GROWING CROPS FOR BIOFUEL AND FORAGE WHILE CONSERVING SOIL AND WATER

by

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Abstract

The use of renewable feedstocks to produce cellulosic ethanol is quickly becoming a reality as facilities to produce cellulosic ethanol are scheduled to open in the upcoming years. Initial feedstocks for these facilities are thought to be crop residues such as corn (*Zea mays* L.) and wheat (*Triticum aestivum* L.) residues. However, additional feedstocks, such as perennial warm-season grasses (WSG), maybe needed to meet the demands of these bioenergy facilities. Thus, the development of regional dedicated energy crop systems is a high priority. Our objectives were to: a) assess the impacts of growing WSG on water storage, soil physical and hydraulic properties, soil organic carbon (SOC) dynamics, and water and wind erosion as compared with row crops, b) assess the impacts of growing WSG on biomass and forage production and quality and c) determine the most adaptable WSG species to dryland conditions. A number of dedicated energy crops and their performance across three different moisture regimes in Kansas were studied. Biomass yield, soil physical and hydraulic properties, and soil water and wind erosion parameters were measured between August 2010 and August 2012. Additionally, forage quality under two cutting systems (biofuel and forage) and two harvest heights (0.1 m and 0.2 m) and water infiltration was determined in 2011. Differences in bulk density, water retention, infiltration and SOC were found to be minimal. However, differences in wind and water erosion parameters indicate that WSG can protect soil from erosion. Furthermore, soil water data indicate that WSG are better suited to use early season moisture to accumulate biomass than annual row crops. Yield results indicate that a two cut hay system with a 0.1 m cutting height can produce more biomass compared with a one cut biofuel system. Additionally, the hay system improved forage quality parameters. Data collected from this project provided insights into the viability of growing various dedicated energy crops across the region during the first five years of production.

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Dedication

I would like to dedicate this work to two great conservationists, my late grandfathers Richard J. Stubbe and Harry W. Evers. Both taught me the importance of conserving resources while farming the land. They proved that a good work ethic and honesty will take a person a long way. I thank them for showing me the good in life and introducing me to a great profession.

Chapter 1 - Literature Review

Introduction

Renewable energy from cellulosic biomass is one of the strategies to reduce dependence on foreign oil and greenhouse gas emissions (Kort et al., 1997). Furthermore, development of environmentally sustainable dedicated energy crops can address concerns over soil and environmental degradation. Dedicated energy crops may decrease water pollution, reduce wind and water erosion, and improve soil quality, particularly when grown on marginal or degraded lands (Blanco-Canqui, 2010). Perennial warm-season grasses (WSG), such as switchgrass (*Panicum virgatum* L.), are viable options due to their deep root system and year-round soil cover. Perennial crops can reduce water runoff and improve soil organic matter, soil structure, and soil water holding capacity (Kort et al., 1997). The concern is, however, that continuous harvesting of these perennial crops for energy may slow or reduce their environmental benefits. Additionally, the establishment of WSG is often slow and can take several years. During this period, a significant erosion hazard may exist due to limited biomass production (Kort et al. 1997).

A number of cellulosic ethanol plants are being constructed across the USA. Crop residues, particularly corn stover, will be the primary initial feedstock for these facilities. Crop residues are an abundant and inexpensive source of biomass that can be removed to produce bioenergy. It is often assumed that minimum or no-tillage farming methods can sustain residue removal (Varvel et al., 2008). However, it has been suggested that large amounts of crop residue removal may not be sustainable (Blanco-Canqui, 2010). Excessive residue removal can reduce soil structural stability, water infiltration, and soil microbial activity. It can also degrade water and air quality, reduce soil productivity, and limit wildlife habitat and diversity.

It is estimated that future dedicated energy crops could occupy as many as 60 million hectares in the United States (Kort et al., 1997). Most of these energy crops will be grown in marginal lands, as energy crops are not projected to be economically competitive with row crops in most regions of the United States (Kort et al., 1997). Furthermore, establishment of energy crops in marginal land may reduce concerns over competition for land between energy crops and prime agricultural production. A number of perennial crops are considered as potential biofuel feedstocks including shrubs, trees, and cool and warm-season grasses (Rashmi et al., 2009). The wide range of potential dedicated energy crops grown on marginal lands provides an opportunity to mimic native vegetation of the land, similar to Conservation Reserve Program (CRP) land management. As an example, in northeastern Kansas, cropland converted back to grassland has increased livestock profitability and reduced soil erosion (Murphy et al., 2004). The increased interest and potential profitability from energy crops could accelerate this trend. This underscores research on dedicated bioenergy crops in relation to their long-term effects on soil and environmental quality.

Soil and Environmental Quality

Soil Physical Properties

Current research on energy crops is mostly focused on (i) developing technologies for conversion of cellulosic feedstocks into ethanol, and (ii) increasing production of biomass (Blanco-Canqui, 2010). As a result, data on the impacts of WSG when grown as forage and biofuel on soil and water conservation, soil physical properties, soil C dynamics, erosion, and other soil and environmental factors are limited, particularly in western Kansas. Climate variability, particularly precipitation amount, can greatly affect establishment and in-season growth of dedicated energy crops. Most current research has been conducted in regions with adequate annual precipitation (Rachman et al., 2004; Udawatta et al., 2008). In the central Great Plains, such as western Kansas, annual precipitation amounts are much lower and plant growth is limited unless it is supplemented with irrigation water. Studying the effects of dedicated energy crops on soil physical quality in water limited areas is needed to assess the feasibility of growing dedicated energy crops in these regions.

Bulk density is an indicator of soil processes such as compaction, water infiltration, soil aeration, root penetrability and erosion potential (Murphy et al., 2004). Pikul et al. (2006) found that soil bulk density under croplands tended to be higher compared with that under native grassland. The establishment of perennial WSG may reduce soil bulk density. Schmer et al. (2011) found that switchgrass had the ability to decrease soil bulk density and attributed that change to an increase in root biomass. Even though the ability of perennial dedicated energy crops to improve soil bulk density is somewhat well recognized, it is relatively unknown how increased machinery traffic during field operations (i.e., repeated biomass harvest cycles) will affect bulk density or soil compaction risks. Literature shows that intensive grazing can reduce the beneficial effects of established native grasses on soil physical properties due to the reduction in total vegetative cover (Murphy et al., 2004; Bauer et al., 1987). Murphy et al. (2004) noted that grazed fields had higher bulk density than fields harvested for hay. Bauer et al. (1987) also reported that grazed sites tended to have higher bulk density values than soils on virgin grasslands.

Timing of harvest or grazing events can impact the effects on bulk density and soil compaction. Naeth et al. (1989) documented that early season grazing caused more compaction to the 30 cm depth than late season grazing on a loam soil in Canada. This can be attributed to greater soil moisture content in spring, which probably increased the soil’s susceptibility to compaction. Proper management and timing of machine harvesting may reduce the impacts of harvest traffic on soil physical properties. Karlen et al. (1999) reported that land managed under native grasses through CRP had lower surface bulk densities than soils managed under traditional cropping systems across Minnesota and Iowa. Murphy et al. (2004) compared bulk density effects of various perennial grass systems including CRP, cool-season grass fields and native WSG fields. They reported that the native WSG fields had the lowest bulk density followed by cool-season fields and CRP.

Aggregate stability is another indicator of soil quality (Karlen et al., 1999). Weak and unstable aggregates can cause surface crusting, increase erosion, and reduce plant available water and water infiltration (Broersma et al., 1996). Cropping systems alter soil structure, aggregate density, aggregate distribution and aggregate strength due to differences in surface cover, rooting characteristics, and organic matter input (Broersma et al., 1996). Integrating dedicated energy crops or perennial WSG into current cropping systems may positively affect these soil properties. However, results have been mixed. Marquez et al. (2004) reported that cool-season grasses (17%) had the highest percentage of macro-aggregates, followed by riparian forest (10%), switchgrass (3%) and non-buffered row crops (2%). In contrast, Broersma et al. (1996) reported that soils managed under continuous grass had greater aggregate stability compared with soils managed under continuous barley (*Hordeum vulgare* L.) and barley/forage rotations. Karlen et al. (1999) reported that land in CRP had higher percentage of water stable soil aggregates compared with traditional cropland in southeast Iowa. Blanco-Canqui (2005) reported that soils managed under switchgrass had significantly lower aggregate density values at the 0 to 10 cm depths than soils in row crop systems. He attributed these differences to the high density of fine roots and below-ground biomass under switchgrass. In addition to reduced aggregate density, Blanco-Canqui (2005) observed an increase in aggregate soil moisture retention compared with row crop systems.

Dedicated energy crops may also improve soil hydraulic properties through their extensive active and decaying root systems. However, data on the affects of dedicated energy crops on these properties are very limited. Rachman et al. (2004 a) found that soils managed as switchgrass hedges had greater hydraulic conductivity at the 50 and 100 mm tensions compared with soils under row crop production. Likewise, Broersma et al. (1995) reported that soils under continuous grass and continuous legume had higher saturated hydraulic conductivity than soil under continuous row crops. They attributed the increases to a greater abundance of large continuous pores. On a silt loam in Missouri, Udawatta et al., (2008) reported that soils under big bluestem (*Andropogon gerardii* L.), little bluestem [*Schizachyrium scoparium* (Michx.) Nash], and indiangrass (*Sorghastrum nutans* L.) had longer pore paths when compared with soils under a corn-soybean [*Glycine max* (L.) Merr.] rotation

Growing energy crops such as switchgrass may have a positive effect on water flow and transmission characteristics in the soil. However, most previous studies were conducted on switchgrass hedges used as conservation buffers and not on dedicated biomass production systems. Impacts of WSG on soil physical properties are often inconsistent, depending on management length, grass species, harvest frequency, soil type, and climate (Schwartz et al., 2003).

Soil Wind and Water Erosion

It is estimated that erosion has degraded 430 million ha worldwide, which is roughly 30% of the world cropland base (Kort et al., 1997). Sediment loss can collect in rivers, lakes and reservoirs causing future environmental and economic problems. Soil lost during wind erosion can also degrade air quality and be a major concern to human health (Pimentel et al., 1995).

Erosion can also degrade soil physical, chemical, and biological properties (Blanco and Lal 2008).

In the central Great Plains, wind erosion is a major concern. The Great Plains witnessed the worst dust storms in U.S. history during the 1930's (Colacicco et al., 1989). Wind erosion reduces crop production and degrades soil quality by removing the most fertile layer of soil, lowering water-holding capacity, degrading soil structure, and increasing soil variability across a field (Presley and Tatarko, 2009). The use of herbaceous wind barriers can reduce wind erosion, improve crop yield, prevent sandblast damage to crops, and trap snow to improve soil moisture (Bilbo and Fryrear, 1988). Like wind barriers, dedicated bioenergy crops, particularly perennial grasses, have the potential to reduce wind erosion by increasing residue input, decreasing the amount of erodible soil aggregates (< 0.84 mm in diameter), and reducing wind velocity. Permanent vegetative cover, provided by WSG, is one of the most effective ways to control wind erosion (Presley and Tatarko, 2009). Established perennial WSG controls wind erosion by stabilizing and anchoring loose and erodible soil with their extensive and deep root systems (Blanco and Lal, 2008). Bilbro and Fryrear (1997) concluded that tall and lodge-resistant plants, such as switchgrass, increased the effective distance of wind barriers. These grasses are able to absorb blowing soil particles and reduce the loss of windblown materials (Blanco and Lal, 2008). Furthermore, these plants maintain almost complete effectiveness throughout the winter because they shed very few leaves and show no significant lodging.

Harvest heights and harvest timing (spring vs. fall cutting) affect switchgrass effectiveness on preventing wind erosion. In addition, grazing intensity and timing can also reduce the effectiveness of WSG to reduce wind erosion. Wind erosion is usually greatest between February and May when winds are high and crops are not present to protect the soil surface (Presley and Tatarko, 2009). Excessive biomass removal reduces the amount of surface litter, leaves the soil bare, and affects root development and future plant growth. Pikul et al. (2006) found that alternative cropping systems had a greater fraction of large aggregates than soils under conventional cropping systems. Soil aggregates under alternative cropping systems also had lower tendency to abrade into small aggregates and, thus, were less susceptible to wind erosion than soils managed under conventional cropping systems.

Water erosion can also be a concern in semiarid regions (Agassi, 2001). While precipitation amounts are low in semiarid regions, rainfall events are often intense, which can cause significant soil erosion. Water erosion is a primary source of non-point source pollution such as sediment, nutrients, and pesticides (Nelson et al., 2006; Lal, 2009). Perennial WSG may reduce soil runoff and erosion by increasing saturated hydraulic conductivity and infiltration rates (Schultz et al. 1995; Rachman et al. 2004a and 2004b; Bharati et al., 2002). In addition, perennial WSG may reduce water erosion year long, even when above ground biomass is harvested, due to their extensive root systems (Zuazo and Pleguezuelo, 2009). Blanco-Canqui et al. (2004a, 2004b) found that narrow switchgrass hedges trapped 91% of sediment leaving croplands compared with plowed plots without hedges.

Soil Carbon

Potential of WSG for improving soil organic carbon (SOC) is receiving unprecedented attention. Organic matter decline is the major cause of soil degradation as SOC levels impact soil physical and hydraulic properties (Stewart et al., 1991). In addition, reduced SOC concentration can negatively affect biomass productivity and water quality (Blanco and Lal, 2008). The SOC levels near the soil surface can quickly decline, particularly during extreme erosion events. The conversion to cultivated agricultural systems can reduce SOC pools by 60% in temperate regions (Lal, 2004). Since the introduction of modern agriculture to the central Great Plains, SOC concentration in cultivated soils has declined by about 50% (Smith et al., 1954).

Converting cultivated lands back to native WSG species has the potential to be a carbon positive system. A majority of the U.S dedicated energy crops will be planted in marginal soils similar to those that are already managed under CRP. Karlen et al. (1999) reported that CRP land increased SOC across four states (Iowa, Minnesota, North Dakota, and Washington) when compared with soils under traditional cropping systems. Liebig et al. (2005) found that stored SOC concentrations of lands managed under switchgrass were up to 7.7 Mg ha^{-1} greater than cultivated soils across various sites in Minnesota, North Dakota, and South Dakota. Similarly, Schmer et al. (2011) reported an average SOC increase of 0.5 to 2.4 Mg ha^{-1} yr^{-1} on soils managed exclusively under switchgrass for biomass production across the upper Midwest.

Omonode and Vyn, 2006 found SOC concentrations of WSG (22.4 g C kg^{-1}) to be greater than in croplands (19.8 g C kg^{-1}) after 5 to 8 years of management, across 10 locations in Indiana.

Despite the positive effects of WSG on SOC sequestration, questions still remain on how increased biomass harvest for energy will affect SOC dynamics (Bransby et al., 1998). Sanderson (2008) found soils that were converted from row crops to switchgrass had 33% greater soil C after 7 year of management near the soil surface. Additionally, by year five, the author noted that 23% of the total SOC at the 0-5 cm depth was derived from C_4 WSG. However, the study did not observe a significant change in SOC between switchgrass stands managed as biofuel crops compared with lands that were previously managed under pasture and hay systems. Stewart et al. (2008) noted that SOC sequestration by WSG can be greater in soils with initial low SOC levels, such as degraded cropland, than in those with high levels, such as in CRP lands. These, along with data reported by Sanderson (2008), may suggest that regardless of clipping intensity and height, switchgrass can improve SOC compared with land managed under tilled row crops. While the greatest short term impact of WSG on SOC is recognized near the soil surface, WSG can also have potential to store SOC in deeper soil profile in the long-term due to their deep and extensive rooting systems (Lemus and Lal, 2005).

Water Use Efficiency

Productivity of dry land agriculture in the central Great Plains is driven by how much precipitation is received during the growing season and how efficiently the precipitation is retained and used (Stone and Schlegel, 2010). Water is often seen as the most important factor that affects plant growth, as 57.2% of crop losses in the United States are caused by water stress, either drought (40.8%) or excess water (16.4%) (Kirkham, 2005). Water storage and plant water use are two major concerns throughout the wide climatic range of Kansas, particularly in areas where irrigation has been used to supplement precipitation. WSG species may increase precipitation capture and minimize soil water loss due to increased residue cover and improved soil physical properties (Stone and Schlegel, 2010).

Efficient water management requires attention to: (i) soil water use by crops (ii) reduction of water runoff and (iii) opportunities to improve water recharge (Pikul et al., 2006). The limiting factor of dry land crop production in western Kansas is the low precipitation, which makes efficient precipitation capture critical to successful crop production. Dedicated bioenergy and forage crops may increase water use efficiency by increasing water capture.

Soil infiltration in semi-arid regions is crucial to crop production as it determines precipitation capture. It affects the soil's ability to replenish soil water and overall water use efficiency (Clothier, 2001). Infiltration is dependent on the physical state of the soil. Dedicated energy crops are thought to improve infiltration by improving the soil physical properties throughout the soil profile. However, past research of infiltration on soils managed under dedicated energy crops have shown mixed results. Bharati et al. (2002) found the average 60 min cumulative infiltration of switchgrass buffer strips to be five times greater than cultivated corn and soybean fields. Similarly, Broersma et al. (1995) found that soils under continuous grass and continuous legume treatments had higher 30 minute infiltration rates than soils managed as continuous row crops and row crop/forage rotations. However, Pikul et al. (2006) did not find significant differences in initial infiltration rates of fields managed under alterative cropping systems and native grasslands when compared with fields managed under traditional cropping systems. Additionally, Nyakatawa et al. (2006) did not observe differences in infiltration of soils managed under switchgrass compared no-till corn and sweetgum (*Liquidambar styraciflua*). Improvements in soil infiltration may take longer to observe. As WSG stands mature and roots start to decay, infiltration rates may increase. This was observed by Bharati et al. (2004) as infiltration rates under switchgrass were greater in November, after senescence occurred, than during the growing season in August.

Biomass Production and Use

Warm- Season Grass Establishment

As the need for cellulosic feedstocks increase, dedicated bioenergy crops, such as WSG, may be grown on marginal lands to meet the need. Perennial grasses have several advantages over annual crops, such as lower establishment cost, reduced soil erosion, increased water quality, and enhanced wildlife habitat (McLaughlin et al., 2002; Roth et al., 2005). Switchgrass is a species that can be grown on sites that would not be favorable for other crops (Parrish et al., 2008). However, switchgrass establishment may be difficult or slow, depending on soil, climate, and management. In addition, climate and poor initial management can result in long-term poor performance. Proper seeding rates, weed control, and attention to agronomic details are essential to successful stand establishment. No single method for switchgrass establishment will work in all situations and regions (Parrish et al., 2005).

Soil temperature can greatly affect germination rate. Switchgrass should be seeded in warm soil roughly 6 to 12 mm deep. Recommended seeding rates range from 1 kg/acre to 4.5 kg/acre, depending on the germination viability of the seed (Parrish, 2008). After germination, first year plant population targets should be around 20 plants m^{-2}, but stands of 10 plants per m^{-2} or more are considered to be acceptable (Launchbaugh et al., 1963). During establishment, stand frequencies of 40% of the target plant density have been shown to be capable of sustaining high biomass production by the second year (Schmer et al., 2006). However, stand frequencies of 25% or greater were considered adequate if the field was not harvested for several years following establishment. Stand frequencies less than 25% are marginal, and re-establishment may be necessary. In addition to seeding rates and weed control, variety selection of switchgrass is essential to adequate stand establishment (Schmer et al., 2006).

As previously stated, one of the major concerns with WSG establishment is weed control (Parrish et al., 2005). Mature WSG stands are capable of controlling many weed species without human interference. However, during establishment, weeds are often able to compete with young plants for resources such as light, water, and nutrients to delay harvestable yields (Mitchell et al., 2010). Schmer et al. (2006) attributed poor stand establishment in South Dakota and North Dakota to improper herbicide applications and improper seeding depth. Many dicot weeds are successfully controlled with the use of 2,4-D (2, 4-Dichlorophenozyactieic acid). However, control of other warm-season annual grasses is difficult. Mitchell et al. (2010) found that herbicides which targeted grassy and broadleaf weeds during establishment decreased weed frequency and increased yields during the second year. When atrazine was used in combination with a grass control herbicide (quinclorac), biomass yields were 0.8 to 3.2 Mg ha^{-1} greater than plots that only used atrazine (Mitchell et al., 2010).

Biomass Production

Biomass production can be influenced by many factors, such as variety selection, seeding rate, harvest frequency, harvest height, and climate. Dedicated energy crops are thought to be less economically competitive with row crops in prime agricultural land, but may prove to be a good alternative on marginal lands. Bransby et al. (2005) estimated the break-even yield for switchgrass, priced at \$55/ton, was about 10 Mg ha^{-1}, and yields above this level would be needed for the crop to be profitable. Launchbaugh (1971) reported the peak productivity of pure switchgrass stands in Hays, KS was 6,900 pounds per acre (7.7 Mg ha^{-1}) in 1962 from a study that took place from 1957 to 1968.

WSG variety selection can greatly influence biomass production. This is particularly true with switchgrass since a wide selection of varieties is available. In general, two types of switchgrass are grown in the U.S, upland and lowland. Upland types typically grow less than 3 m tall and are less coarse. They tend to be grown more throughout the northern region of the U.S. as they are more cold tolerant than lowland types (Parrish et al., 2008). Lowland types are capable of producing more biomass than upland types under favorable conditions. However, lowland types are more prone to moisture stress. Growing switchgrass in the central Great Plains where moisture is limited and unpredictable usually favors the establishment of upland varieties such as Blackwell and Pathfinder. Parrish et al. (2008) recommends growing a switchgrass variety that originates one hardiness zone south of the location where it will be grown. This will improve biomass production as it will delay seed head production due to photoperiod delay, allowing the cultivar to generate more stem and leaf. However, that strategy can also make stand establishment difficult and can also increase the potential for winter kill.

Cutting frequency can greatly impact biomass production and quality. Sanderson (2008) reported that a three cut system yielded 24% more biomass than a two-cut system. Furthermore, he found that the three cut system reduced yield distribution variability from year to year. Climate can dramatically impact biomass yields. Stout (1992) noted that limited soil water availability can decrease switchgrass production by 30 to 50%. Sanderson (2008) saw a difference in forage production distribution between two years. In a year with below normal rainfall, early season growth only accounted for 28% of the total production, while in a normal year, early season growth accounted for 60% of the total production.

