3.70
212	3	87.15	0.46	15.8	38.1	82.8	6.01E-03	4.63
302	3	113.21	0.58	8.7	42.4	73.1	4.35E-03	3.73
411	3	87.22	0.51	13.4	39.7	77.8	5.64E-03	4.25
110	4	86.34	0.53	8.8	42.3	79.8	5.53E-03	5.26
201	4	53.21	0.57	7.0	42.6	74.7	6.51E-03	4.34
307	4	68.04	0.69	9.6	40.2	58.3	4.65E-03	3.89
409	4	127.89	0.56	9.6	41.7	74.5	5.86E-03	4.32
109	5	95.65	0.44	6.8	42.0	95.5	4.82E-03	4.98

211	5	89.93	0.54	16	39.8	73.7	5.71E-03	4.88
312	5	84.68	0.45	8.5	41.8	92.8	8.48E-03	5.61
407	5	77.5	0.83	13.8	39.0	47.0	4.78E-03	3.92
107	6	53.53	0.66	10.3	41.1	62.2	4.45E-03	3.58
205	6	118.27	0.43	7.7	42.2	98.1	4.75E-03	4.18
311	6	88.38	0.52	9.0	41.2	79.2	6.19E-03	4.42
413	6	65.57	0.56	11.1	38.2	68.2	5.02E-03	4.38
111	7	51.06	0.66	11.7	40.0	60.6	5.69E-03	4.41
206	7	91.72	0.62	9.7	40.2	64.8	4.26E-03	4.17
313	7	71.08	0.46	9.8	40.8	88.7	6.41E-03	5.96
408	7	97.79	0.59	12.0	40.4	68.5	4.37E-03	3.28

Table B.6 Aboveground biomass, total N content, ash content, total C content, C:N ratio, SE and SS at Colby in Fall 2013 sampling period

Plot #	Trt	Reside Biomass	Total-N	Ash	Total-C	C:N	SE	SS
102	1	67.9	0.64	7.7	41.8	65.3	5.19E-03	4.17
209	1	80.33	0.45	16.0	39.1	86.9	5.25E-03	3.90
309	1	51.09	0.70	9.4	41.0	58.6	5.95E-03	3.82
410	1	77.96	0.652	20.29	36.5	56.0	6.13E-03	4.07
112	2	41.65	0.52	14.9	38.6	74.2	4.60E-03	3.83
207	2	66.74	0.56	12.77	40.5	72.3	4.45E-03	3.32
301	2	57.68	0.71	13.2	40.5	57.0	5.77E-03	3.40
403	2	74.13	0.78	21.4	33.7	43.0	7.25E-03	3.60
108	3	62.12	0.51	12.99	42.1	82.5	7.00E-03	4.11
208	3	36.4	0.51	13.3	41.8	82.0	4.97E-03	3.75
305	3	77.61	0.71	9.5	40.9	57.6	6.67E-03	3.44
402	3	68.63	0.72	17.1	36.2	50.6	7.42E-03	3.27
101	4	47.96	0.69	14.0	37.5	54.3	5.28E-03	3.21
203	4	76.82	0.54	16.1	38.1	70.6	5.42E-03	3.73
310	4	43.42	0.63	12.59	40.5	64.3	4.75E-03	3.46
404	4	95.09	0.61	10.2	39.6	65.0	5.51E-03	3.71
104	5	90.28	0.56	9.7	41.5	74.1	5.21E-03	4.58
204	5	85.66	0.58	18.0	36.9	63.6	4.46E-03	4.16
308	5	64.1	0.57	6.7	41.2	72.3	8.57E-03	3.96
405	5	89.27	0.66	20.5	33.4	50.5	7.32E-03	3.09
113	6	27.02	0.6	28.78	34.0	56.7	5.74E-03	3.99
213	6	58.91	0.43	17.9	39.3	91.4	4.61E-03	3.86
304	6	63.87	0.68	10.49	41.8	61.5	6.58E-03	3.23
401	6	84.8	0.61	20.1	35.2	57.7	6.04E-03	3.81
103	7	78.6	0.53	10.0	41.4	78.1	6.38E-03	4.40
210	7	78.68	0.69	10.3	39.9	57.8	4.80E-03	3.62
303	7	68.08	0.64	9.7	40.9	63.9	4.81E-03	3.49
412	7	80.4	0.52	14.6	38.9	75.1	5.37E-03	4.95
105	2	71.07	0.65	13.3	40.8	62.8	7.02E-03	3.92
202	2	63.88	0.51	14.0	38.5	75.5	4.50E-03	3.95
306	2	86.95	0.70	13.1	40.0	57.1	5.76E-03	3.20
406	2	86.01	0.60	20.5	32.3	53.5	5.52E-03	3.12
106	3	53.61	0.65	9.3	40.7	62.6	4.03E-03	3.21
212	3	56.68	0.46	15.7	37.7	82.0	5.48E-03	4.27
302	3	30.27	0.84	12.1	39.6	47.1	6.82E-03	3.07
411	3	87.6	0.58	18.7	36.0	62.2	8.26E-03	4.60
110	4	69.73	0.64	18.24	36.9	57.7	4.66E-03	4.30
201	4	59.43	0.63	10.6	40.6	64.4	4.47E-03	3.55
307	4	73.1	0.69	8.61	41.6	60.3	5.91E-03	5.16
409	4	79.94	0.70	16.5	35.0	50.0	6.29E-03	4.16
109	5	81.33	0.47	14.1	39.5	84.0	4.82E-03	4.64