Biomass yields of WSG species can be affected by soil fertility, particularly nitrogen and phosphorus. Brejda et al. (1995) documented that indiangrass forage yields increased with increasing N rates up to 168 kg N ha^{-1}. Big bluestem yields peaked with fertilization between 101 to 161 kg N ha^{-1} depending on year. Similarly, Stout (1992) found increased N fertilization increased yields on soils that were naturally low in N. However, it was also found that N application rates did not affect biomass yields in soils that had high native N levels. The application of 50 kg N ha^{-1} increased yields of eastern gamagrass (*Tripsacum dactyloides* L.*)* by 44%, and an additional 15% yield increase was observed with an application of an additional 50 kg N ha^{-1} over a five year period in Kansas (Moyer and Sweeney, 2008).

Seeded perennial WSG research in western Kansas has consisted mostly of seedling establishment trials (Launchbaugh and Anderson, 1963) and grazing animal production trials (Launchbaugh, 1971). Propheter et al. (2010) compared different dedicated energy crops in Kansas. They reported that total biomass yields were greatest for sweet sorghum [*Sorghum bicolor* L. (Moench.)] in 2007 and 2008. However, they also noted that biomass yields of perennial WSG greatly increased between 2007 and 2008 and that production may continue to improve overtime. The continued investigation of WSG over the long-term may prove them to be competitive with row crops. Furthermore, recent production potential of annual WSG in western Kansas has been well documented (Roozeboom et al., 2005), but comparisons of summer annual and perennial WSG production and water use efficiency in western KS are lacking. This justifies the need for additional long-term comprehensive investigation of dedicated energy crops in the region.

Biofuel Quality

The two major concerns surrounding dedicated energy crops in the United States are net energy efficiency and economic feasibility. However, long-term production data of perennial herbaceous plants grown and managed as a bioenergy crop is limited when compared with other production crops such as corn (Schmer et al., 2007). Continued research, along with genetic and management progress of dedicated energy crops, will ultimately determine if dedicated energy crops are a viable option.

As previously stated, a majority of dedicated energy crop production is planned to take place on marginal lands where they may become more economically competitive with other cropping systems. Varvel et al. (2008) reported that the potential ethanol yield of switchgrass was greater than the potential of corn grain and harvested stover when they were fertilized at the same rate on marginal land. However, ethanol yields of switchgrass can be sensitive to climatic conditions, stand age, and agricultural inputs (Schmer et al., 2007). Furthermore, harvest date and maturity can affect ethanol production of WSG. By allowing senescence to occur before harvesting aboveground biomass, a producer can greatly reduce the percentage of winter kill, improve N conservation, and improve feedstock quality (Parrish, 2007). Adler et al. (2006) observed a 40 % decrease in switchgrass yield when harvest was delayed until spring. Approximately 90% of the yield reduction was due to biomass being left behind rather than a reduction in tiller mass. However, Adler et al. (2006) also observed that some biofuel quality parameters, such as carbohydrate concentrations, improved with delayed harvest. This increase in quality is attributed to the loss of seeds and the leaching of soluble components.

Forage Quality

Ruminant animal production is an important part of Untied States agriculture since it supplies the nation with value added animal products. The driving force of efficient, domesticated animal production depends on the quality of the animal feed (Burns, 2008). Worldwide, a majority of cattle meet their energy requirements from rangeland, pasture, and other sources of forage (Craine et al., 2010). In the central Great Plains, a variety of warm and cool-season grasses, along with improved forages, are used as feedstuffs for these ruminants (Craine et al., 2010). Warm-season grasses complement other forages as they can provide valuable forage during summer (Vogel, 2004). Increased forage yield and digestibility of WSG makes them a potential dual purpose crop, forage and biofuel, which may encourage more producers to convert row crop acres to seeded WSG.

Healthy ruminant production is dependent on a diet that meets the animal’s digestible energy and digestible protein requirements while providing a balance of minerals and vitamins (Blaser, 1964). Forage quality of grasses used for animal consumption, both grazed and fed, is an important component to a profitable operation. If forage quality is not adequate, supplemental feed is required and economic gains can be reduced (Craine et al., 2010). The nutritive value of forages primarily depends on the morphological development of a grass at the time of harvest (Moore and Moser, 1995; Blaser, 1964). As plants grow to maturity, they generally decline in digestibility. Twidwell et al. (1988) observed that late season harvested switchgrass showed a decline in forage quality when compared with switchgrass that was harvested at flag leaf stage. Launchbaugh (1971) found switchgrass to have the highest crude protein of WSG during June, July and August. Additionally, Anderson et al. (1988) demonstrated that yearling cattle preferred to top graze switchgrass prior to the boot stage, and the cattle avoided grazing reproductive plants in preference to plants still in vegetative stages. Even though plant maturity is often used to predict forage quality parameters, growth and morphological development of WSG can change when grown in drier climates. Harmoney and Hickman (2004) demonstrated that big bluestem displayed a different development curve in western Kansas compared to eastern Kansas or Nebraska.

Summary

It is apparent that the establishment and production of dedicated energy crops will be essential to meet the demands of future biofuel production. Furthermore, a majority of the land likely to be used for biofuel production will be marginal or degraded lands where they are capable of producing ethanol yields equivalent to corn (Varvel et al., 2008). Low agronomic inputs and the ability to get yields from marginal lands may make dedicated energy crops profitable in some situations (Bransby et al., 2005). Perennial WSG have also been proven to be a valuable livestock feed, in addition to a biofuel feedstock (Craine et al., 2010). The duality of these crops can provide producers additional marketing options and ultimately increase their economic viability. In addition to feedstock benefits, perennial WSG can improve soil physical properties, organic carbon, and water capture, and can reduce soil losses due to wind and water erosion (Blanco-Canqui, 2010). In the long-term, the establishment of perennial crops on degraded lands may be capable of reclaiming these lands back to past productivity. However, stand establishment, initial soil quality, and annual precipitation all can greatly affect the economic viability of these crops. Continued research is needed to fully understand the capabilities and limitations of dedicated energy crops, particularly on a regional scale.

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Chapter 2 - Soil Hydraulic Properties and Organic Carbon

Abstract

Indiscriminate crop residue removal for biofuel production may negatively impact soil hydraulic properties. However, dedicated bioenergy crops, such as warm-season grasses (WSG), may improve soil hydraulic properties, increase soil organic carbon (SOC) storage and generate biomass feedstock for biofuel production. Experimental data are, however, few. Our objectives in this study were to quantify the impacts of growing WSG on water storage, soil physical and hydraulic properties, soil organic carbon (SOC) dynamics as compared with row crops and determine the most adaptable WSG species to dryland conditions. Differences in bulk density, water retention, infiltration and SOC were not generally significant. However, WSG had a higher mean weight diameter (MWD) of wet aggregates than soils managed as row crops. Additionally, WSG had higher amounts of macro-aggregates (>4.75 mm) and a lower proportion of micro-aggregates (<0.25 mm), suggesting that WSG can improve soil structural quality. Furthermore, results of field soil water content suggested that the established root system of perennial crops may allow plants to access moisture in deeper soil profile and accumulate biomass in spite of limited and inconsistent precipitation events. The limited or no effects of WSG on soil hydraulic properties and SOC and N concentration in this study were somewhat surprising, particularly for the long-term study at the Manhattan site, which had been established for five growing seasons. Further monitoring is warranted to assess long-term impacts soil quality and agricultural sustainability.

Introduction

Biomass production, across the central Great Plains, is commonly limited by climate and soil quality (Aandahl A., 1982). Productivity of dryland agriculture in the central Great Plains is driven by how much precipitation is received during the growing season and how efficiently the precipitation is retained and used (Stone and Schlegel, 2010). Soil physical properties such as aggregate stability, pore size distribution, infiltration and water retention affect the water use relationship between plants and soil (Blanco and Lal, 2008). Soil infiltration in semi-arid regions is crucial to crop production as it determines precipitation capture. Studies have shown that warm-season grasses (WSG) can improve infiltration, saturated hydraulic conductivity and reduce bulk density when implemented as a stiff stemmed hedge or riparian buffers (Rachman et. al 2004, Bharati et al., 2002). However, these previous studies were conducted on switchgrass (*Panicum virgatum* L.) hedges used as conservation buffers and not on dedicated WSG systems.

Current research on feedstocks for bioenergy I spredominantly focused on (i) developing technologies for conversion of cellulosic feedstocks into ethanol, and (ii) increasing production of biomass (Blanco-Canqui, 2010). Few studies have quantified WSG effects on soil physical and hydraulic properties, particularly when managed as a dedicated energy crop. Karlen et al. (1999) reported that dedicated native WSG stands improved soil physical properties when managed under the Conservation Reserve Program (CRP). However, soil physical properties effects of CRP lands may respond different than dedicated energy crops, as harvest of the biomass is restricted on CRP lands. Douglas et al. (1992) documented that increased traffic of harvest equipment on dedicated energy crops can increase bulk density and affect pore size. Even with increased harvest traffic studies indicate that WSG can improve soil quality compared to annual row crops. Blanco-Canqui et al. (2005) reported that soils managed under switchgrass had lower aggregate density and the ability to retain significantly more moisture than soil managed under row crops in southeastern United States. However, variable soil and climate conditions warrant regional studies across the Great Plains to quantify soil effects of WSG species.

Potential of WSG for improving soil organic carbon (SOC) is receiving unprecedented attention. Organic matter decline is the major cause of soil degradation as SOC concentrations impact soil physical and hydraulic properties (Stewart et al., 1991). Returning cultivated lands back to native WSG species has the potential to be a carbon positive system (Karlen et al., 1999). Lands managed under WSG have the potential to increase SOC concentrations by as much as 33% when compared with lands managed in row crop production (Sanderson 2008). However, past SOC results on lands managed under dedicated energy crops have been mixed and are dependent on time, climate and original SOC levels (Zan et al., 2001; Ma et al., 2000). These inconsistencies warrant regional assessments of SOC sequestration by WSG.

Impacts of WSG on soil physical properties are often inconsistent, depending on management length, grass species, harvest frequency, soil type, and climate (Schwartz et al., 2003). This justifies the assessment of WSG on a regional scale across different soil types and climatic conditions. This study was designed to quantify the effects WSG have on soil carbon and soil physical and hydraulic properties when managed as dedicated biomass production systems in three different moisture regimes.

Materials and Methods

Field Experiment Locations and Treatments

This study was conducted during the initial phase of three long-term energy crop experiments in Kansas. The experimental sites were located at (1) the Kansas State University (KSU) Northwest Research-Extension Center in Colby Kansas (39º23’N, 101º03’W), (2) the KSU Agricultural Research Center in Hays Kansas (38º52’N, 99º19’W), and (3) the KSU Agronomy Research Farm at Manhattan (39º11’N, 96º35’W). The duration of this study is from August 2010 through April 2012. Soil types of each location were a Keith silt loam (fine-silty, mixed, super active, mesic Cumulic Hapludolls) at Colby, a Harney silt loam (fine, smectitic, mesic Typic Argiustolls) at Hays and a Kahola silt loam (fine-silty, mixed, super active, mesic Cumulic Hapludolls) at Manhattan. The three sites were primarily selected due to the differences in historic mean annual precipitation. Historic mean annual precipitation included 465 mm at Colby, 579 mm at Hays and 838 mm at Manhattan respectively (High Plains Regional Climate Center).

The study designed is a randomized complete block experiment with four replications at Manhattan and three replications at Colby and Hays. In Manhattan, the individual plot size was 6.1 m wide by 10.7 m long and the dimensions of the plots at Colby and Hays were 6.1 m wide and 6.1 m long. The experiment at Manhattan was established in 2007 and consisted of three perennial warm-season grasses (‘Kanlow’ switchgrass, big bluestem (*Andropogon gerardii* L.),, and miscanthus (Miscanthus × giganteus)), two native grass mixtures (indiangrass (*Sorghastrum nutans* L.) /switchgrass/big bluestem mix and a switchgrass/big bluestem mix), corn (*Zea mays* L.) grown continuously and rotated with soybean, and three sorghum (Sorghum bicolor L. [Moench.]) cultivars (photoperiod sensitive, sweet, and grain sorghum) in rotation with soybeans(*Glycine max* (L.) Merr.).

The corn hybrids grown at Manhattan in 2010 and 2011 were Pioneer ‘33K40’ (Bt) and Pioneer ‘33K44’ (Bt), respectively, both of the same parent family with relative maturity of 114 days (Pioneer Hi-Bred International, Johnston, IA). Sorghum cultivars included Land O’Lakes ‘DKS59-09’ (Land O’Lakes, St. Paul, MN) DP FS, Mississippi State University ‘M81E’ sweet sorghum, Sorghum Partners ‘NK300’ (Sorghum Partners, Inc., New Deal, TX) DP FS, and Sorghum Partners ‘1990CA’ PS sorghum. The soybean variety planted at Manhattan both study years for rotational purposes was KSU Foundation ‘KS3406RR’ (Kansas State Univ., Manhattan, KS).

The experiments at Hays and Colby were established in spring 2009 and consisted of two varieties of switchgrass (‘Pathfinder’ and ‘Blackwell’), indiangrass, big bluestem, sand bluestem [*Schizachyrium scoparium* (Michx.) Nash], eastern gamagrass (*Tripsacum dactyloides* L.*)* mixed native grasses, miscanthus, forage sorghum, grain sorghum, and no-till wheat (*Triticum aestivum* L.)-sorghum-fallow (W-S-F) with (100%) and without (0%) residue removal.

Establishment of WSG stand in Colby and Hays was challenging as low annual precipitation (Figure 2.5) and high weed pressure limited growth of young plants. In 2011, select plots were abandoned at Colby which included the Pathfinder switchgrass, indiangrass, big bluestem, sand bluestem, eastern gamagrass and mixed native grass treatments. Additionally, annual row crops production was also reduced or eliminated during this time period at Colby and Hays due to lower than average annual rainfall and concentrated animal pest pressure. During the

2011 growing season, proper weed control at Colby and Hays improved stand quality and biomass production. This was accomplished by applying 0.56 kg ha^{-1} of quinclorac herbicide pre-emergence to the spring 2011 growing season. Additional herbicide applications of Starane (flurozypyr), 0.56 kg ha^{-1}, and 2, 4-D dimethylamine [(2, 4-dichlorophenoxy) acetic acid] 0.56 kg ha^{-1} were applied at the three leaf stage. Hand weeding with the use of hand clippers was also done as necessarythroughout the growing season both years.

Weather Monitoring

Each study location was located near a Kansas State University Research and Extension weather station. Daily precipitation totals were monitored and total monthly precipitation accumulation was calculated to monitor yearly precipitation distribution in addition to total annual precipitation. All data were downloaded from the Kansas State University Research and Extension Weather Data Library.

Bulk Density

Bulk density was determined at the end of the growing season at Colby and Hays in 2010 and before the growing seasons in 2011 and 2012 (Table 2.1) at all locations. All treatments were sampled minus the abandoned treatments in Colby. This was accomplished by collecting intact soil cores that were 7.5 cm in diameter to a depth of 7.5 cm using a Uhland soil sampler (Uhland, 1949).

Infiltration

Infiltration was determined on all treatments at all sites in the spring of 2011 (Table 2.1), except for Colby where the abandoned treatments were not measured. Infiltration was measured using a schedule 40 Polyvinyl Chloride (PVC) single-ring infiltrometer (Rachman et al., 2004) with a 20 cm inside diameter. Prior to the ring insertion, the soil surface was prepared by cutting the grasses level with the soil surface. The ring was carefully inserted vertically into the soil to the 15 cm depth with a custom made hammer tool to reduce soil surface disturbance. During the duration of the test, a constant head of 25 mm was maintained in the infiltrometer using a Mariotte bottle system (Figure C.1). The Mariotte bottles were 1 m in height 15.25 cm in diameter and constructed out of schedule 40 PVC. Sewer caps were secured at both ends using PVC primer and cement to close the system. Two holes were drilled in the top of the bottle one 4.0 cm in diameter and one 3.5 cm in diameter. A #6 rubber stopper, with a 1.25 m long acrylic tubing (0.635 cm outside diameter x 0.3175 cm inside diameter) through the middle, was placed in the 3.5 cm diameter hole. This apparatus was used to control the head of the infiltrometer by adjusting the location of the acrylic tubing. The 4.0 cm diameter hole was used as a water filling port and a #9 rubber stopper was placed in the hole during the test to close the system. The bottle was equipped with a 1.25 cm nylon fitting at the bottom for an outlet. Additionally, a water level gauge was constructed by placing two 1.25 cm 90^o nylon fittings 90 cm apart from each other and connected them by a piece of tygon tubing. Infiltration test were conducted for 180 minutes, with readings taken at various time intervals. Readings were taken at 0, 1, 2, 3, 4, 5, 10, 20, 40, 60, 90, 120, 150, and 180 minutes. The electrical conductivity of the water used was 0.6 dS m^{-1} at Colby, 1.8 dS m^{-1} at Hays, and 0.4 dS m^{-1} at Manhattan. The sodium adsorption ratio (SAR) was 1.98 at Colby, 1.28 at Hays and 1.22 at Manhattan.

Water Retention

Intact soil cores were collected before the growing season in 2011 and 2012 (Table 2.1). All plots were sampled except for the abandoned plots at Colby during the spring of 2012. Intact samples were collected using a Uhland type soil sampler (Uhland, 1949). Samples were collected for the surface layer (0- to 7.5 cm depth) using aluminum, brass and PVC rings that were 7.5 cm in diameter and 7.5 cm tall. Once the ring was inserted to the proper depth, it was then excavated, trimmed and stored in an air tight bag. Cores were placed in a cool room that maintained a temperature of 4^o C between sampling and lab analysis.

Prior to each sample set, a layer of cheesecloth was placed on the bottom of each undisturbed core and was held in place using rubber bands. Initial saturation of the cores was accomplished by placing the cores in a plastic container resting on a rubber mat to allow for the cores to wet from the bottom. A 1 mM $CaCl_2$ solution was used to prevent dispersion of clays in the sample (Klute, 1986). The solution was slowly delivered using a Mariotte bottle to achieve a solution level that was approximately equal to the height of the soil core. The solution level was maintained and the cores were allowed to saturate for a 24 hour period. The soil cores were then removed and allowed to drain in a separate container until a majority of the drainage ceased. Samples were then weighed to determine saturated volumetric water content.

The samples were then placed on a tension table to determine the volumetric water contents at the 0.5, 1.0, 3.0, and 6.0 kPa pressure steps. The tension table was constructed by the KSU Physics Research Machine Shop from 1/2” clear polycarbonate plastic. Each joint of the table was bonded together using “weld on #3” fusion agent. For additional support, eight #32 stainless steel flat head screws were placed equally across all joints. Nine modified brass bulk head fixtures, placed in a grid pattern of 19 cm, were used as outlets. Bulk head fittings were constructed from brass threaded nipples, brass retaining nuts, and a brass 0.635 cm barbed hose fitting. A water proof seal was obtained by the use of Buna-N O-rings on each side of the bulk head. A 0.5 mm woven brass screen was placed on the top of each bulk head fitting to prevent debris from collecting in the system. The system was plumbed using 0.50 cm ID by 0.80 cm OD tygon tubing (Saint Gobain Performance Plastics, Strongsville, OH) connected to a volumetric flask to create a hanging water column (Topp and Zebchuk, 1978). Soil cores were allowed to equilibrate for 2 days at each pressure step, before being weighed and moved to the next pressure step. In an attempt to reduce evaporation losses, a Plexiglas lid was placed over the samples. Furthermore, the laboratory air temperature was maintained constant to eliminate water density and surface tension changes, since water surface tension value changes 0.2% for each degree in temperature change (Danielson and Sutherland, 1986).

Water retention at pressures of 10, 33.3 and 500 kPa, and 1.5 MPa was measured with ceramic plates and a high-pressure apparatus (Klute, 1986). Undisturbed soil cores were used for the 10 and 33.3 kPa samples. The cores were placed on a 1-bar ceramic plate (Soil Moisture Equipment Corp., Santa Barbara, CA) immediately after the samples were removed from the tension table and placed in a pressure chamber. Equilibration times of 4 days were used for both the 10 and 33.3 kPa pressures. After the soil core mass was obtained at the 33.3 kPa pressure step the soil cores were removed from the ring, weighed and placed in a 105^{o}C oven for a 24 hour period. After the drying period soils, were then re-weighed and then passed through a 2 mm sieve. The dry sieved soils were used to obtain water retention at the 500 kPa and 1.5 MPa pressures. Samples were packed into rubber rings that were approximately 1 cm tall and 5 cm in diameter. Samples were then saturated using a 1 mM $CaCl_2$ solution. Samples were kept in the solution for a 24 hour period before being placed in the pressure apparatus. A 5-bar ceramic plate (Soil Moisture Equipment Corp., Santa Barbara, CA) was used for the 500 kPa measurement and a 15-bar ceramic plate (Soil moisture Equipment Corp., Santa Barbara, CA) was used for the 1.5MPa measurement. A 15-bar extractor (Soil Moisture Equipment Corp., Santa Barbara, CA) was used for both the 500 kPa and 1.5 MPa sample. A 7 day equilibrium time was used at both the 500 kPa and 1.5 MPa pressures. After removal from the pressure apparatus, samples were weighed, dried in a 105^{o} C oven for a 24 hour period and reweighed to determine gravimetric water content. All values were converted to volumetric water content using the bulk density values from the undisturbed samples.

Field Water Content

Soil moisture measurements were collected in Manhattan using a neutron probe (503 DR Hydroprobe Moisture Gauge, CPN International, In., Martinez, CA). Readings were recorded at 15 cm depth increments to a total depth of 2.0 m. Access tubes were placed in the center of the plot, in between rows of the planted crop, approximately 2 m from the edge of the plot. Due to a high water table present at the site, PVC access tubes were installed instead of traditional aluminum tubes. Access tubes were 2.5 meters in length and constructed from unscreened, schedule 40 PVC with an OD of 4.82 cm and ID of 4.06 cm. In an effort to keep water from entering the access tubes; a fabricated well point, constructed from solid PVC rod, was secured at one end using PVC primer and cement. All parts for the PVC access tubes were custom fabricated (Environmental Manufacturing Inc., Manhattan, KS) to specifications. The PVC access tubes were installed in select plots using an undersized pilot hole that was made with a Giddings Soil Probe (Giddings Machine Company Inc.; Windsor, CO). Access tubes were started down the pilot hole by striking the well point of the access tube with a solid steel rod.

The Giddings Soil Probe was then used to push the access tube until only 15 cm of the access tube was left above the surface. To ensure maximum soil contact and reduce the risk of water running down the side of the access tubes, No. 16 bentonite chips were placed at the top of the tube. A dummy probe was inserted down each access tube to test the integrity of the well-point and well casing joint and that no free water was present. This step was repeated each sampling period, prior to inserting the neutron probe. Once the access tubes were installed, soil moisture readings were taken approximately every 2 weeks from May until November. Standard counts were recorded at the beginning and completion of each sample period. A mean standard count was used to calculate the count ratio (CR) from each tube-measured count (CR=measured count/mean standard count). The factory calibration equation with a factory adjustment for PVC access tubes ($\theta = 0.2929CR - 0.01170$) was used to calculate volumetric water content (θ).

Continuous soil moisture measurements were recorded in Hays, using Sentek EnviroScan (Sentek Technologies Stepney SA 5069Australia) soil moisture probes. Similar to the neutron probe, the EnviroScan sensors used schedule 40 PVC access tubes. The bottom of each PVC access tube was equipped with a metal cutting ring to ease insertion into the ground. Each access tube was installed using the drop-hammer method to maximize contact between the soil and the tube wall. Soil was removed from the inside of the tubes with an auger until the probes were driven to the proper depth. The bottom of the access tube was then sealed using a double-ringed expandable rubber bung which provided two sealing points to prevent underground moisture from entering the tube. Manufacture calibrated soil sensors were placed in the access tubes at the 10, 20, 50, and 100 cm depths and were connected to a Sentek RT6 data logger. A flexible plastic conduit was placed around the data-logger cord as a pest deterrent. However, this did not fully work as jackrabbits (*Caprolagus hispidus*) were capable of chewing through the plastic guard and cable, which disrupted soil monitoring. A variety of tactics were developed to reduce rodent disturbance including the installation of thicker conduit and metal fencing. The top of the access tubes were sealed using a screw cap that was provided by the manufacturer. The soil sensors were then identified and programmed using data editor software(Sentek Technologies Stepney SA 5069Australia) that was previously loaded to a laptop computer. Soil moisture data were downloaded in a CSV format using IrrMAX software that was purchased from the soil probe manufacture.

Wet Aggregate Stability

Composite samples were collected in August 2010, from the three replications for baseline measurements, at Colby and Hays only. Additional soil samples were collected at the beginning and end of the growing season between 2010 and 2012 (Table 2.1). Soil was collected from random locations within each plot from the 0-7.5 and 7.5-15 cm depths and placed in bags.

The soils were then allowed to air dry for 72 hrs, after which it was sieved to obtain aggregates that were 8.00 to 4.75 mm diameter in size. Size distribution of water-stable aggregates (WSA) was determined by wet sieving (Kemper and Rosenau 1986) with a machine that moved a nest of six sieves through a vertical displacement of 37 mm at 30 cycles min^{-1}. Each sieve had a diameter of 127 mm and depth of 40 mm with screen openings of 4.75, 2.00, 1.00, 0.50, and 0.25 mm. A 50 g sample was placed on the top sieve of a nest, immersed in tap water, soaked for 10 min, and sieved in water for 10 min. After sieving the material retained on each sieve was place in a 105°C oven to dry. Oven-dry material from each sieve after sieving was determined. Water stable aggregates were determined by the following equation;

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

where m_m is dry mass of material on a sieve after sieving, m_f is dry mass of fragments on the same sieve after dispersion, and m_t is total sample dry mass. The mean weight diameter (MWD) of WSA was calculated as:

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

where wi represents the dry mass of aggregates (w_1 through w_5) determined for each of the five sieve sizes (aggregates and fragments after sieving [mm] minus fragments on the same sieve after dispersion [m_f]) and dry mass (w_6) of material passing through the sieve with 0.21mm openings during sieving (Kemper and Rosenau, 1986), x_i represents mean diameter of each of the six size fractions (size of smallest fraction [x_6] was calculated as 0.21 mm/2), and ma is total dry mass of aggregates (sum of w_1 through w_6).

Total Carbon and Nitrogen

Bulk soils samples were collected in the fall 2010 at Colby and Hays from the 0.0 to 5.0 cm and 5.0 to 10.0 cm depths and in spring 2012 from the 0.0 to 7.5 and 7.5 to 15.0 cm depths at all sites. After collection, soils were air dried and sieved to pass through a 0.25 mm sieve. The ground sample was then used to analyze total C and N by combustion using a LECO TruSpecCN analyzer (LECO Corp., St. Joseph, MI). The reported C and N percentages along with measured bulk density values were used to calculate the mass of C and N, in megagrams per hectare.

Statistical Analysis

Data were statistically analyzed using PROC Mixed in SAS 9.2 (SAS Institute 2008). Least square differences were used to determine differences at the 0.05 probability levels (SAS Institute, 2008). Significance of main effect differences and their interactions was determined, with species as the fixed effect and replication as random effects.

Results and Discussion

Wet Aggregate Stability

Bioenergy crops affected wet aggregate stability at all sites, but effects varied with sampling periods and soil depths (Table 2.2 through 2.12). Treatment effects were greatest in Manhattan where aggregate stability changes were observed at both depths (0 to 7.5 cm and 7.5 to 15 cm) during all sampling periods. These results are reasonable as the earlier establishment date and higher biomass production potential due to higher precipitation has given the perennial grasses a maturity advantage.

In spring 2011, the indiangrass mixture (31.5%) had more large aggregates (>4.75 mm) near the soil surface than grain sorghum (2.4%) (Table 2.10). At the lower depth, Kanlow switchgrass (16.4%) had the highest amount of >4.75 mm aggregates, while the photo period sorghum (0.7%), sweet sorghum (0.7%) and grain sorghum (0.6%) had the least (Table 2.10). Furthermore, at the soil surface mean, weight diameter of aggregates (MWD) values for Kanlow switchgrass (2.1 mm), miscanthus (1.9 mm) and indiangrass mixture (2.6 mm) were two times greater than all row crop treatments (Figure 2.8). Differences at the 7.5 to 15 cm depth were most noticeable for miscanthus (1.6 mm) and Kanlow switchgrass (1.2 mm; Figure 2.8).

In fall 2011, at Manhattan, MWD values for the WSG continued to be up to two times higher than the row crop treatments at both depths (Figure 2.8). Differences in large aggregates were not, however, observed at the soil surface due to high sample variability (Table 2.11). At the lower depth, Kanlow switchgrass (24.5%) and switchgrass mix (26.3%) had the highest amount of large aggregates >4.75 mm, while the photo period sensitive sorghum (1.9%) had the least (Table 2.11). In spring 2012, indiangrass mix (26.8%) and miscanthus (19.4%) had more>4.75 mm aggregates compared with continuous corn (9.1%) and sweet sorghum (8.6%) (Table 2.12). Similarly, surface MWD for switchgrass mix (2.4 mm) and miscanthus (2.3 mm) was nearly twice as high compared with continuous corn (1.3 mm (Figure 2.8). These data show that after five years of establishment, perennial WSG species improved soil structural properties compared with annual row crops. However, differences among WSG species can vary depending on sampling period and sample depth.

At Hays, differences in aggregate stability became more distinct over the course of the study (Figure 2.7). During fall 2010, Blackwell switchgrass (1.59 mm) had three times greater MWD than W-S-F 0% removal treatment (0.49 mm) at the 0 to 5 cm depth (Figure 2.7 andTable 2.6). Despite the poor performance of the WSG treatments during the 2010 growing season, the continuous cover combined with the extensive root systems under WSG positively impacted soil quality near the surface. Treatment effects were also observed during the spring 2011 sampling period at the 0 to 7.5 cm depth (Figure 2.7 and Table 2.7). The WSG had two times greater MWD (Figure 2.7) and 10% more large aggregates (>4.75 mm) than annual row crops (Table 2.7). Furthermore, at the 7.5 to 15 cm depth, Blackwell switchgrass (7.2%) had more large aggregates (>4.75 mm) than grain sorghum (1.6%) and sweet sorghum (1.0%). The continuous cover under WSG probably improved soil properties by minimizing the impacts of freeze- thaw events. Also, a more productive 2011 growing season, due to proper weed control, increased soil quality benefits from WSG treatments. All of the WSG species, except for miscanthus, had higher MWD values than annual row crops during both fall 2011 and spring 2012 (Figure 2.7). The greatest differences were observed at the surface. Additionally, Blackwell switchgrass (18.5 %) had 17% more large aggregates than the W-S-F with and without removal at the soil surface while eastern gamagrass (9.4%) had 9% more large aggregates than row crops at the lower depth during fall 2011 (Table 2.8).

Limited soil aggregate stability improvements under miscanthus in Hays can be attributed to the poor performance despite proper weed control. Unlike the miscanthus at the Manhattan location, the miscanthus in Hays has been unable to increase plant density through the spread of rhizomes. However, results suggest that as grass stands mature the soil quality benefits can be amplified.

The experiment in Colby showed differences in MWD only during the spring in 2012 at the 7.5 to 15 cm depth (Figure 2.6). However, these differences are most likely due to spatial and sampling variability as no other differences were observed. The establishment and success of grass species at Colby was more difficult than at other sites. The lack of production and poor stand quality can explain the limited treatment effects at this site.

Bulk Density Soil Water Retention and Infiltration

Treatment effects on bulk density were inconsistent at all sites. Similar to bulk density, treatment effects on soil water retention and water infiltration were non-significant. Infiltration data at all locations were highly variable, which limited the ability to conclude whether or not there were differences attributable to the treatments. These results are similar to those reported by Nyakatawa et al. (2006), who found no differences in water infiltration between dedicated switchgrass and no-till corn. However, our results contrast with those reported by Bharati et al. (2002) and Rachman et al. (2004) who reported higher water infiltration under switchgrass hedges and buffer strips than under row crops. Differences in length of switchgrass establishment and plant densities may explain the inconsistentcy between the present study and other studies.

Field Water Content

Neutron probe data at the Manhattan site allowed for the observation of water use trends during the 2011 growing season. Early season water use was highest under WSG species, particularly miscanthus (Figure 2.9). However, the WSG species accumulated a majority of their biomass by midsummer which reduced late season water use. By August, the annual row crops had the lowest soil water contents as the demand for water increased (Figure 2.10). By late September, the soil water content under corn began to recharge due to reduction in water use (Figure 2.10). During this period, the photo period sensitive sorghum continued to use water and display the lowest moisture contents across the profile. Similar trends were observed at the beginning of 2012 (Figure 2.11). However, an accidental herbicide application on May 9th increased the variability in water use data and limited observed effects.

Similar to the Manhattan site, the Sentek soil moisture probe data at Hays showed significant water use trends. Early season soil moisture was lowest for the Blackwell switchgrass and W-S-F 100% residue removal treatments (Figure 2.12). However, by August, the sweet sorghum had the lowest soil water content values (Figure 2.12). In August 2011, the sweet sorghum experienced excessive drought stress which caused complete stand failure. This failure caused the sweet sorghum treatment to act similar to the fallow treatment for the remainder of the growing season (Figure 2.13).

The ability of a plant to efficiently use water resources correlates with the potential of the soil to capture and store water; therefore, monitoring soil water content is essential for understanding water use and timing of different plant species. Establishing species that can use water when it is available is important particularly in the central Great Plains where low precipitation amounts and sporadic precipitation events occur. From these data, it is evident that perennial WSG have the ability to utilize stored moisture and early season precipitation to accumulate biomass.

Total Carbon and Nitrogen

Soil C and N concentration was measured in the fall of 2010 at Colby and Hays, and in spring 2012 at all sites. Two sample depths were analyzed each sample period and included the 0 to 5 cm and 5 to 10 cm depths in fall 2010 and the 0 to 7.5 cm and 7.5 to 15 cm depths in spring 2012. Sample depths were switched between fall 2010 and spring 2011 in order to match depths of other sampling procedures. Differences in soil C and N concentration among treatments were highly variable and not significant at any site. Even after five years of management at Manhattan WSG had no significant effects on SOC and total N relative to row crops. The high variability in SOC data at Manhattan was most likey due to inherent variability within the soil. The site is located near a stream and is regularly flooded. As an example, in June 2011, a rainfall event produced over 12 cm of precipitation in a 24 hour period which flooded the study site and moved residues. Results were again somewhat surprising but not unexpected considering the short-term management of WSG (five years at Manhattan and three years at Hays and Colby).

Conclusions

This study indicated that WSG species may improve some soil properties even in the short term (three to five years post-establishment). Perennial WSG improved soil structural stability but had no effects on water infiltration, water retention characteristics, and SOC and N concentration. Results of field soil water content suggested that the established root system of perennial crops may allow plants to access moisture deeper in the soil profile and accumulate biomass in spite of limited and inconsistent precipitation events. The limited or absent effects of WSG on soil hydraulic properties and SOC and N concentration in this study were somewhat surprising, particularly for the Manhattan site. Results suggest that impacts of WSG on some soil properties can be inconsistent, depending on management length, grass species, harvest frequency, soil type, and climate (Schwartz et al., 2003; Pikul et al., 2006; Nyakatawa et al., 2006). We hypothesize that the increased aggregate stability shown by the WSG will improve soil hydraulic properties in the long-term.

Figures and Tables

Figure 2.1 Location of the study sites within the precipitation gradient of Kansas.

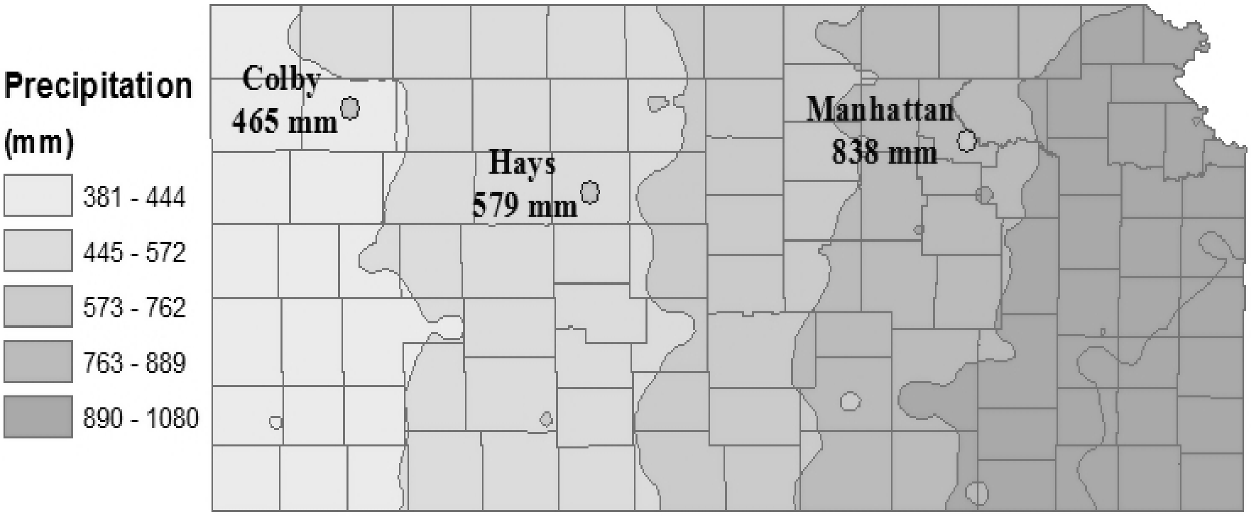


Figure 2.2 Plot layout of energy crops at Colby.

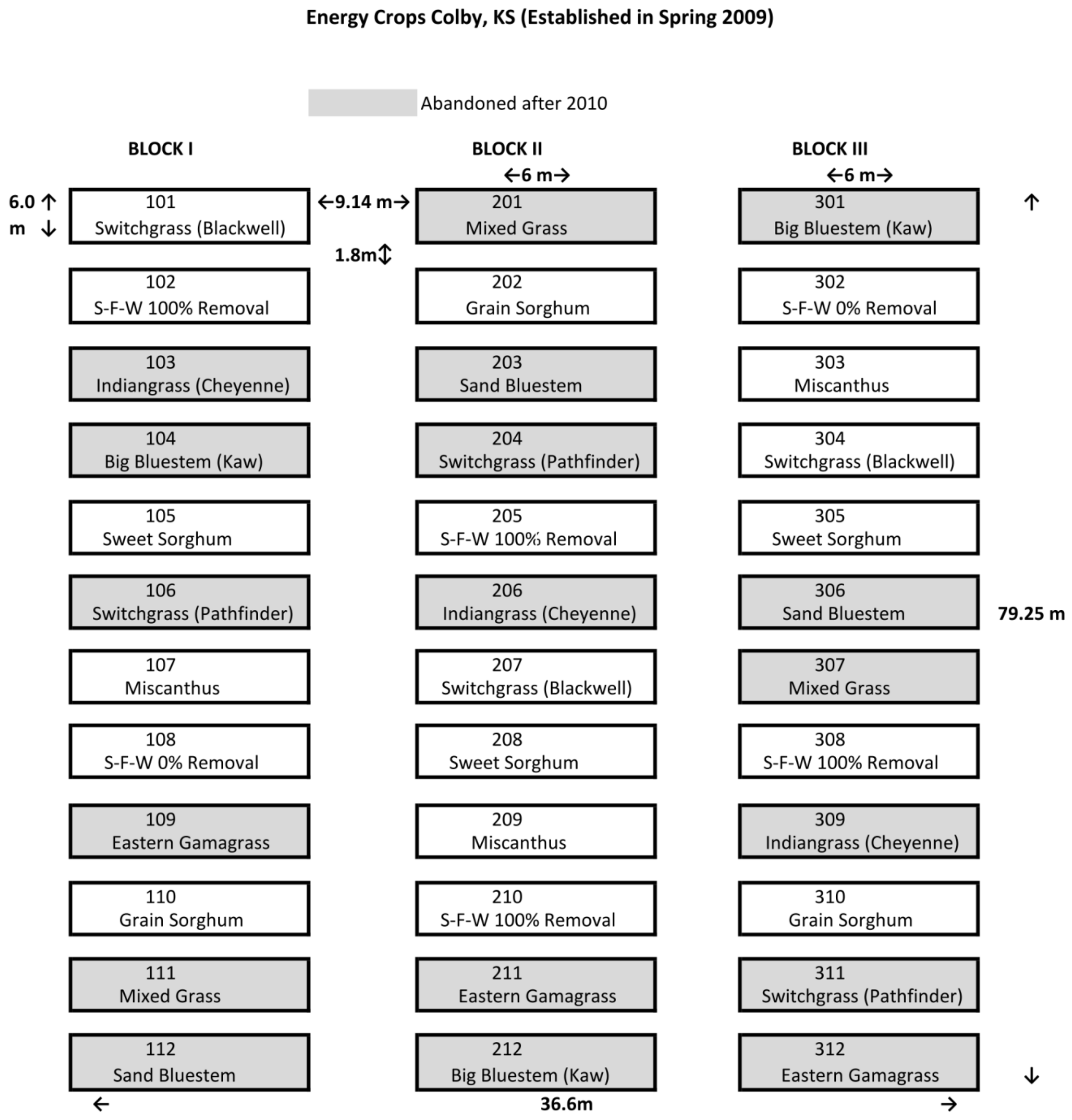


Figure 2.3 Plot layout of energy crops at Hays.