211	5	54.03	0.46	15.31	37.0	80.4	5.31E-03	3.87
312	5	45.13	0.65	12.0	40.9	62.9	5.83E-03	3.44
407	5	76.73	0.587	13.6	40.1	68.3	5.61E-03	3.17
107	6	71.73	0.64	9.57	42.4	66.3	6.52E-03	3.71
205	6	68.26	0.54	12.6	41.1	76.1	5.50E-03	3.67
311	6	56.16	0.66	17.9	36.5	55.3	5.67E-03	3.90
413	6	88.6	0.48	17.8	37.2	77.3	5.79E-03	4.83
111	7	47.05	0.51	17.2	37.6	73.7	4.64E-03	4.09
206	7	60.66	0.62	15.04	38.3	61.8	4.23E-03	3.96
313	7	32.82	0.48	8.6	42.4	88.7	5.44E-03	4.04
408	7	91.19	0.65	13.3	37.3	57.8	4.48E-03	3.27

Table B.7 Aboveground biomass, total N content, ash content, total C content, C:N ratio, SE and SS at Garden City in summer 2012 sampling period

Plot #	Trt	Reside Biomass	Total-N	Ash	Total-C	C:N	SE	SS
102	1	39.72	0.32	2.7	45.6	142.5	8.90E-03	5.75
209	1	34.35	0.34	5.1	43.5	127.9	7.78E-03	7.59
309	1	61.29	0.38	7.1	43.1	113.4	6.14E-03	6.59
410	1	70.18	0.38	5.3	44.7	117.6	9.36E-03	6.68
112	2	31.38	0.34	2.6	46.0	135.3	8.04E-03	6.41
207	2	30.13	0.39	4.1	45.4	116.4	6.99E-03	6.61
301	2	43.75	0.40	4.1	44.3	110.8	6.69E-03	6.02
403	2	79.13	0.41	5.2	43.5	106.1	6.43E-03	6.51
108	3	49.21	0.34	5.8	44.8	131.8	7.36E-03	6.86
208	3	45.35	0.41	5.0	44.6	108.8	6.82E-03	6.49
305	3	88.98	0.44	7.8	43.0	97.7	7.20E-03	6.80
402	3	77.55	0.50	4.5	43.9	87.8	5.32E-03	5.17
101	4	45.33	0.34	3.0	45.7	134.4	7.33E-03	6.43
203	4	62.16	0.44	5.2	43.4	98.6	8.43E-03	6.12
310	4	48.86	0.35	3.5	45.4	129.7	7.78E-03	6.56
404	4	78.63	0.38	5.6	43.6	114.7	7.15E-03	5.97
104	5	55.41	0.42	6.6	43.6	103.8	7.07E-03	5.80
204	5	46.36	0.36	3.4	44.8	124.4	6.47E-03	5.37
308	5	83.72	0.38	5.1	44.1	116.1	7.84E-03	6.85
405	5	65.13	0.35	4.9	44.7	127.7	6.18E-03	6.02
113	6	35.44	0.38	2.9	45.3	119.2	9.24E-03	6.30
213	6	14.04	0.33	4.4	44.1	133.6	9.32E-03	7.37
304	6	25.98	0.39	5.8	42.6	109.2	1.04E-02	7.53
401	6	76.33	0.36	5.3	43.9	121.9	6.33E-03	6.19
103	7	53.77	0.45	4.0	45.3	100.7	5.23E-03	3.85
210	7	24.99	0.33	2.4	45.4	137.6	8.57E-03	6.44
303	7	36.27	0.43	9.0	41.1	95.6	6.66E-03	5.69
412	7	32.71	0.38	4.4	44.9	118.2	7.66E-03	6.40
105	2	107.57	0.47	3.2	45.0	96.2	5.11E-03	4.72
202	2	51.28	0.37	3.2	45.5	123.0	6.45E-03	5.85
306	2	90.35	0.40	4.4	43.3	108.3	7.17E-03	5.89
406	2	82.67	0.44	3.8	45.1	102.5	6.62E-03	5.41
106	3	89.89	0.49	9.6	43.2	88.2	6.86E-03	5.60
212	3	22.49	0.37	4.4	44.9	121.4	8.58E-03	7.60
302	3	36.12	0.44	4.6	44.4	100.9	8.38E-03	7.30
411	3	44.71	0.38	3.8	45.4	119.5	8.97E-03	6.41
110	4	29.24	0.39	4.6	45.1	115.6	7.61E-03	6.54
201	4	67.52	0.44	4.1	44.9	102.0	6.31E-03	6.44
307	4	64.63	0.46	4	44.1	95.9	7.36E-03	6.75
409	4	74.15	0.45	5.7	44.5	98.9	5.38E-03	5.36
109	5	48.23	0.37	5.7	44.0	118.9	6.26E-03	6.29