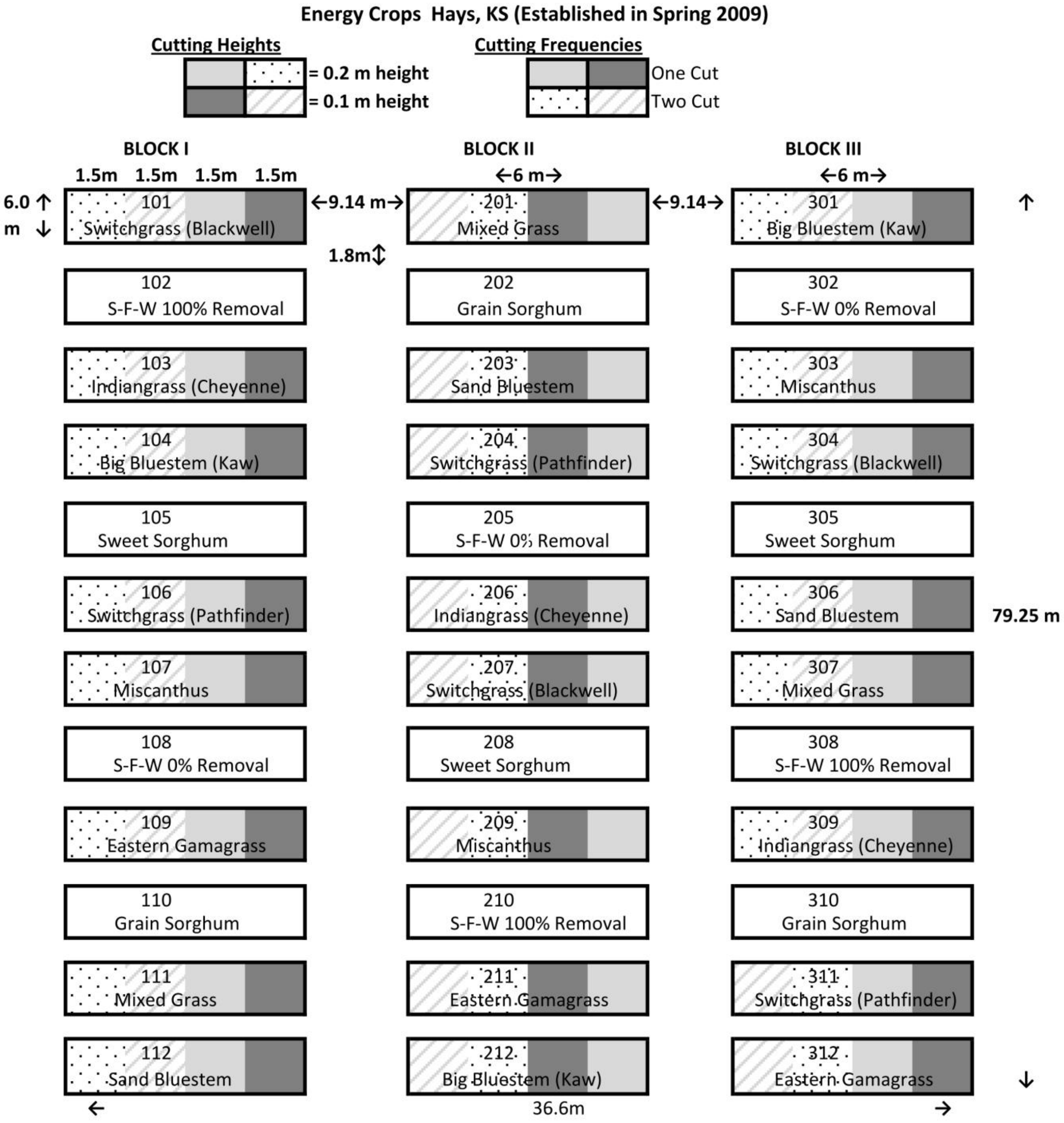
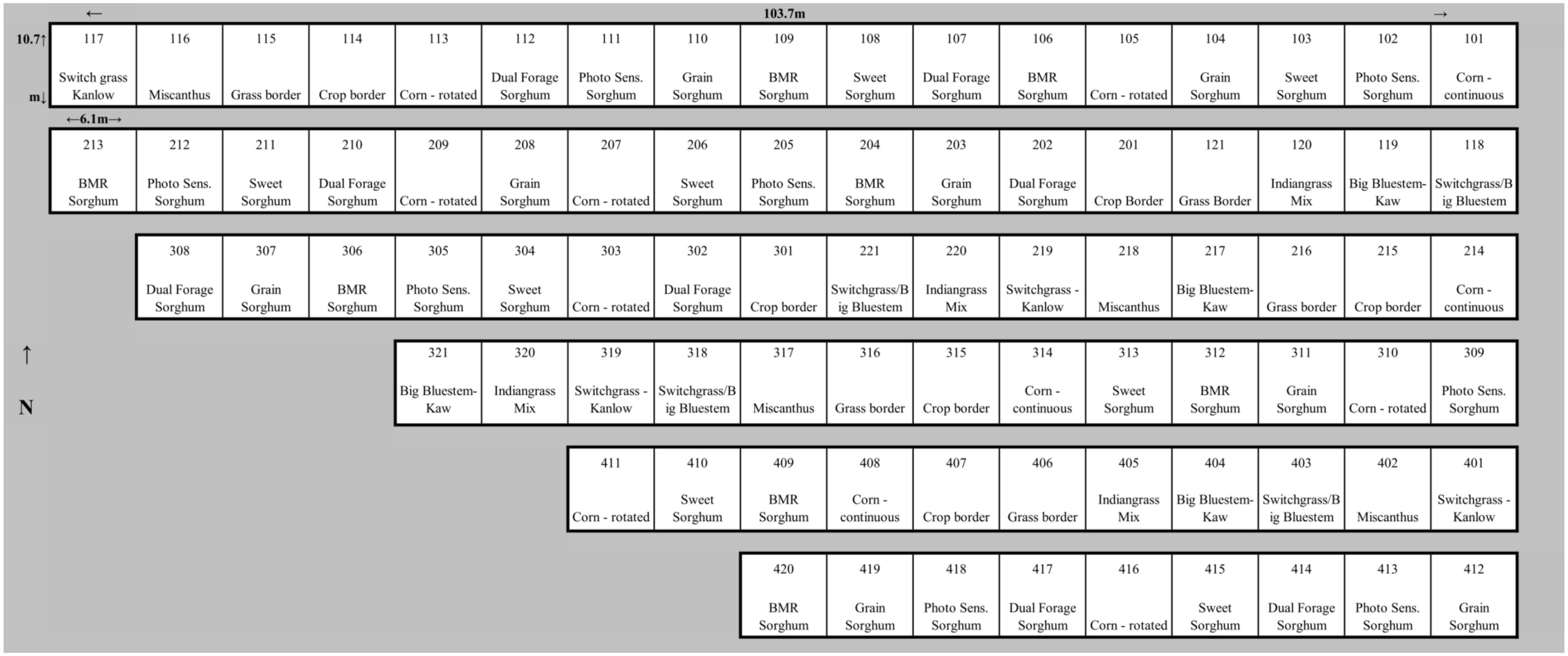


Figure 2.4 Plot layout of energy crops at Manhattan.



117 Switch grass Kanlow	116 Miscanthus	115 Grass border	114 Crop border	113 Corn - rotated	112 Dual Forage Sorghum	111 Photo Sens. Sorghum	110 Grain Sorghum	109 BMR Sorghum	108 Sweet Sorghum	107 Dual Forage Sorghum	106 BMR Sorghum	105 Corn - rotated	104 Grain Sorghum	103 Sweet Sorghum	102 Photo Sens. Sorghum	101 Corn - continuous
213 BMR Sorghum	212 Photo Sens. Sorghum	211 Sweet Sorghum	210 Dual Forage Sorghum	209 Corn - rotated	208 Grain Sorghum	207 Corn - rotated	206 Sweet Sorghum	205 Photo Sens. Sorghum	204 BMR Sorghum	203 Grain Sorghum	202 Dual Forage Sorghum	201 Crop Border	121 Grass Border	120 Indiangrass Mix	119 Big Bluestem-Kaw	118 Switchgrass/Big Bluestem
	308 Dual Forage Sorghum	307 Grain Sorghum	306 BMR Sorghum	305 Photo Sens. Sorghum	304 Sweet Sorghum	303 Corn - rotated	302 Dual Forage Sorghum	301 Crop border	221 Switchgrass/Big Bluestem	220 Indiangrass Mix	219 Switchgrass - Kanlow	218 Miscanthus	217 Big Bluestem-Kaw	216 Grass border	215 Crop border	214 Corn - continuous
				321 Big Bluestem-Kaw	320 Indiangrass Mix	319 Switchgrass - Kanlow	318 Switchgrass/Big Bluestem	317 Miscanthus	316 Grass border	315 Crop border	314 Corn - continuous	313 Sweet Sorghum	312 BMR Sorghum	311 Grain Sorghum	310 Corn - rotated	309 Photo Sens. Sorghum
						411 Corn - rotated	410 Sweet Sorghum	409 BMR Sorghum	408 Corn - continuous	407 Crop border	406 Grass border	405 Indiangrass Mix	404 Big Bluestem-Kaw	403 Switchgrass/Big Bluestem	402 Miscanthus	401 Switchgrass - Kanlow
								420 BMR Sorghum	419 Grain Sorghum	418 Photo Sens. Sorghum	417 Dual Forage Sorghum	416 Corn - rotated	415 Sweet Sorghum	414 Dual Forage Sorghum	413 Photo Sens. Sorghum	412 Grain Sorghum

Figure 2.5 Precipitation distribution by month (High Plains Regional Climate Center).

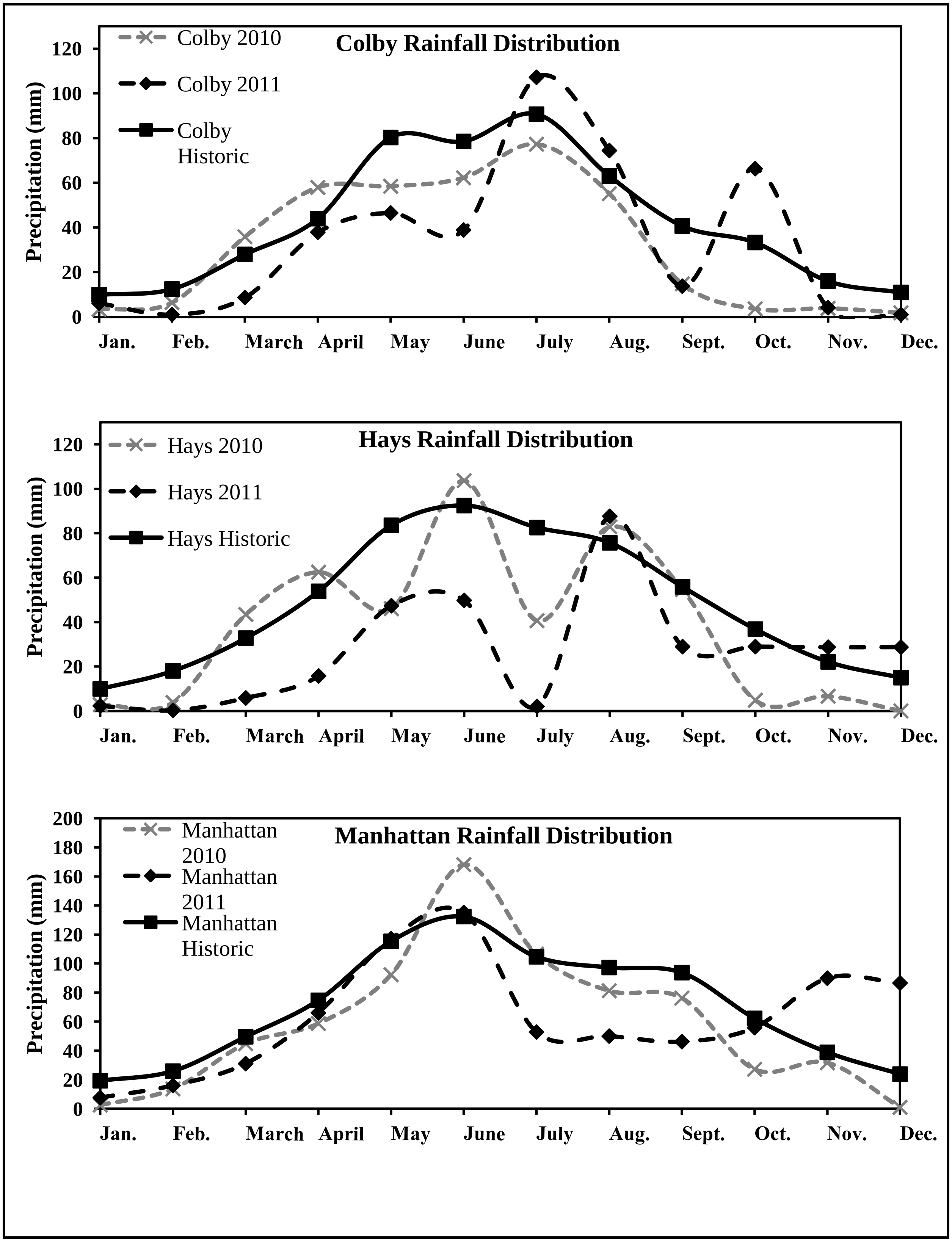


Figure 2.6 Mean weight diameter of water-stable aggregates at Colby. Treatments with different letters are significantly different at the P=0.05 level. NS indicates no significant differences among treatments.

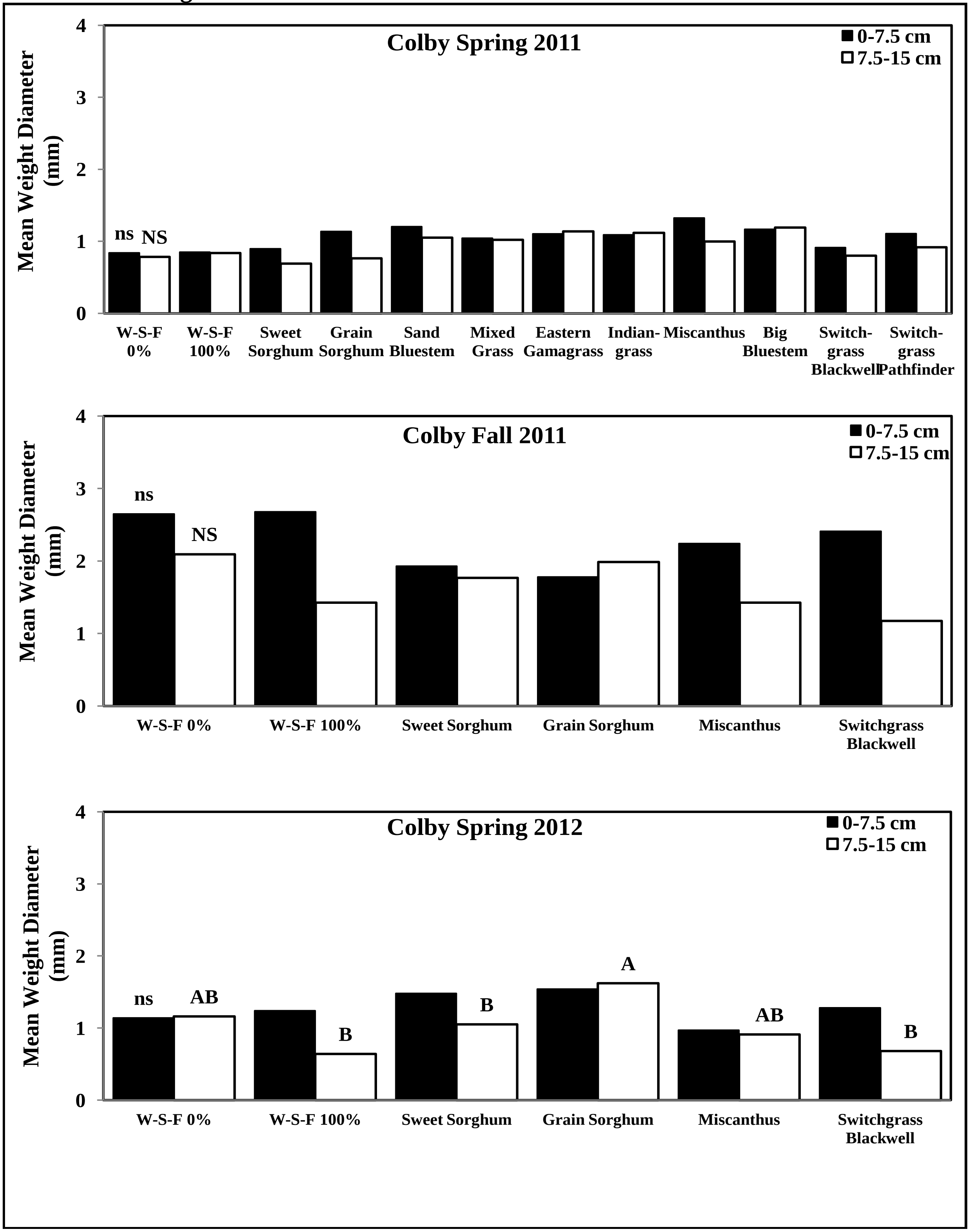
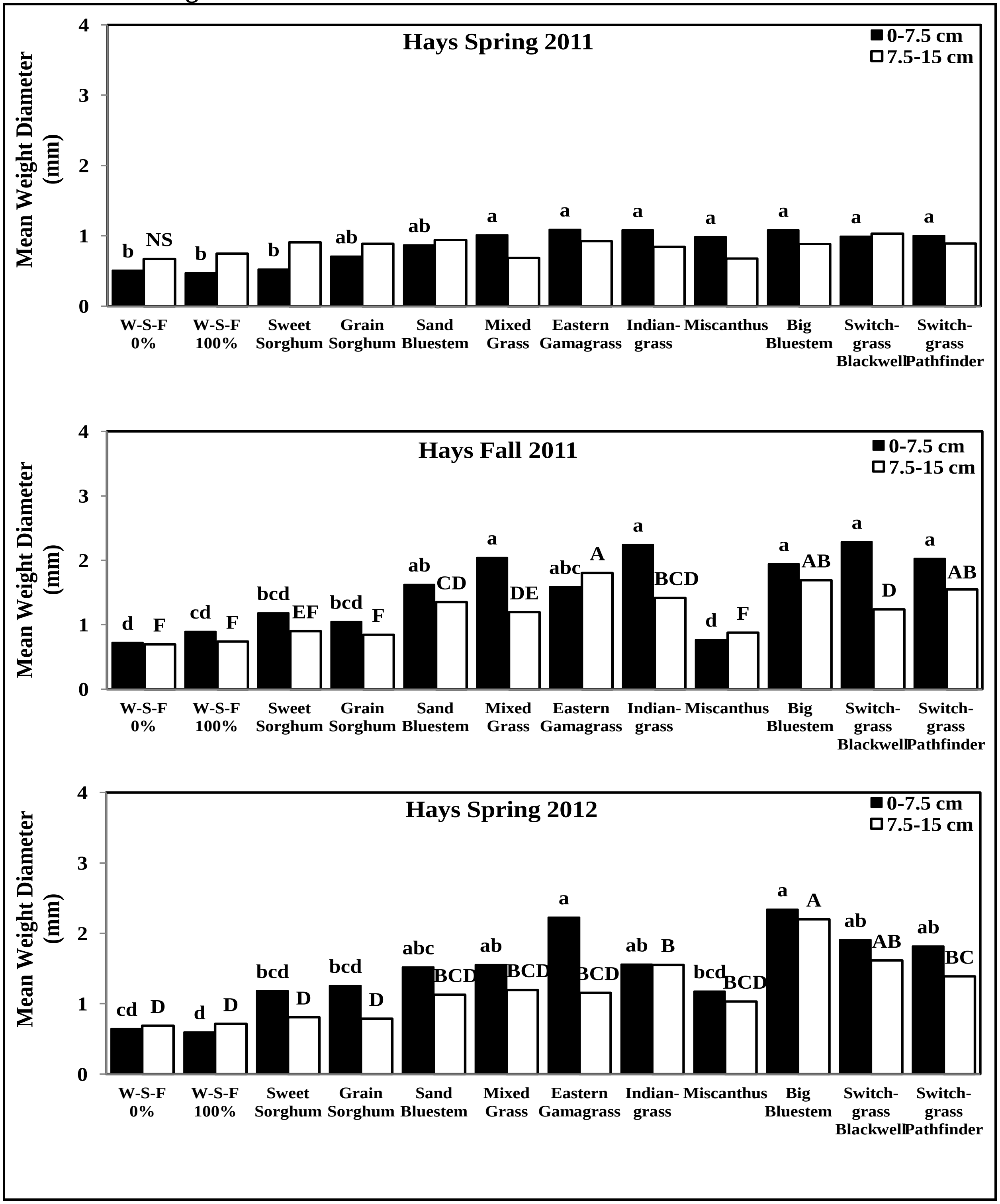


Figure 2.7 Mean weight diameter of water-stable aggregates at Hays. Treatments with different letters are significantly different at the P=0.05 level. NS indicates no significant differences among treatments.



Hays Spring 2011

Hays Fall 2011

Hays Spring 2012

Figure 2.8 Mean weight diameter of water-stable aggregates at Manhattan. Treatments with different letters are significantly different at the P=0.05 level.

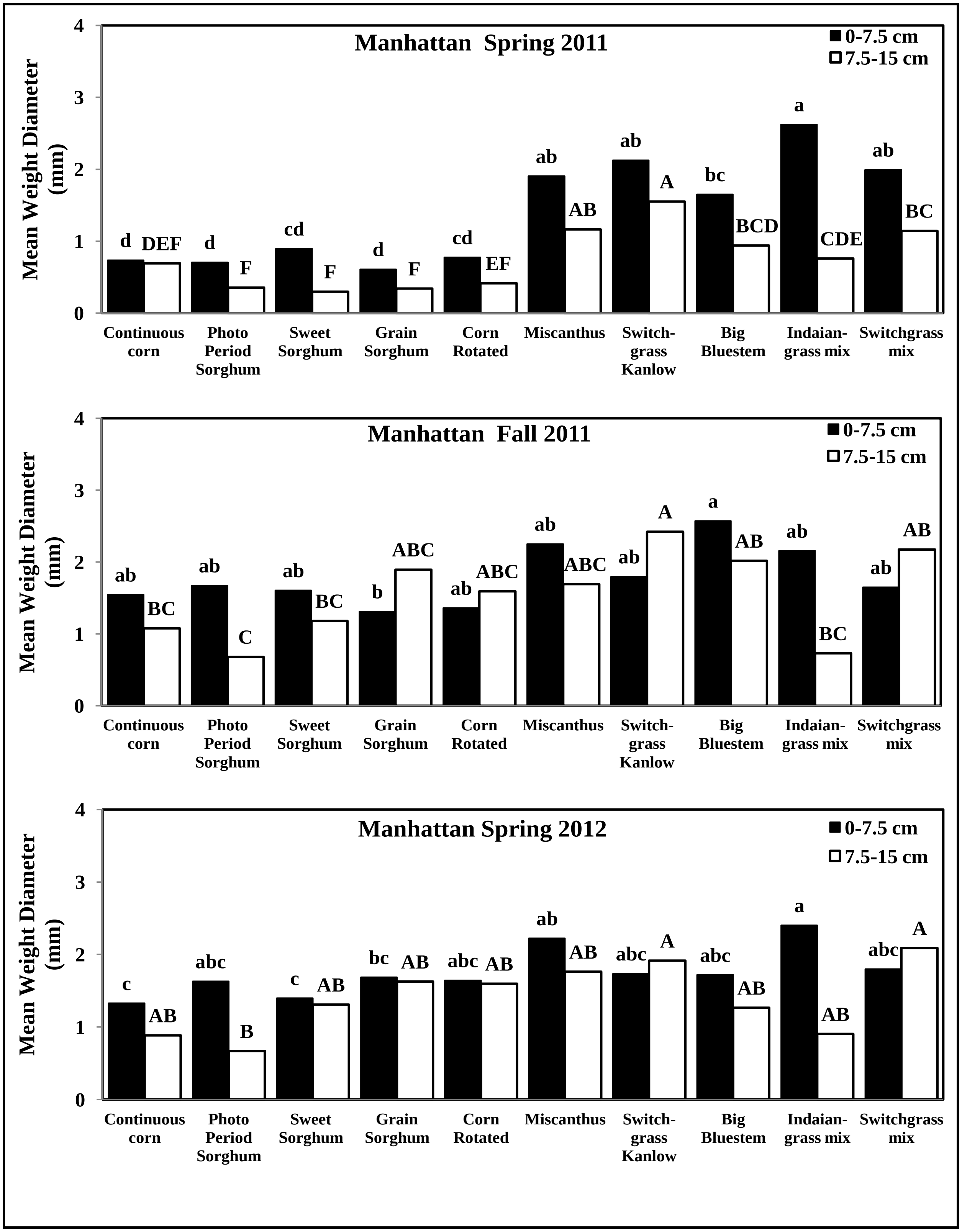


Figure 2.9 Early season water content profiles in Manhattan in 2011.

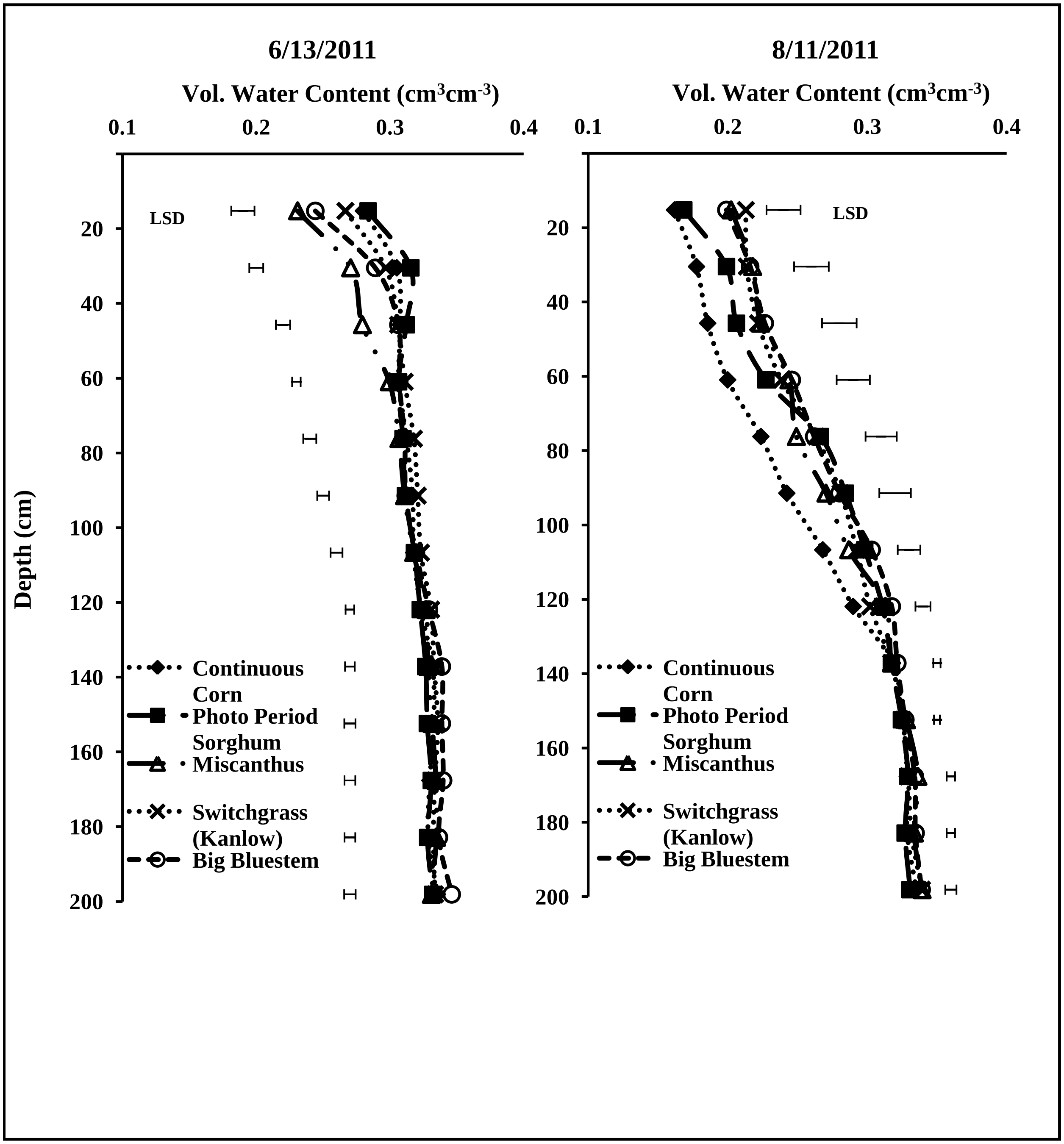


Figure 2.10 Late season water content profiles in Manhattan in 2011.

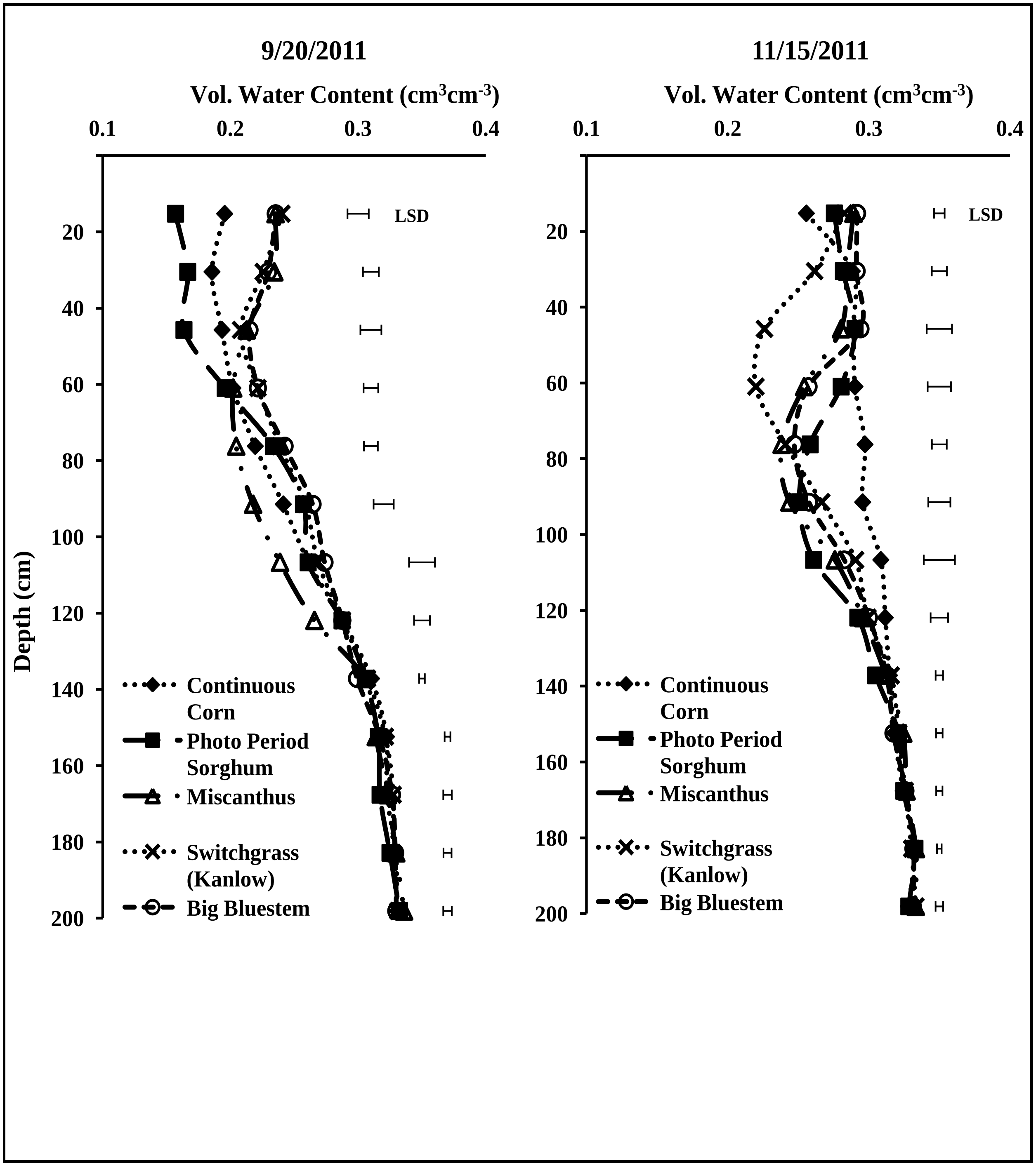


Figure 2.11 Early season water content profiles in Manhattan in 2012.

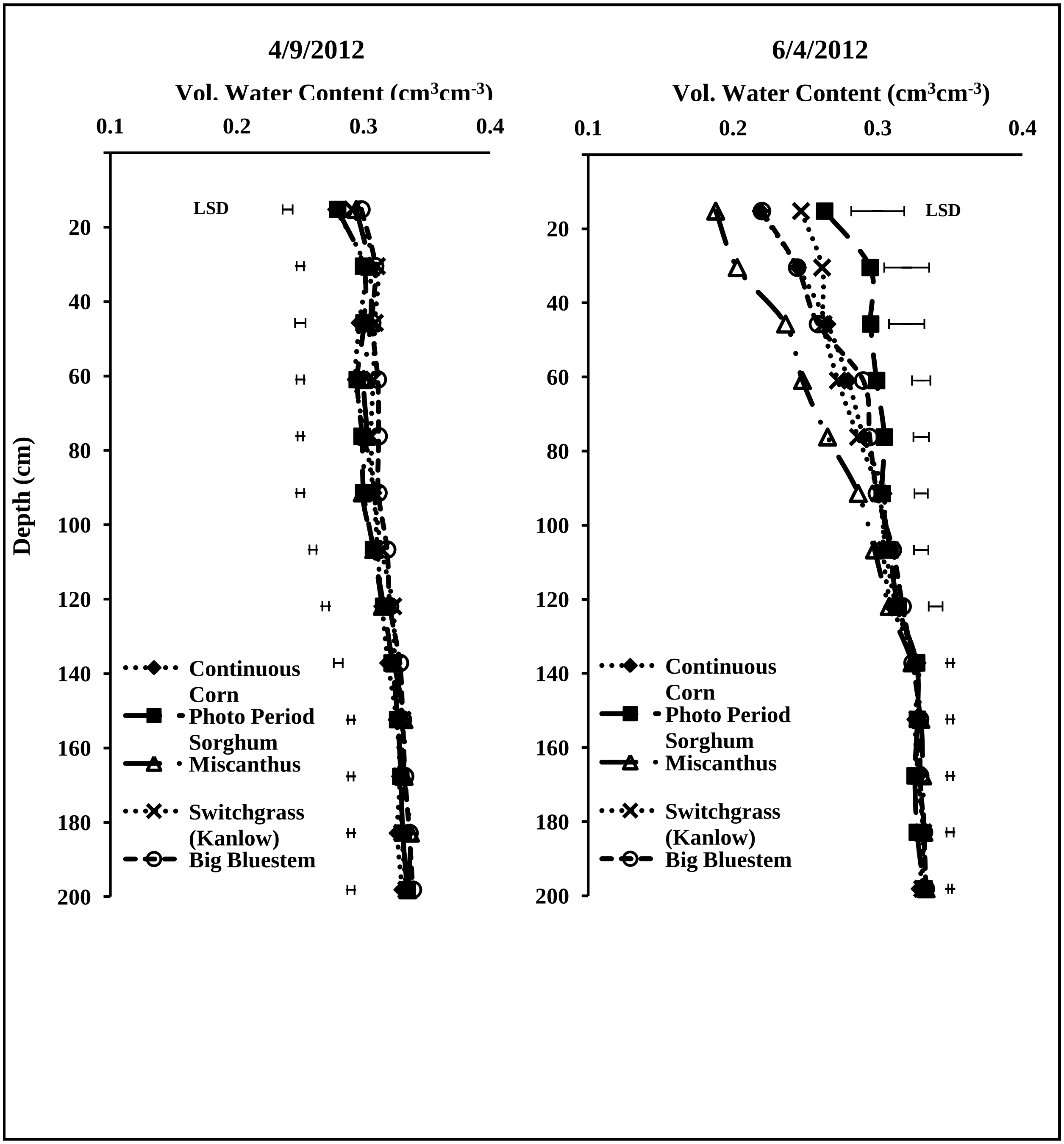


Figure 2.12 Early season water content profiles in Hays in 2011.

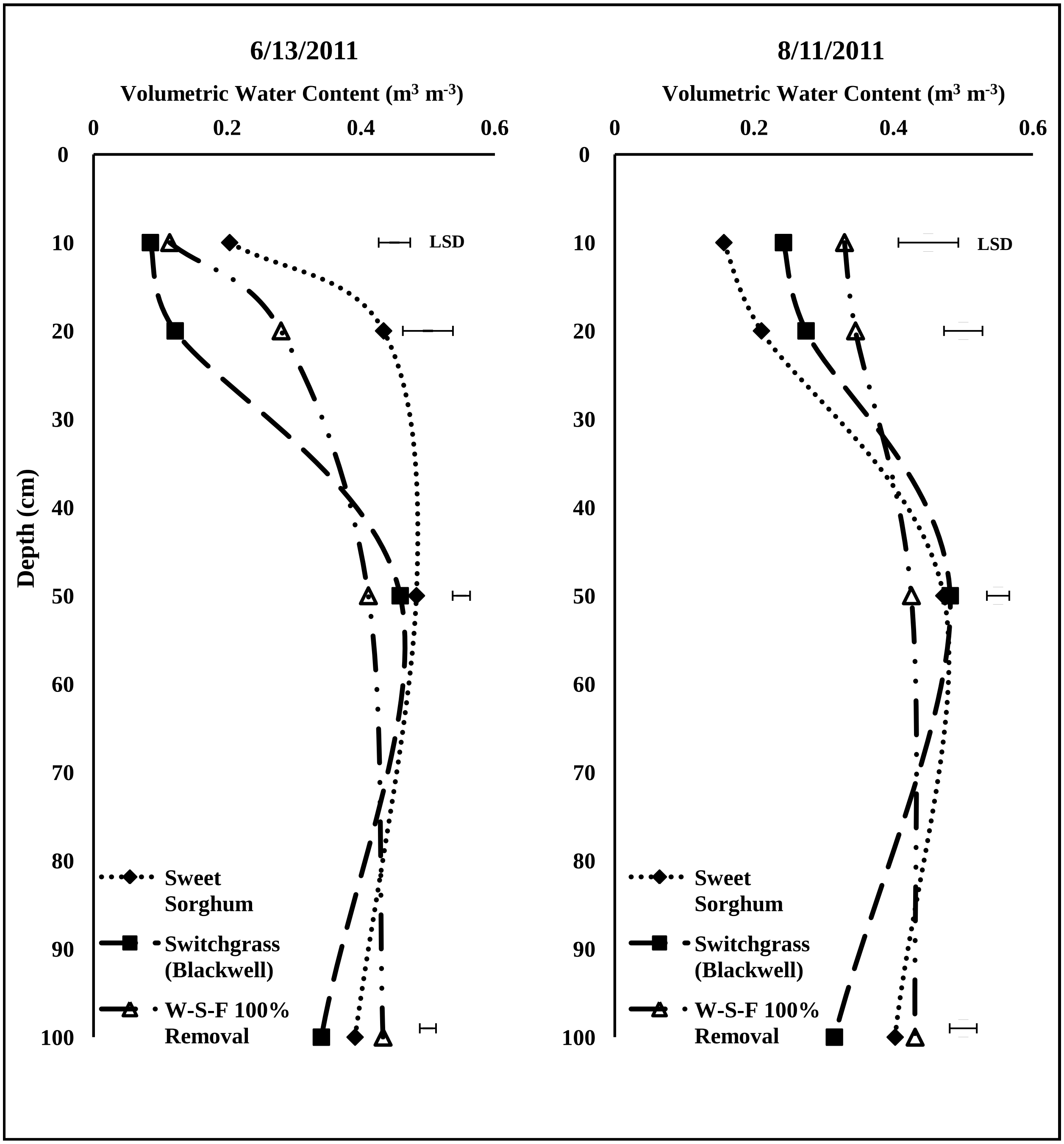


Figure 2.13 Winter and early season water content profiles in Hays 2011 and 2012.

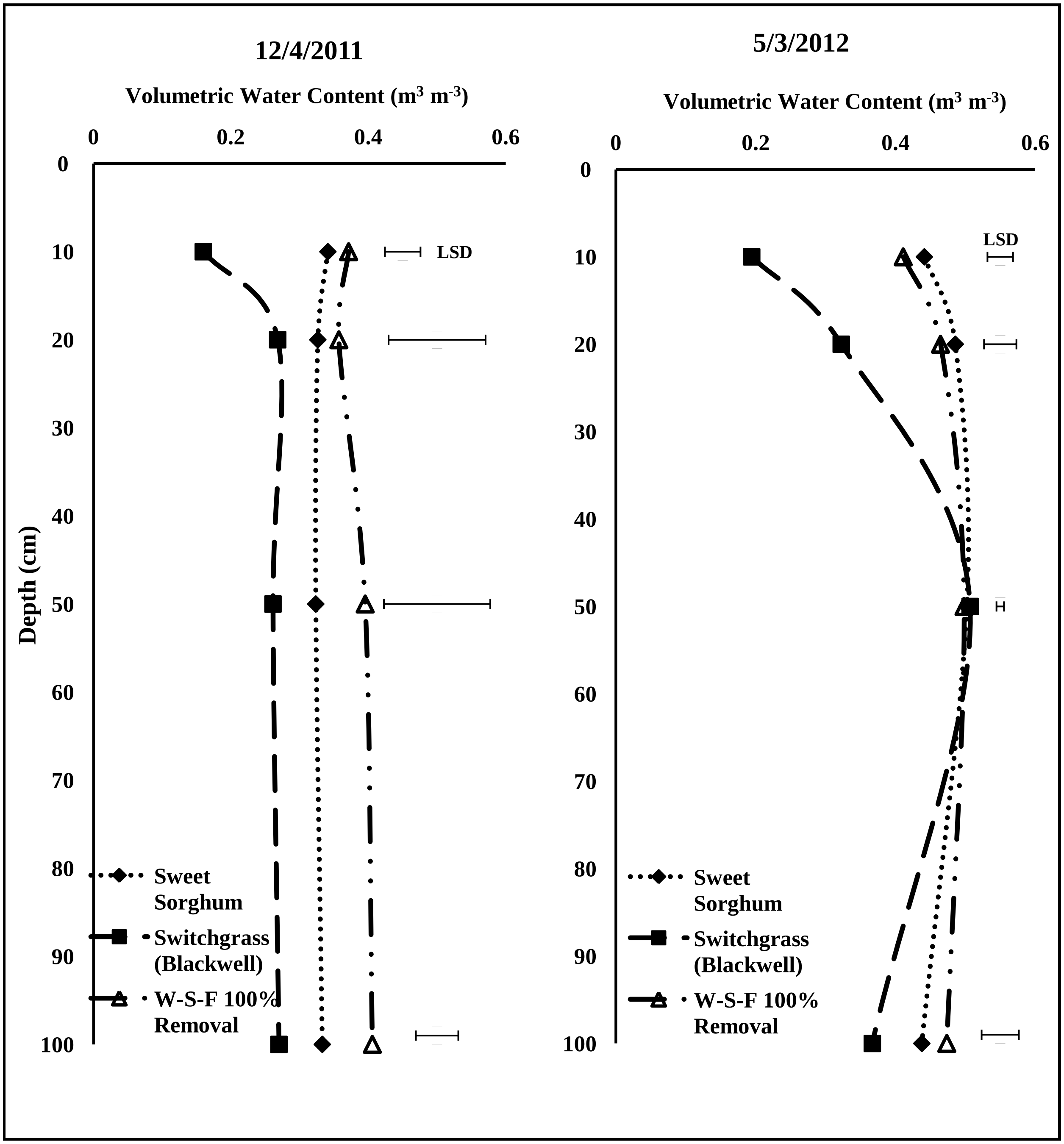


Table 2.1 Schedule of soil sampling.

Wet Aggregate Stability, Bulk Density and SOC

Site	Time Period	Sample Date
Colby	Fall 2010	19-Nov-10
Hays	Fall 2010	28-Nov-11
Colby	Spring 2011	29-Apr-11
Hays	Spring 2011	28-Apr-11
Manhattan	Spring 2011	1-May-11
Colby	Fall 2011	18-Nov-11
Hays	Fall 2011	19-Nov-11
Manhattan	Fall 2011	10-Nov-11
Colby	Spring 2012	18-Mar-12
Hays	Spring 2012	19-Mar-12
Manhattan	Spring 2012	14-Mar-12

Water Retention

Site	Time Period	Sample Date
Colby	Spring 2011	29-Apr-11
Hays	Spring 2011	28-Apr-11
Manhattan	Spring 2011	1-May-11
Colby	Spring 2012	18-Mar-12
Hays	Spring 2012	19-Mar-12
Manhattan	Spring 2012	14-Mar-12

Infiltration

Site	Time Period	Sample Date
Colby	Spring 2011	8-Jun-11
Hays	Spring 2011	7-Jun-11
Manhattan	Spring 2011	14-Jun-11

Table 2.2 Distribution of water-stable aggregate factions at Colby, for the 0 to 5cm depth in Fall 2010. Different letters within the same size fraction indicate significant differences at the P=0.05 level.

	Aggregate Size Fraction (mm)					
Treatment	**>4.75**	**2-4.75**	**1-2**	**0.5-1**	**0.25-0.5**	**<0.25**
	---Water Stable Aggregates (%)---					
Switchgrass (Blackwell)	14.1 ab	9.8	3.59	6.0 ab	7.8 b	60.0 ab
Miscanthus	15.8 a	12.1	8.02	12.0 a	13.8 a	40.4 b
Sweet Sorghum	12.2 ab	7.8	6.09	14.8 a	9.6 ab	50.6 ab
Grain Sorghum	9.1 bc	9.7	6.03	8.0 ab	11.1 ab	57.2 ab
W-S-F 0% residue removal	4.7 c	8.7	5.49	7.6 ab	9.7 ab	64.7 a
W-S-F 100% residue removal	5.5 c	10.2	7.03	5.0 b	8.3 b	66.2 a

Table 2.3 Distribution of water-stable aggregate factions at Colby in spring 2011. Different letters within the same size fraction and same depth interval indicate significant differences at the P=0.05 level.