211	5	34.46	0.54	8.8	43.9	81.3	6.55E-03	5.64
312	5	36.71	0.34	6.4	43.8	128.8	6.78E-03	6.25
407	5	101.75	0.44	7.3	42.8	97.3	5.98E-03	6.18
107	6	31.32	0.4	3.3	45.3	113.3	7.37E-03	5.85
205	6	41.87	0.42	8.0	43.4	103.3	6.86E-03	4.86
311	6	47.02	0.30	3.4	45.3	151.0	8.62E-03	7.22
413	6	15.05	0.39	5.1	45	115.4	1.08E-02	6.82
111	7	34.82	0.44	4.2	45.3	103.0	7.10E-03	5.89
206	7	39.81	0.44	5.6	44.0	100.0	6.56E-03	6.50
313	7	24.06	0.42	4.8	44.7	106.4	7.60E-03	6.70
408	7	117.64	0.52	9.9	42.1	81.0	5.76E-03	5.79

Table B.8 Aboveground biomass, total N content, ash content, total C content, C:N ratio, SE and SS at Garden City in Summer 2013 sampling period

Plot #	Trt	Reside Biomass	Total-N	Ash	Total-C	C:N	SE	SS
102	1	109.81	0.71	38.2	23.0	32.4	.	.
209	1	53.61	0.88	14.4	38.8	44.1	.	.
309	1	47.68	0.85	9.4	40.3	47.4	.	.
410	1	56.39	0.94	17.19	38.4	40.9	.	.
112	2	86.28	1.09	34.2	29.9	27.4	.	.
207	2	37.78	0.92	20	35	38.0	.	.
301	2	79.84	1.19	22.3	31.6	26.6	.	.
403	2	71.32	0.93	14.4	40.3	43.3	.	.
108	3	82.25	0.94	33.14	28.1	29.9	.	.
208	3	55.48	1.08	25.3	32.2	29.8	.	.
305	3	74.48	0.82	20.9	35.6	43.4	.	.
402	3	48.13	0.98	16.7	39.8	40.6	.	.
101	4	95.05	0.95	30.9	29.8	31.4	.	.
203	4	119.27	1.12	27.7	31.6	28.2	.	.
310	4	69.23	1.07	23.81	32.2	30.1	.	.
404	4	84.72	0.88	16.7	37.9	43.1	.	.
104	5	58.99	0.89	28.8	33	37.1	.	.
204	5	71.31	1.10	29.5	28.7	26.1	.	.
308	5	54.64	0.95	12.6	40.4	42.5	.	.
405	5	65.08	0.95	13.0	39.3	41.4	.	.
113	6	37.33	0.71	14.73	40.1	56.5	.	.
213	6	44.08	0.85	11.2	39.6	46.6	.	.
304	6	72.52	1.05	17.28	36.3	34.6	.	.
401	6	65.71	0.94	13.0	40.9	43.5	.	.
103	7	49.94	1.04	26.0	31.5	30.3	.	.
210	7	51.98	0.94	36.4	26.3	28.0	.	.
303	7	38.33	1.05	26.4	35.7	34.0	.	.
412	7	77.11	0.93	12.5	40.4	43.4	.	.
105	2	64.39	0.94	27.5	30.5	32.4	.	.
202	2	57.25	0.83	23.9	33.3	40.1	.	.
306	2	164.94	0.73	34.6	27.5	37.7	.	.
406	2	48.23	1.08	17.0	39.4	36.5	.	.
106	3	78.89	0.88	26.6	29.9	34.0	.	.
212	3	85.66	0.93	21.9	34.7	37.3	.	.
302	3	85.55	1.24	29.4	30.5	24.6	.	.
411	3	66.07	0.80	9.0	42.5	53.1	.	.
110	4	60.52	1.1	32.54	32.0	29.1	.	.
201	4	56.74	1.03	25.5	28.7	27.9	.	.
307	4	61.81	0.95	13.04	38.5	40.5	.	.
409	4	56.5	1.08	15.1	39.6	36.7	.	.
109	5	77.33	0.93	31.3	31.9	34.3	.	.