		Aggregate Size Fraction (mm)					
Treatment	**Depth (cm)**	**>4.75**	**2-4.75**	**1-2**	**0.5-1**	**0.25-0.5**	**<0.25**
		---Water Stable Aggregates (%) ---					
Switchgrass (Blackwell)	7.5	3.1	13.2 ab	6.3 abc	9.4 bcd	10.0 b	58.7 ab
Switchgrass (Pathfinder)	7.5	7	12.3 ab	5.7 abc	7.7 bcd	7.3 b	61.1 ab
Miscanthus	7.5	8.9	12.5 ab	9.1 ab	14.7 a	8.9 b	46.8 b
Big Bluestem	7.5	5	15.5 a	10.2 a	9.7 bcd	10.9 b	50.0 ab
Sand Bluestem	7.5	9.3	10 bcd	6.7 abc	9.1 bcd	9.1 b	55.8 ab
Mixed Grass	7.5	6.8	11.1 abc	5.2 bc	6.5 cd	8.2 b	62.9 ab
Indiangrass	7.5	5.6	13.7 ab	6.4 abc	9.4 bcd	9.7 b	55.4 ab
Eastern Gamagrass	7.5	5.7	11.7 ab	9.5 ab	12.6 b	12.6 ab	48.8 b
Grain Sorghum	7.5	8.9	7.5 bcd	7.1 ab	10.7 bc	18.3 a	49.2 b
Sweet Sorghum	7.5	7.1	4.6 cd	5.6 abc	11.5 abc	12.0 ab	60.1 ab
W-S-F 0% residue removal	7.5	4.6	8.1 bcd	5.7 abc	10.3 abc	8.1 b	64.5 ab
W-S-F 100% residue removal	7.5	8.3	3.4 d	2.3 c	5.2 d	12.6 ab	68.8 a
Switchgrass (Blackwell)	15	3.3	10.1 abc	3.5 b	11.6 a	7.3 c	65.7 ab
Switchgrass (Pathfinder)	15	4.9	9.6 abc	6.7 b	9.3 ab	9.1 bc	61.0 ab
Miscanthus	15	9	5.4 bc	4.6 b	7.5 ab	8.3 c	65.6 ab
Big Bluestem	15	6.5	14.4 ab	7.6 b	11.2 a	6.3 c	53.9 ab
Sand Bluestem	15	6	11.4 abc	6.7 b	9.6 ab	11.6 abc	55.0 ab
Mixed Grass	15	7.9	9.2 abc	4.1 b	4.7 b	6.9 c	67.6 a
Indiangrass	15	8.5	8.9 abc	7.3 b	7.8 ab	8.3 c	59.9 ab
Eastern Gamagrass	15	2.5	17.2 a	14.9 a	10.7 ab	9.9 abc	45.0 b
Grain Sorghum	15	3.8	5.4 bc	7.5 b	12.6 a	15.9 a	55.2 ab
Sweet Sorghum	15	5	3.4 cd	3.6 b	8.9 ab	15.1 ab	64.4 ab
W-S-F 0% residue removal	15	3.6	6.7 bc	8.1 ab	11.0 ab	14.9 ab	56.6 ab
W-S-F 100% residue removal	15	2.4	13.8 ab	2.8 b	7.4 ab	11.1 abc	62.9 ab

Table 2.4 Distribution of water-stable aggregate factions at Colby in Fall 2011. Different letters within the same size fraction and depth interval indicates significant differences at the P=0.05 level.

		Aggregate Size Fraction (mm)					
Treatment	**Depth (cm)**	**>4.75**	**2-4.75**	**1-2**	**0.5-1**	**0.25-0.5**	**<0.25**
		---Water Stable Aggregates (%) ---					
Switchgrass (Blackwell)	7.5	25.7	14.8	8.2	8.5	11.8	30.9
Miscanthus	7.5	32.7	10.8	4.5	7.2	11.0	33.9
Grain Sorghum	7.5	33.4	10.3	5.1	7.4	10.5	33.7
Sweet Sorghum	7.5	16.3	18.5	7.0	9.3	12.7	36.2
W-S-F 0% residue removal	7.5	21.4	17.2	9.3	10.1	12.3	29.6
W-S-F 100% residue removal	7.5	15.7	15.1	7.1	9.0	11.9	41.1
Switchgrass (Blackwell)	15	9.0 b	9.8	5.4 ab	9.8 ab	13.5	52.3
Miscanthus	15	23.6 a	10.3	6.1 b	8.0 b	10.9	41.1
Grain Sorghum	15	8.9 b	13.1	14.5 a	14.1 a	12.9	36.5
Sweet Sorghum	15	15.9 ab	14.2	7.0 b	8.6 b	12.6	41.5
W-S-F 0% residue removal	15	11.1 ab	11.1	10.5 ab	11.9 ab	10.5	45.3
W-S-F 100% residue removal	15	19.2 ab	15.0	7.0 ab	7.8 b	11.4	39.5

Table 2.5 Distribution of water-stable aggregate factions at Colby in Spring 2012. Different letters within the same size fraction and depth interval indicates significant differences at the P=0.05 level.

		Aggregate Size Fraction (mm)					
Treatment	**Depth (cm)**	**>4.75**	**2-4.75**	**1-2**	**0.5-1**	**0.25-0.5**	**<0.25**
			---Water Stable Aggregates (%) ---				
Switchgrass (Blackwell)	7.5	1.7	13.4	4.5 b	10.7 b	17.7 ab	52.3
Miscanthus	7.5	1.3	8.2	6.3 ab	16.2 b	18.7 a	49.1
Grain Sorghum	7.5	3.1	13	7.6 ab	14.2 b	17.3 ab	45.1
Sweet Sorghum	7.5	5.2	10.3	9.1 ab	25.2 a	9.4 b	40
W-S-F 0% residue removal	7.5	4.7	14.5	11.3 a	13.2 b	13.9 ab	42.5
W-S-F 100% residue removal	7.5	5.7	15.6	8.4 ab	13.2 b	17.5 ab	39.6
Switchgrass (Blackwell)	15	19.1 ab	9.9	7.8 ab	10.0 b	13.4 abc	40.4 ab
Miscanthus	15	2.5 c	10.3	9.6 ab	18.6 a	19.8 a	38.9 ab
Grain Sorghum	15	5.5 bc	8	4.2 b	8.7 b	18.7 ab	54.6 ab
Sweet Sorghum	15	5.8 bc	15.3	6.6 ab	10.8 ab	12.4 bc	48.9 ab
W-S-F 0% residue removal	15	3.3 c	8.2	5.2 ab	9.6 b	13.8 abc	60.0 a
W-S-F 100% residue removal	15	21.4 a	13.6	12.7 a	6.6 b	9.3 c	36.6 b

Table 2.6 Distribution of water-stable aggregate factions at Hays for the 0 to 5cm depth in Fall 2010. Different letters within the same size fraction indicate significant differences at the P=0.05 level.

		Aggregate Size Fraction (mm)					
Treatment	**MWD (mm)**	**>4.75**	**2-4.75**	**1-2**	**0.5-1**	**0.25-0.5**	**<0.25**
			---Water Stable Aggregates (%) ---				
Switchgrass (Blackwell)	1.59 a	13.3	15.5 a	4.6 ab	5.4	11.9 ab	49.1 d
Switchgrass (Pathfinder)	1.40 ab	13.5	7.9 ab	6.5 ab	8.9	10.6 ab	52.7 cd
Miscanthus	1.23 abcd	10.6	8.8ab	5.2 ab	9.6	10.7 ab	54.7 bcd
Big Bluestem	1.04 abcd	9.4	5.3b	4.5 ab	8.4	16.5 a	56.1 abcd
Sand Bluestem	1.10 abcd	9.5	7.5 ab	4.6 ab	5.8	12.3 ab	60.3 abcd
Mixed Grass	1.41 ab	12.1	10.5 ab	9.0 a	5.7	10.3 ab	52.5 cd
Indiangrass	0.98 abcd	7.3	7.3 ab	6.1 ab	7.3	12.9 ab	58.8 abcd
Sweet Sorghum	0.58 cd	13.3	8.2 ab	5.2 ab	7.2	8.2 b	57.1 abcd
Eastern Gamagrass	1.36 abc	5.6	2.0 b	5.2 ab	5.4	7.6 b	73.6 a
Grain Sorghum	0.66 bcd	3.2	2.3 b	7.0 ab	7.9	11 ab	68.2 abc
W-S-F 0% residue removal	0.49 d	2.6	2.5 b	3.2 b	6.1	14.1 ab	71.3 ab
W-S-F 100% residue removal	0.93 abcd	6.9	6.8 b	5.7 ab	7.8	12.5 ab	59.8 abcd

Table 2.7 Distribution of water-stable aggregate factions at Hays in Spring 2011. Different letters within the same size fraction and depth interval indicates significant differences at the P=0.05 level.

		Aggregate Size Fraction (mm)					
Treatment	**Depth (cm)**	**>4.75**	**2-4.75**	**1-2**	**0.5-1**	**0.25-0.5**	**<0.25**
		---Water Stable Aggregates (%) ---					
Switchgrass (Blackwell)	7.5	6.8 abc	8.3 ab	7.3 abc	8.3 ab	10.0 cde	58.2abc
Switchgrass (Pathfinder)	7.5	6.5 abc	9.3 a	7.3 abc	7.7 ab	9.3 de	58.3 abc
Miscanthus	7.5	7.8 ab	6.4 bcd	5.6 cde	9.1 ab	13.3 c	56.3 bc
Big Bluestem	7.5	6.2 bcd	10.8 a	9.8 a	10.0 ab	10.2 cde	50.3 c
Sand Bluestem	7.5	4.3 bcd	7.7 abc	8.1 ab	12.3 a	13.8 b	52.2 c
Mixed Grass	7.5	8.3 ab	6.4 bcd	6.4 bcd	8.0 ab	9.2 de	60.2 abc
Indiangrass	7.5	11.6 a	4.3 bcd	3.0 def	5.8 b	7.0 e	67.7 ab
Eastern Gamagrass	7.5	7.8 ab	8.0 ab	9.5 a	9.4 ab	11.4 bcd	53.3 bc
Grain Sorghum	7.5	2.1 cd	3.0 cd	3.9 def	10.6 ab	17.7 a	60.6 abc
Sweet Sorghum	7.5	1.7 cd	2.1 d	1.6 f	6.1 ab	13.6 bc	72.8 a
W-S-F 0% residue removal	7.5	1.3 d	1.8 d	2.4 ef	7.0 ab	13.7 b	72.6 a
W-S-F 100% residue removal	7.5	1.2 d	2.4 d	2.1 ef	7.4 ab	13.4 bc	72.0 a
Switchgrass (Blackwell)	15	7.2a	7.3	9.3 ab	10.4	10.9 bc	54.6 ab
Switchgrass (Pathfinder)	15	4.7 abc	7.3	8.8 ab	12.5	14.6 abc	50.3 ab
Miscanthus	15	1.4 cd	6.4	10.5 ab	12.9	13.7 abc	54.1 ab
Big Bluestem	15	5.2 ab	7.5	6.3 ab	10.8	16.1 ab	52.8 ab
Sand Bluestem	15	4.1 abc	7.3	12.3 a	18.1	17.6 a	38.8 b
Mixed Grass	15	2.6 bcd	5.2	9.1 b	11.7	15.5 abc	54.5 ab
Indiangrass	15	3.3 bcd	7.3	10.0 ab	16.3	12.9 abc	48.4 ab
Eastern Gamagrass	15	4.9 abc	7.3	12.1 a	11	9.6 c	53.3 ab
Grain Sorghum	15	1.6 bcd	5.4	6.2 ab	13.3	15.4 abc	56.4 ab
Sweet Sorghum	15	1.0 d	2.3	6.6 b	14.9	15.6 abc	58.1 ab
W-S-F 0% residue removal	15	2.0 bcd	4	4.9 b	14.3	15.6 abc	59.0 a
W-S-F 100% residue removal	15	1.6 bcd	2.2	6.8 b	16.2	16.9 ab	56.0 ab

Table 2.8 Distribution of water-stable aggregate factions at Hays in Fall 2011. Different letters within the same size fraction and depth interval indicates significant differences at the P=0.05 level.

		Aggregate Size Fraction (mm)					
Treatment	**Depth (cm)**	**>4.75**	**2-4.75**	**1-2**	**0.5-1**	**0.25-0.5**	**<0.25**
		---Water Stable Aggregates (%) ---					
Switchgrass (Blackwell)	7.5	18.5 a	23.4 abc	11.2	11.3 ab	9.8 c	25.6 def
Switchgrass (Pathfinder)	7.5	8.8 bcd	32.9 a	14.0	8.3 ab	7.9 c	27.1 cde
Miscanthus	7.5	1.1 d	10.5 d	9.6	7.0 b	25.3 ab	46.8 a
Big Bluestem	7.5	17.1 ab	14.8 bcd	12.1	11.4 ab	12.6 c	32.0 abc
Sand Bluestem	7.5	14.0 abc	12.9 cd	8.9	9.2 ab	10.9 c	44.2 ab
Mixed Grass	7.5	8.9 bcd	31.6 a	17.4	10.1 ab	8.9 c	22.6 f
Indiangrass	7.5	16.0 abc	25.9 b	13.1	10.3 ab	9.9 c	24.3 ef
Eastern Gamagrass	7.5	3.7 cd	26.9 ab	18.9	11.0 ab	9.7 c	29.9 bcd
Grain Sorghum	7.5	3.0 d	12.2 bcd	16.6	13.1 a	15.9 bc	39.8 abc
Sweet Sorghum	7.5	3.8 cd	15.8 bcd	13.9	12.9 a	14.1 c	39.2 abc
W-S-F 0% residue removal	7.5	1.2 d	7.0 d	11.5	12.2 a	26.3 a	41.8 ab
W-S-F 100% residue removal	7.5	1.3 cd	10.7 d	17.2	9.2 ab	14.3 c	46.1 a
Switchgrass (Blackwell)	15	1.8 b	17.7 abc	22.2	16.0	12.2 abc	30.9 ab
Switchgrass (Pathfinder)	15	5.3 ab	23.3 a	17.5	10.8	10.8 abc	32.3 ab
Miscanthus	15	2.5 ab	6.4 c	19.4	16.7	11.9 abc	45.0 a
Big Bluestem	15	7.0 ab	21.8 ab	19.4	22.5	7.9 bc	21.9 b
Sand Bluestem	15	4.6 ab	17.0 abc	18.4	14.5	20.2 a	26.2 ab
Mixed Grass	15	3.2 ab	15.3 abc	18.8	15.3	7.8 c	40.1 ab
Indiangrass	15	7.1 ab	16.4 abc	11.4	19.9	12.8 abc	32.2 ab
Eastern Gamagrass	15	9.4 a	26.1 a	7.4	20.9	6.3 c	30.3 ab
Grain Sorghum	15	1.5 b	8.7 bc	13.5	17.3	19.5 ab	39.4 ab
Sweet Sorghum	15	2.5 ab	6.9 c	18.2	19.9	11.2 abc	41.7 a
W-S-F 0% residue removal	15	0.3 b	4.4 c	17.9	18.1	20.5 a	38.6 ab
W-S-F 100% residue removal	15	0.5 b	7.2 c	15.3	14.9	15.8 abc	44.4 a

Table 2.9 Distribution of water-stable aggregate factions at Hays in Spring 2012. Different letters within the same size fraction and depth interval indicates significant differences at the P=0.05 level.

		Aggregate Size Fraction (mm)					
Treatment	**Depth (cm)**	**>4.75**	**2-4.75**	**1-2**	**0.5-1**	**0.25-0.5**	**<0.25**
		---Water Stable Aggregates (%) ---					
Switchgrass (Blackwell)	7.5	9.1 ab	15.2 ab	12.6 ab	15.1 ab	16.1 ab	31.6 b
Switchgrass (Pathfinder)	7.5	9.0 ab	22.9 ab	10.9 ab	14.5 ab	12.7 ab	29.6 b
Miscanthus	7.5	9.5 ab	12.9 ab	10.2 ab	17.3 ab	16.9 ab	32.8 b
Big Bluestem	7.5	4.4 ab	21.7 ab	19.5 a	14.6 ab	11.8 ab	27.6 b
Sand Bluestem	7.5	17.7 a	15.1 ab	10.4 ab	9.7 b	11.0 ab	35.8 ab
Mixed Grass	7.5	5.1 ab	7.8 b	8.1 b	13.6 ab	14.4 ab	51.1 a
Indiangrass	7.5	1.5 b	12.5 ab	14.9 ab	16.1 ab	18.9 a	36.3 ab
Eastern Gamagrass	7.5	9.7 ab	11.3 ab	7.7 b	12.4 ab	14.3 ab	44.1 ab
Grain Sorghum	7.5	4.3 ab	18.6 ab	18.8 a	12.6 ab	12.3 ab	32.7 b
Sweet Sorghum	7.5	4.7 ab	23.1 ab	15.7 ab	18.5 a	9.5 b	28.9 b
W-S-F 0% residue removal	7.5	8.5 ab	26.3 a	13.7 ab	12.6 ab	11.0 ab	28.1b
W-S-F 100% residue removal	7.5	14.5 ab	21.0 ab	13.9 ab	9.7 b	12.7 ab	28.5 b
Switchgrass (Blackwell)	15	1.9	8.9	23.6 a	20.0 ab	18.7 ab	27.3
Switchgrass (Pathfinder)	15	6.4	12.9	13.7 b	16.5 ab	17.0 ab	33.5
Miscanthus	15	7.4	9.4	12.6 b	18.7 ab	23.4 a	28.9
Big Bluestem	15	4.3	15.2	14.4 ab	19.0 ab	14.7 b	32.1
Sand Bluestem	15	1.2	12	15.4 ab	17.6 ab	13.3 b	40.7
Mixed Grass	15	1.1	6.3	17.5 ab	24.1 a	17.3 ab	34.4
Indiangrass	15	1.5	16.1	18.8 ab	20.9 ab	14.3 b	28.6
Eastern Gamagrass	15	7.9	5.9	11.7 b	20.4 ab	18.9 ab	34.5
Grain Sorghum	15	2.5	15.9	16.7 ab	15.9 b	14.0 b	35.7
Sweet Sorghum	15	3.6	7.9	11.3 b	19.3 ab	21.3 ab	37
W-S-F 0% residue removal	15	13.8	12.4	12.2 b	16.7 ab	15.6 ab	29.3
W-S-F 100% residue removal	15	5.6	15.6	15.0 ab	16.4 b	15.4 ab	31.7

Table 2.10 Distribution of water-stable aggregate factions at Manhattan in Spring 2011. Different letters within the same size fraction and depth interval indicates significant differences at the P=0.05 level.

		Aggregate Size Fraction (mm)					
Treatment	**Depth (cm)**	**>4.75**	**2-4.75**	**1-2**	**0.5-1**	**0.25-0.5**	**<0.25**
				---Water Stable Aggregates (%) ---			
Continuous Corn	7.5	4.5 cd	4.5 c	4.8 ab	15.1 a	10.1 ab	60.4 ab
Photo Period Sorghum	7.5	4.6 cd	5.4 bc	3.5 b	7.3 ab	11.0 ab	67.4 a
Sweet Sorghum	7.5	7.4 cd	5.6 bc	3.2 ab	8.0 ab	12.0 a	62.8 ab
Grain Sorghum	7.5	2.4 d	5.2 bc	4.7 ab	11.7 ab	11.4 ab	63.3 ab
Rotated Corn	7.5	5.6 cd	3.9 c	6.1 ab	10.2 ab	11.4 ab	62.4 ab
Miscanthus	7.5	21.2 ab	9.4 abc	5.5 b	7.5 ab	10.1 ab	45.2 bc
Switchgrass (Kanlow)	7.5	21.8 ab	14.2 a	7.6 a	7.8 ab	9.2 ab	38.4 c
Big Bluestem	7.5	16.2 bc	12.0 a	3.7 b	8.5 ab	8.8 ab	49.4 abc
Indiangrass Mix	7.5	31.5 a	12.2 a	5.6 ab	6.0 b	6.9 b	36.6 c
Switchgrass Mix	7.5	22.3 ab	10.9 ab	5.0 ab	6.6 b	8.8 ab	45.9 bc
Continuous Corn	15	3.5 cde	5.0 bcd	5.7 ab	11.6 a	13.6 ab	59.5 cde
Photo Period Sorghum	15	0.7 e	1.8 e	3.1 bcd	8.1 abc	15.1 a	70.7 bc
Sweet Sorghum	15	0.7 e	2.0 e	1.9 d	3.2 d	8.7 b	83.0 a
Grain Sorghum	15	0.6 e	2.3 de	2.4 cd	5.7 bcd	14.1 a	74.3 ab
Rotated Corn	15	2.0 de	1.9 e	3.5 bcd	4.6 cd	11.6 ab	75.4 ab
Miscanthus	15	9.3 b	8.6 a	6.3 a	9.8 ab	13.1 ab	52.9 def
Switchgrass (Kanlow)	15	16.4 a	7.2 ab	5.2 ab	10.5 ab	12.1 ab	48.2 f
Big Bluestem	15	7.3 bc	6.4 abc	5.0 abc	8.3 abc	11.2 ab	61.0 cde
Indiangrass Mix	15	6.3 bcd	3.6 cde	3.4 bcd	7.5 abc	11.2 ab	66.9 bcd
Switchgrass Mix	15	10.2 bc	6.7 ab	4.0 bcd	10.9 a	11.6 ab	55.6 def

Table 2.11 Distribution of water-stable aggregate factions at Manhattan in Fall 2011. Different letters within the same size fraction and depth interval indicates significant differences at the P=0.05 level.

		Aggregate Size Fraction (mm)					
Treatment	**Depth (cm)**	**>4.75**	**2-4.75**	**1-2**	**0.5-1**	**0.25-0.5**	**<0.25**
		---Water Stable Aggregates (%) ---					
Continuous Corn	7.5	10.1	17.1 ab	8.7 ab	11.6 ab	15.5 abc	36.7 ab
Photo Period Sorghum	7.5	13.1	15.3 ab	8.7 ab	11.0 ab	13.1 abc	38.4 ab
Sweet Sorghum	7.5	14.3	10.8 b	9.2 ab	10.2 ab	17.1 abc	38.3 ab
Grain Sorghum	7.5	10.9	9.1 b	7.7 ab	10.1 ab	15.0 abc	47.1 a
Rotated Corn	7.5	5.4	18.5 ab	11.9 ab	13.3 a	18.8 a	31.8 ab
Miscanthus	7.5	20.3	18.6 ab	11.6 ab	9.2 ab	11.5 bc	28.6 b
Switchgrass (Kanlow)	7.5	10.6	21.5 a	14.4 a	11.5 ab	13.4 abc	28.5 b
Big Bluestem	7.5	26.8	18.4 ab	6.7 ab	7.2 b	9.8 c	30.9 ab
Indiangrass Mix	7.5	18.5	22.6 a	4.4 b	6.4 b	13.7 abc	34.0 ab
Switchgrass Mix	7.5	13	16.7 ab	5.9 ab	8.5 ab	10.2 bc	45.3 ab
Continuous Corn	15	3.4 bc	10.8 ab	18.6 a	13.2 a	18.6 ab	35.0 ab
Photo Period Sorghum	15	1.9 c	5.3 b	10.1 ab	11.7 ab	19.6 a	51.4 a
Sweet Sorghum	15	6.2 abc	13.6 ab	8.6 ab	10.4 ab	17.0 abc	44.0 ab
Grain Sorghum	15	17.1 abc	14.7 ab	8.5 b	9.7 ab	14.4 abc	35.4 ab
Rotated Corn	15	12.1 abc	14.7 ab	9.1 ab	11.1 ab	13.5 abc	39.2 ab
Miscanthus	15	8.9 abc	22.3 a	12.5 ab	11.9 ab	12.8 bc	31.4 ab
Switchgrass (Kanlow)	15	24.5 a	16.6 ab	8.5 ab	12.3 ab	10.6 c	27.4 b
Big Bluestem	15	19.9 abc	14.5 ab	7.1 b	6.8 b	11.9 c	39.5 ab
Indiangrass Mix	15	2.3 bc	8.6 b	9.3 ab	9.9 ab	14.3 abc	56.1 a
Switchgrass Mix	15	26.3 a	8.4 b	4.1 b	6.2 b	12.5 abc	42.8 ab

Table 2.12 Distribution of water-stable aggregate factions at Manhattan in Spring 2012. Different letters within the same size fraction and depth interval indicates significant differences at the P=0.05 level.

		Aggregate Size Fraction (mm)					
Treatment	**Depth (cm)**	**>4.75**	**2-4.75**	**1-2**	**0.5-1**	**0.25-0.5**	**<0.25**
			---Water Stable Aggregates (%) ---				
Continuous Corn	7.5	9.1 b	12.0	11.2 ab	10.5 ab	15.4 ab	42.2 a
Photo Period Sorghum	7.5	11.4 ab	15.6	13.1 ab	13.9 a	11.2 ab	35.2 ab
Sweet Sorghum	7.5	8.6 b	12.4	16.1 a	13.3 ab	17.3 a	32.7 ab
Grain Sorghum	7.5	11.6 ab	15.1	6.0 b	9.9 ab	18.0 a	40.1 a
Rotated Corn	7.5	12.3 ab	15.5	9.0 ab	15.4 a	16.1 a	32.1 ab
Miscanthus	7.5	19.4 ab	18.8	12.4 ab	12.4 ab	15.5 ab	22.1 b
Switchgrass (Kanlow)	7.5	15.8 ab	12.9	7.2 b	12.6 ab	15.1 ab	36.9 ab
Big Bluestem	7.5	12.8 ab	17.9	8.5 ab	11.0 ab	16.6 a	33.8 ab
Indiangrass Mix	7.5	26.8 a	15.4	4.7 b	6.1 b	7.8 b	39.9 a
Switchgrass Mix	7.5	14.6 ab	17.1	8.2 ab	9.5 ab	18.7 a	32.5 ab
Continuous Corn	15	3.8	8.2 bc	9.2	14.3	19.0	46.2
Photo Period Sorghum	15	1.1	5.8 d	11.3	14.6	18.3	49.3
Sweet Sorghum	15	10.8	9.6 abc	6.8	10.2	19.0	44.1
Grain Sorghum	15	12.6	7.0 d	7.4	11.2	18.4	43.9
Rotated Corn	15	16.4	7.8 d	6.6	12.1	16.3	41.0
Miscanthus	15	13.3	17.7 ab	8.8	13.1	17.3	30.4
Switchgrass (Kanlow)	15	15.9	18.1 a	7.5	12.3	15.4	31.2
Big Bluestem	15	6.7	13.3 abc	11.2	17.8	13.6	37.8
Indiangrass Mix	15	2.5	11.6 abc	8.3	13.7	19.8	44.4
Switchgrass Mix	15	21.1	12.8 abc	11.2	9.1	12.7	33.6

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Chapter 3 - Soil Wind Erodibility Properties

Abstract

Excessive amounts of crop residue removal for expanded uses, such as a feedstock for bioenergy, may increase the soil's susceptibility to wind erosion. Growing warm-season grasses (WSG) may be an alternative to crop residue removal to reduce wind erosion and generate biomass feedstock for biofuel production. Therefore, this project was designed to quantify the impacts of growing WSG on wind erosion properties as compared with row crops. Soil samples were collected from existing bioenergy crop experiments in Manhattan, Hays, and Colby, KS and analyzed for soil wind erodibility parameters. In Manhattan, soils managed under WSG had a higher geometric mean diameter (GMD) and more stable dry aggregates compared with annual row crops during all sampling periods. Treatment differences during establishment at Colby and Hays were limited. However, WSG had a lower wind erodible fraction (WEF) and higher GMD than row crops as the WSG stands matured. Data from this project show that mature stands of perennial crops can reduce the soil's susceptibility to wind erosion. This study also illustrated that perennial crops may not significantly reduce wind erosion during establishment years. This is particularly true for sites that receive low annual precipitation or during years with precipitation below normal. Results reiterate that proper stand establishment and weed control are not only critical to biomass production but also to soil quality improvement under perennial grasses. Further studies assessing long-term and regional specific effects of alternative cropping systems or perennial rotations with WSG on wind erosion parameters are needed to identify and verify appropriate WSG species.

Introduction

In the central Great Plains, wind erosion is a major concern. The Great Plains witnessed the worst dust storms in United States history during the 1930's (Colacicco et al., 1989). Wind erosion reduces crop production and degrades soil quality by removing the most fertile layer of soil, lowering water-holding capacity, degrading soil structure, and increasing soil variability across a field (Presley and Tatarko, 2009).

It has been well documented that herbaceous wind barriers can reduce wind erosion, improve crop yield, prevent sandblast damage to crops and trap snow to improve soil moisture (Bilbro and Fryrear, 1988). Permanent vegetative cover, provided by WSG, can be one of the most effective ways to control wind erosion (Presley and Tatarko, 2009). Perennial WSG can control wind erosion by stabilizing and anchoring loose and erodible soil with their extensive and deep root systems (Blanco and Lal, 2008). Pikul et al. (2006) found that alternative cropping systems had a greater fraction of large aggregates than soils under conventional cropping system. He also noted that soil aggregates under alternative cropping systems were also less likely to abrade into small aggregates and thus were less susceptible to wind erosion than soils managed under conventional cropping systems.

In the central Great Plains, wind erosion is usually greatest between February and May when winds are high and crops are not present to protect the soil surface (Presley and Tatarko, 2009). Bilbro and Fryrear (1997) concluded that tall and lodge-resistant plants such as switchgrass (*Panicum virgatum* L.) increased the effective distance of wind barriers. These grasses are able to trap blowing soil particles and reduce the loss of windblown materials (Blanco and Lal, 2008). However, it is unknown if biomass removal will negatively impact soil erodibility. This warrants that the assessment of wind erosion parameters of soils managed under dedicated WSG be a priority across the central Great Plains, where soil types and climatic conditions make wind erosion a high concern. This study was designed to quantify the effects of WSG on wind erosion parameters when managed as dedicated biomass production systems in three different moisture regimes in Kansas.

Materials and Methods

Field Experiment Locations and Treatments

This study was conducted during the initial phase of three long-term energy crop experiments in Kansas. The experimental sites were located at (1) the Kansas State University (KSU) Northwest Research-Extension Center in Colby Kansas (39º23’N, 101º03’W), (2) the KSU Agricultural Research Center in Hays Kansas (38º52’N, 99º19’W), and (3) the KSU Agronomy Research Farm at Manhattan (39º11’N, 96º35’W). The duration of this study is from August 2010 through April 2012. Soil types of each location were a Keith silt loam (fine-silty, mixed, super active, mesic Cumulic Hapludolls) at Colby, a Harney silt loam (fine, smectitic, mesic Typic Argiustolls) at Hays and a Kahola silt loam (fine-silty, mixed, super active, mesic Cumulic Hapludolls) at Manhattan. The three sites were primarily selected due to the differences in historic mean annual precipitation. Historic mean annual precipitation included 465 mm at Colby, 579 mm at Hays and 838 mm at Manhattan respectively (High Plains Regional Climate Center).

The study designed is a randomized complete block experiment with four replications at Manhattan and three replications at Colby and Hays. In Manhattan, the individual plot size was 6.1 m wide by 10.7 m long and the dimensions of the plots at Colby and Hays were 6.1 m wide and 6.1 m long. The experiment at Manhattan was established in 2007 and consisted of three perennial warm-season grasses (‘Kanlow’ switchgrass, big bluestem (*Andropogon gerardii* L.),, and miscanthus (Miscanthus × giganteus)), two native grass mixtures (indiangrass (*Sorghastrum nutans* L.) /switchgrass/big bluestem mix and a switchgrass/big bluestem mix), corn (*Zea mays* L.) grown continuously and rotated with soybean, and three sorghum (Sorghum bicolor L. [Moench.]) cultivars (photoperiod sensitive, sweet, and grain sorghum) in rotation with soybeans(*Glycine max* (L.) Merr.).

The corn hybrids grown at Manhattan in 2010 and 2011 were Pioneer ‘33K40’ (Bt) and Pioneer ‘33K44’ (Bt), respectively, both of the same parent family with relative maturity of 114 days (Pioneer Hi-Bred International, Johnston, IA). Sorghum cultivars included Land O’Lakes ‘DKS59-09’ (Land O’Lakes, St. Paul, MN) DP FS, Mississippi State University ‘M81E’ sweet sorghum, Sorghum Partners ‘NK300’ (Sorghum Partners, Inc., New Deal, TX) DP FS, and

Sorghum Partners ‘1990CA’ PS sorghum. The soybean variety planted at Manhattan both study years for rotational purposes was KSU Foundation ‘KS3406RR’ (Kansas State Univ., Manhattan, KS).

The experiments at Hays and Colby were established in spring 2009 and consisted of two varieties of switchgrass (‘Pathfinder’ and ‘Blackwell’), indiangrass, big bluestem, sand bluestem [*Schizachyrium scoparium* (Michx.) Nash], eastern gamagrass (*Tripsacum dactyloides* L.*)* mixed native grasses, miscanthus, forage sorghum, grain sorghum, and no-till wheat (*Triticum aestivum* L.)-sorghum-fallow (W-S-F) with (100%) and without (0%) residue removal.

Establishment of WSG stand in Colby and Hays was challenging as low annual precipitation (Figure 2.5) and high weed pressure limited growth of young plants. In 2011, select plots were abandoned at Colby which included the Pathfinder switchgrass, indiangrass, big bluestem, sand bluestem, eastern gamagrass and mixed native grass treatments. Additionally, annual row crops production was also reduced or eliminated during this time period at Colby and Hays due to lower than average annual rainfall and concentrated animal pest pressure. During the 2011 growing season, proper weed control at Colby and Hays improved stand quality and biomass production. This was accomplished by applying 0.56 kg ha^{-1} of quinclorac herbicide pre-emergence to the spring 2011 growing season. Additional herbicide applications of Starane (flurozypyr), 0.56 kg ha^{-1}, and 2, 4-D dimethylamine [(2, 4-dichlorophenoxy) acetic acid] 0.56 kg ha^{-1} were applied at the three leaf stage. Hand weeding with the use of hand clippers was also done as necessarythroughout the growing season both years.

Measurement of Soil Wind Erodibility Properties

Aggregate size distribution (Chepil, 1950, 1953), aggregate stability (Skidmore and Layton, 1992), and surface roughness (Hagen and Armbrust, 1992) were measured and wind erodible fraction (WEF), aggregate geometric mean diameter (GMD), and geometric standard deviation (GSD) were computed for each site. These parameters were used to evaluate the impact of energy crops on soil wind erodibility. Soil samples were collected across different seasons to study how changes or differences in biomass removal and precipitation input affected soil response to energy crops. Soil samples for the determination of soil wind erodibility were collected in spring 2011, fall 2011, and spring 2012 from the three sites (Colby, Hays, and Manhattan).

Aggregate Size Distribution

Aggregate size distribution (ASD) was determined at the beginning and end of the growing season between 2011 and 2012 (Table 3.1) of select treatments at each location. Treatments sampled at the Colby and Hays locations included Blackwell switchgrass, miscanthus, grain sorghum, sweet sorghum, W-S-F 0% residue removal and W-S-F 100% residue removal. The Manhattan treatments sampled included continuous corn, photo period sensitive sorghum, sweet sorghum, grain sorghum, miscanthus, Kanlow switchgrass and big bluestem. Samples were collected using a flat shovel to collect a soil sample that was approximately 4 kg. The soil samples were taken with care from each plot to ensure that samples were collected with intact aggregates for the 0 to 5 cm soil depth. Samples were then placed into collection pans for transport and drying. The pans were oven-dried at 60°C for 2 days. The dry samples were then passed through a rotary sieve apparatus (Chepil, 1962 and Lyles et al., 1970). Sample aggregate sizes were collected in drop pans and weighed from each of the different sieve size fractions. Sieve size fractions included: <0.42, 0.42-0.84, 0.84-2.0, 2.0-6.35, 6.35-14.05, 14.05-44.45 and >44.45mm. As indicated earlier, calculations determined from the mass of the different size fractions included the WEF or the percent of aggregates less than 0.84 mm in diameter (%< 0.84mm), GMD, and GSD. The equation used to determine GMD and GSD were derived from the Wagner and Ding (1994) method as follows;

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

and

$$\mathrm{GSD} = \exp\left[\sum \mathrm{m_i}\ (\ln \mathrm{d_i})^2 - (\ln \mathrm{GMD})^2\right]^{0.5}$$

These parameters are considered a good measure of dry aggregate size distribution since it has been shown that size distribution of the dry surface soil is commonly log-normal distributed (Hagen et al., 1987).

Aggregate Stability

Separate samples were collected from the same select plots previously described to determine the stability of individual aggregates. Samples were collected using a flat shovel for a 5cm soil depth and passed through a 19.0 mm diameter sieve in the field. Field samples were then air-dried for 72 h. A subsample of 30 aggregates approximately 3 to 10 grams in mass were selected from each air-dry sample and were finger manipulated to obtain an approximate spherical shape. Each aggregate was then individually crushed using a crushing meter. The aggregate crushing-meter apparatus consisted of two parallel plates, supported by a load cell, which was connected to a computer which measures the crushing energy of the aggregate (Boyd et al., 1983). For the purpose of these studies, dry aggregate stability is expressed as the natural log of the crushing energy per unit mass (Hagen et al., 1992).

Surface Roughness

Surface roughness was measured from the surface of selected plots using a microrelief pin meter. The meter was designed with 101 pins that were placed on a metal guide which was attached to the backboard of the meter. Each pin was 50 cm long, 6 mm in diameter and spaced 10 mm apart (i.e., 1 m total length). Two metal supporting arms were connected to the back board so the meter can stand freely as a tripod apparatus. A digital camera was placed at the junction of the two supporting arms. Before placing the meter in the plot, a section of soil was prepared by removing most of the residues. After preparation the meter was placed in the plot with the pins aligned with the prepared surface. Once in place, the pin guide was released from the backboard of the meter, and the pins were allowed to freely move vertically to conform to the soil surface. The pins were allowed to rest on the surface of the soil making sure no pins were resting on a piece of residue. If the pin came to rest on a piece of residue, the residue was removed so that the pin rested on the soil surface. A picture was taken of the tops of the pins at each site. Photos were then processed using Sigma Scan Pro 5(SPSS Science, 1998) and roughness was calculated as the standard deviation of height readings, after the readings were corrected for slope (Wagner and Yu, 1991).

Statistical Analysis

Data were statistically analyzed using PROC Mixed in SAS 9.2 (SAS Institute, 2008). Least square differences were used to determine differences at the 0.05 probability levels (SAS Institute, 2008). Significance of main effect differences and their interactions was determined, with species as the fixed effect and replication as the random effect.

Results and Discussion

Aggregate Size Distribution

Treatment effects on soil wind erodibility properties were variable due to differences in plant maturity and biomass production among the three sites. In spring 2011 (four years after experiment establishment), the treatments in Manhattan showed the greatest effects (Figure 3.3). The wind erodible fraction (WEF) under miscanthus (6.9%) and Kanlow switchgrass (7.9%) was lower than under row crops. The highest WEF of all was observed under the sweet sorghum treatment (18.99%). The reduced WEF under miscanthus and Kanlow switchgrass treatments is attributed to the extensive root system and increased continuous uniform surface cover relative to row crops.

The GMD results displayed similar trends to the WEF data at Manhattan in spring 2011. The GMD of the Kanlow switchgrass (31.7), miscanthus (28.6) and big bluestem (15.0) treatments did not differ (Figure 3.6). However, Kanlow switchgrass and miscanthus had higher GMD values than row crops. The Kanlow switchgrass (10.6) had lower geometric standard deviation (GSD) than continuous corn (14.2) and grain sorghum (14.0). Additionally, miscanthus (10.9) had a lower GSD than continuous corn (14.2). Overall, the three WSG species displayed better dry aggregate stability values, indicating an improvement in the soils physical properties and a reduced susceptibility to wind erosion. The limited effect of big bluestem as opposed to the other grass treatments may be explained by the fact that this native grass had the least mature stand at the time of sampling, which was 4 years after establishment. This can be verified by the lower biomass yields as discussed in Chapter 4.

In spring 2011 (two years after experiment establishment), no treatment differences were observed for WEF, GMD, and GSD at either Colby or Hays (Figures 3.1, 3.2, 3.4 and 3.5) (Table 3.2 and 3.3). Immature stands and limited biomass production which lead to minimal vegetative cover and thus , limited protection of the soil surface, are likely the reasons for the lack of differences between WSG and row crop treatments in Hays and Colby in spring 2011.

Following harvest, additional samples were collected from the same plots that were previously sampled in the spring of 2011 at all sites. The sample timing allowed treatments to complete a full growing season, but were taken prior to exposure of winter conditions. Data from this sampling period are valuable, as they can show which treatment may resist better the winter weathering caused by freezing and thawing.

During fall 2011, the WSG treatments at Manhattan once again had a lower WEF than row crops (Figure 3.3). This time, the WEF in big bluestem (10.9%) and Kanlow switchgrass (6.6%) was lower than the row crops, while WEF in miscanthus (13.2%) was lower than row crop treatments at the P=0.10 level. The GMD data were similar to WEF data in fall and spring 2011. Kanlow switchgrass (21.0 mm) had the highest GMD (Figure 3.6). Row crops and big bluestem displayed similar values. Similarly, Kanlow switchgrass (8.9) had lower GSD than continuous corn (14.3), grain sorghum (13.9) and photo period sensitive sorghum (13.7) (Table 3.4) at Manhattan in fall and spring 2011.

In fall 2011, mean WEF among treatments at the Colby site was not significant, mirroring the data from spring 2011 (Figure 3.1). The lack of significant effects was most likely due to poor stand quality and lower biomass production at this site. However, WEF at the Hays site began to show significant differences. The W-S-F 100% (59.1%) removal treatment had the highest WEF, while Blackwell switchgrass (2.58%) had the lowest WEF (Figure 3.2). The WEF of the Blackwell switchgrass was similar to all other treatments. The improved soil quality of the Blackwell switchgrass treatment was also observed through the GMD data as it had the highest GMD value of any treatment (Figure 3.5). No differences were present in GSD values at the Colby and Hays sites (Table 3.2 and 3.3). Better weed control during the 2011 growing season, which led to better stands and higher yields, probably explains the improved soil properties and reduced susceptibility to wind erosion under switchgrass in this period.

At Manhattan, in spring 2012, treatment effects were similar to those in fall 2011. The three grass treatments continued to show improved soil properties and were less susceptible to wind erosion when compared with row crops. All of the grass treatments had lower WEFs than the row crop treatments (Figure 3.3). Miscanthus (13.56%) had the lowest WEF of all treatments. The row crop treatments had similar WEF values, except for the sweet sorghum (31.7%) which had a lower WEF than continuous corn (43.1%). It is interesting to note that sweet sorghum had the highest WEF in 2011. This is most likely explained by the spatial variability in each plot. While samples were consistently taken between rows, the sampling location within the plot changed each sampling period. No consistent trends in soil wind erodibility among grass treatments nor among row crop treatments were observed.

The GMD data in spring 2012 also followed trends of previous sampling periods. The miscanthus (9.3) had the highest GMD of all treatments, but it was similar to both the Kanlow switchgrass (6.6) and big bluestem (5.8) treatments (Figure 3.6). Big bluestem had similar values to row crop treatments, while Kanlow switchgrass was higher than continuous corn (1.2). For the same period, GSD means among grass treatments did not differ, but th grass GSD values were lower than row crop treatments (Table 3.4). All of the row crop treatments displayed similar GSD values for this time period.

In spring 2012, at Colby, WEF values differed among treatments for the first time (Figure 3.1). The Blackwell switchgrass (30.7%) treatment had the lowest WEF and was similar only to the W-S-F 100% (34.2%) removal treatment (Table 3.2). The remaining treatments did not differ. In this period, GMD showed similar trends to WEF at Colby (Figure 3.4). The Blackwell switchgrass (2.7) treatment had the highest GMD and was only similar to the W-S-F 100% (2.2) removal treatment. No differences in GSD were present in spring 2012 (Table 3.2). Results indicate that perennial WSG may improve soil quality in the long-term as the grass stands mature. However, the need for proper management, such as effective weed control cannot be over emphasized to increase biomass production and improve soil quality.