211	5	54.74	1.08	24.08	35.5	32.9	.	.
312	5	91.02	1.01	23.5	31.8	31.5	.	.
407	5	59.65	0.88	14.31	40.1	45.6	.	.
107	6	52.94	1.08	18.78	37.9	35.1	.	.
205	6	50.56	1.01	16.2	37.9	37.5	.	.
311	6	49.18	0.81	12.1	40.6	50.1	.	.
413	6	77.69	0.82	9.4	41.7	50.9	.	.
111	7	59.14	1.05	30.4	32.1	30.6	.	.
206	7	46.81	0.93	13.53	39.2	42.2	.	.
313	7	36.51	0.83	13.5	39.6	47.7	.	.
408	7	64.95	0.82	9.3	42.4	51.7	.	.

Appendix C - SAS Codes

EF, GMD, GSD, Stability, Random Roughness, and SWEEP results

```
data site;
input trt$ EF rep;
datalines;
;
run;
proc mixed data=site;
class trt;
model EF=trt;
random rep;
lsmeans trt/pdiff;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'C:\Users\Jack He\Downloads\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);

data site;
input trt$ GMD rep;
datalines;
;
run;
proc mixed data=site;
class trt;
model GMD=trt;
random rep;
lsmeans trt/pdiff;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'C:\Users\Jack He\Downloads\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);

data site;
input trt$ GSD rep;
datalines;
;
run;
proc mixed data=site;
class trt;
model GSD=trt;
random rep;
lsmeans trt/pdiff;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'C:\Users\Jack He\Downloads\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);

data site;
input trt$ RR rep;
datalines;
```

```
;
run;
proc mixed data=site;
class trt;
model RR=trt;
random rep;
lsmeans trt/pdiff;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'C:\Users\Jack He\Downloads\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
```

Aboveground biomass, SE, SS, total C, N, and ash content

```
data site;
input trt$ bio rep time$;
datalines;
;
proc mixed data=site;
class trt time;
model bio=trt time trt*time;
random rep;
lsmeans trt time trt*time/pdiff;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'C:\Users\Jack He\Downloads\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);

data site;
input trt$ SE rep time$;
datalines;
;
proc mixed data=site;
class trt time;
model SE=trt time trt*time;
random rep;
lsmeans trt time trt*time/pdiff;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'C:\Users\Jack He\Downloads\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);

data site;
input trt$ SS rep time$;
datalines;
;
proc mixed data=site;
class trt time;
model SS=trt time trt*time;
random rep;
lsmeans trt time trt*time/pdiff;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
```

```
run;
%include 'C:\Users\Jack He\Downloads\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);


data site;
input trt$ C rep time$;
datalines;
;
proc mixed data=site;
class trt time;
model C=trt time trt*time;
random rep;
lsmeans trt time trt*time/pdiff;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'C:\Users\Jack He\Downloads\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);

data site;
input trt$ N rep time$;
datalines;
;
proc mixed data=site;
class trt time;
model N=trt time trt*time;
random rep;
lsmeans trt time trt*time/pdiff;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'C:\Users\Jack He\Downloads\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);

data site;
input trt$ ash rep time$;
datalines;
;
proc mixed data=site;
class trt time;
model ash=trt time trt*time;
random rep;
lsmeans trt time trt*time/pdiff;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'C:\Users\Jack He\Downloads\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
```

Regressions

```
data site;
input trt$ biomass N ash C CtoN SE SS time$;
datalines;
```

```
;
proc reg data=site;
model SE = C N ash/selection=stepwise;
model SS = C N ash/selection=stepwise;
run;
```