At Hays, the Blackwell switchgrass (42.2%) treatment continued to have the lowest WEF in spring 2012 (Figure 3.2). Similar to WEF, Blackwell switchgrass (2.1) had a higher GMD than the rest of treatments (Figure 3.5). The GMD did not differ among row crop treatments. The Blackwell switchgrass (13.2) also had a higher GSD than any of the other treatments (Table 3.3). Data from spring 2012 for the Hays site suggest that WSG can improve soil quality parameters even when they have not reached their full potential. Similarly, at Colby, despite the slow growth, Blackwell switchgrass and miscanthus have started to show some signs of soil quality improvement. This trend is expected to continue as the stands mature.

Aggregate Stability

In spring 2011, the miscanthus (4.12 ln J kg^{-1}) treatment had the highest aggregate stability at the Manhattan site (Figure 3.9). The other two grass treatments, Kanlow switchgrass (3.65 ln J kg^{-1}) and big bluestem (3.60 ln J kg^{-1}) had similar values, but switchgrass displayed a higher aggregate stability than row crops. All row crop treatments had similar values. These results were consistent with WEF measured in spring 2011 previously discussed. Data on aggregate stability were similar among treatments in spring and fall 2011 for the Manhattan site. However, the treatment differences in fall 2011 were not as distinct as in spring 2011 (Figure 3.9). This may be expected as the soils have not been exposed to winter conditions. All of the treatments showed similar values except for the Kanlow switchgrass and big bluestem treatments, which had a greater aggregate stability value than grain sorghum and sweet sorghum. In spring 2012, the treatments in Manhattan continued to display trends similar to the previous two sampling periods. Treatment differences were particularly distinct in spring, probably due to freezing and thawing cycles during winter. Miscanthus (4.08 ln J kg^{-1}) and big bluestem (3.87 ln J kg^{-1}) had the highest aggregate stability (Figure 3.9).

Unlike the Manhattan site, differences in aggregate stability among treatments were not significant at Colby and Hays in spring 2011(Figure 3.8). The lack of statistical differences in aggregate stability at both sites could be explained by poor stands and low biomass production of the WSG. The small differences among treatments were more likely caused by spatial variability than by the actual treatment. Similar results were observed in fall 2011. In spring 2012, no treatment effects were present at Colby (Figure 3.7), but at the Hays location, Blackwell switchgrass (3.73 ln J kg^{-1}) had the greatest value (Figure 3.8). All other treatments yielded similar values. The increased aggregate stability under switchgrass for the Hays site suggests that resistance of soil to erosion can increase as WSG treatments mature, and produce more biomass. This conclusion is supported by the results from the Manhattan site. Even though no baseline aggregate stability data was taken at Manhattan it is likely that the observed treatment affects are due to the extensive root system and continuous surface cover provided by the more mature and productive WSG systems. Long-term data collection is needed in less productive systems, such as Colby and Hays, to determine the effects a well established WSG stand will have on aggregate stability.

Surface Roughness

The WEF and aggregate stability, discussed previously, are critical to evaluating soil susceptibility to wind erosion. Another important factor of soil erodibility is soil surface roughness. A soil surface that is vegetated or contains cloddy rough ridges can greatly alter the wind speed at the soil surface (Blanco and Lal, 2008). This reduction in wind speed can greatly reduce the energy available to transport soil particles and further break down clods. If there is insufficient vegetation or roughness on the soi l surface, emergency tillage practices are used during high wind erosion periods in an effort to reduce the negative impacts of an erosion event. For this reason, it is relevant to measure and compare the surface roughness of each treatment.

Roughness data were collected at the same time as the WEF and aggregate stability samples each season. The roughness data across all sites greatly varied between seasons and no consistent trends were observed. An effort was made to take roughness measurements from the same location within the plot each year in an effort to reduce the effects of spatial variability. However, planting, harvesting and plot maintenance activities often changed the roughness factor each season. This was particularly evident with the annual row crops since annual planting increased machine traffic on each plot. Even in a no till system, depressions and ridges made by tractor tires and planter disks were visible.

In spring 2011, roughness values at Hays did not show any differences among treatments (Figure 3.11). Differences were observed at the Colby and Manhattan sites; however, as previously mentioned, these trends would not continue in the subsequent sampling periods. At Colby, miscanthus had the lowest value and the grain sorghum treatment had the highest (Figure 3.10). These two treatments were the only two that differed from each other. In Manhattan, big bluestem and photo period sensitive sorghum had the lowest roughness (Figure 3.12), but all other treatments exhibited similar values.

In fall 2011, treatments effects were also inconsistent. Contrary to the pervious sampling, differences were only observed at the Hays location in the fall of 2011 (Figure 3.11). At Hays, the miscanthus treatment resulted in the greatest roughness value followed by grain sorghum. In the spring of 2012, treatment effects at Colby were significant at the P=0.10 level where Blackwell switchgrass had greater roughness than sweet sorghum. The values at Hays and Manhattan were inconsistent similar to previous sampling periods. In Hays, Blackwell switchgrass had higher roughness factor than all other treatments except for miscanthus (Figure 3.11). All of the row crop treatments had similar roughness values. In Manhattan, miscanthus had the highest roughness value and differed from all of the row crop treatments. However, it was similar to the two other grass treatments. These roughness values may not show direct treatment differences as seasonal changes yielded inconsistent effects. However, these data can be useful input for model applications.

Conclusions

Data on soil wind erodibility illustrate that mature stands of perennial crops can reduce soil susceptibility to wind erosion. This study also showed that perennial crops may not significantly reduce wind erosion during establishment years. This is particularly true for sites that receive low annual precipitation or during years with below average precipitation. Results suggest that proper stand establishment and weed control are not only critical to biomass production but also to control of wind erosion under perennial grasses.

Perennial crops such as WSG offer potential for reducing wind erosion and improving the overall soil quality in addition to producing biomass for expanded uses. This is especially true in areas where soil quality, water resources and growing conditions are considered to be marginal or unpractical for row crop production. Furthermore, the perennial WSG have the potential to be placed in a long-term rotation as a low input soil builder to improve future production of cash crops. Although this study suggests potential soil improvement benefits from perennial WSG, it also has exposed some of the limitations that may occur with stand establishment, stand failures and overall management of WSG. Further studies assessing long-term and regional specific effects of alternative crop systems or perennial crop rotations with WSG on wind erosion parameters are needed to verify and identify appropriate WSG species.

Figures and Tables

Figure 3.1 Wind Erodible Fraction (% <0.84 mm) at Colby, KS. Treatments with different letters indicate significant differences at the P=0.05 level. NS indicates no significant differences among treatments.

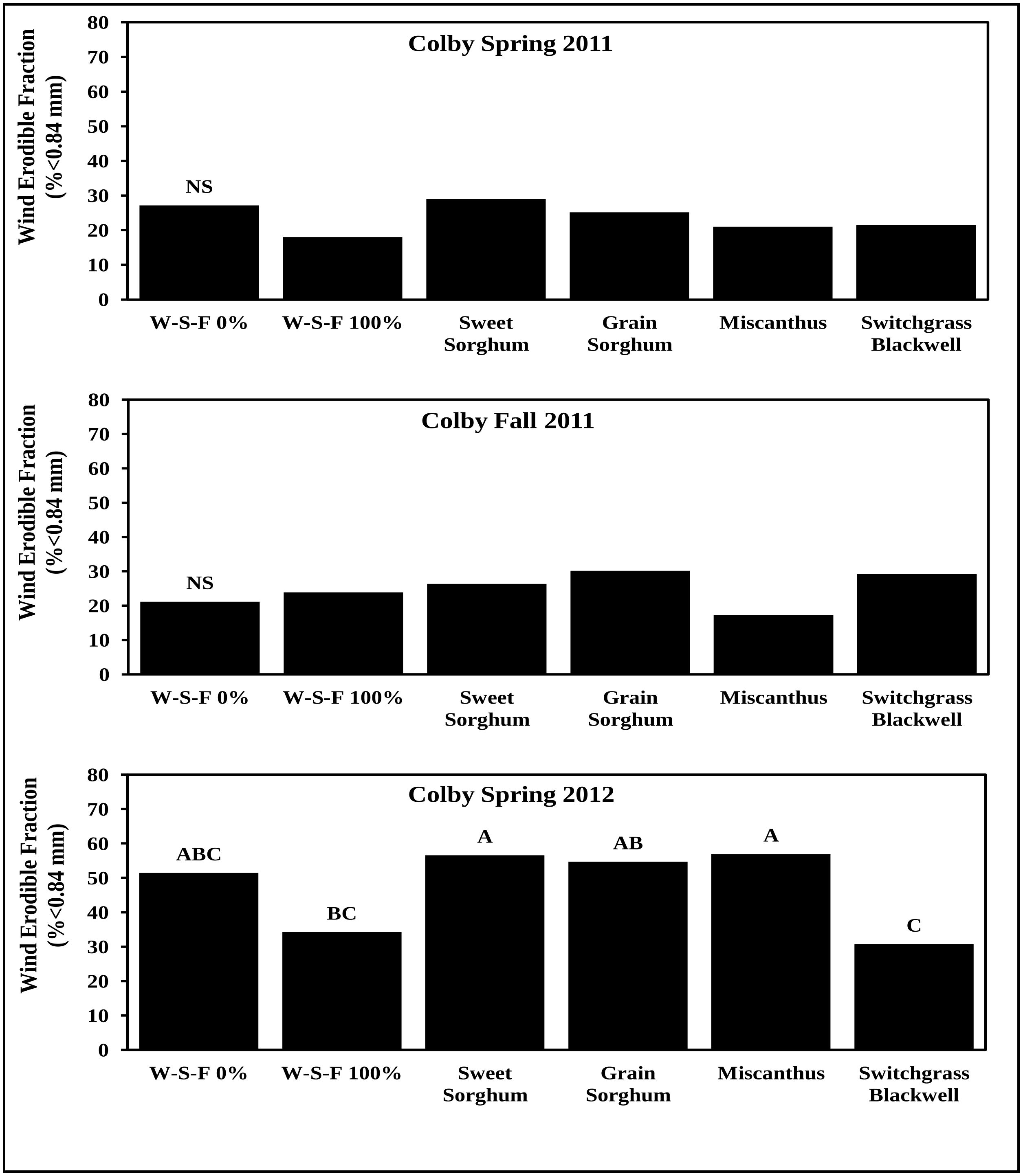


Figure 3.2 Wind Erodible Fraction (% <0.84 mm) at Hays, KS. Treatments with different letters indicate significant differences at the P=0.05 level.

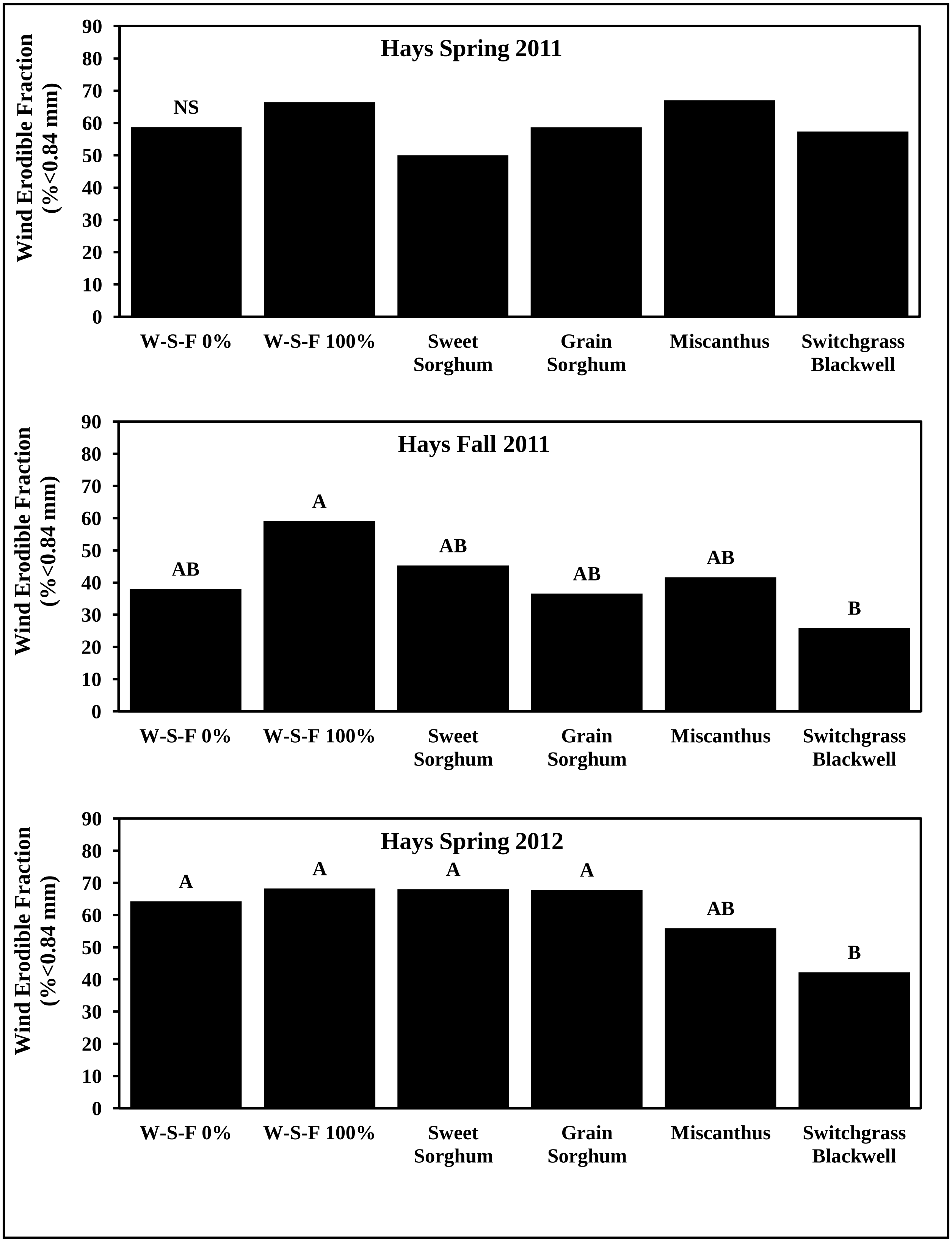


Figure 3.3 Wind Erodible Fraction (% <0.84 mm) at Manhattan, KS. Treatments with different letters indicate significant differences at the P=0.05 level.

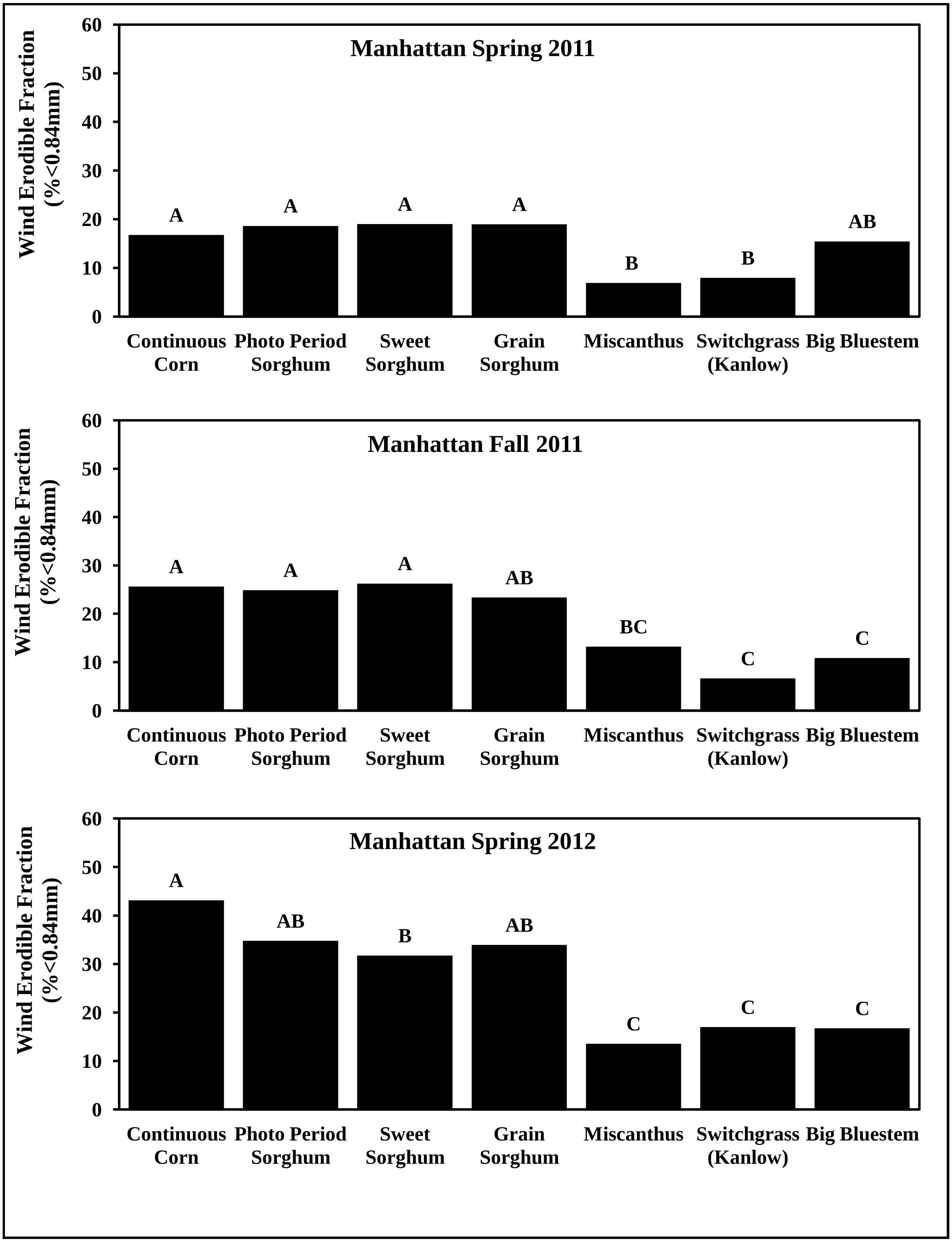


Figure 3.4 Geometric mean diameter (GMD) of dry aggregates Colby, KS. Treatments with different letters indicate significant differences at the P=0.05 level. NS indicates no significant differences among treatments.

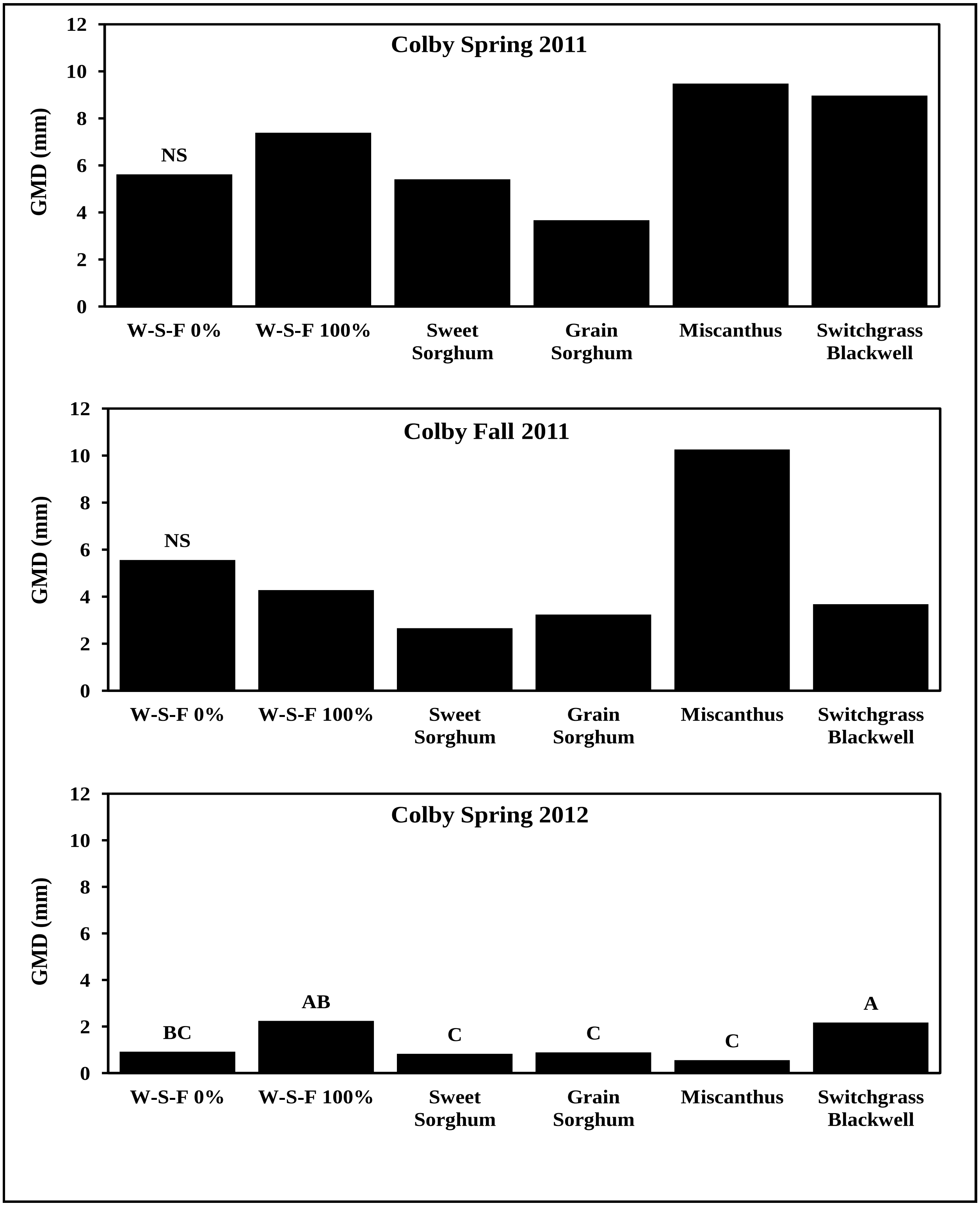


Figure 3.5 Geometric mean diameter (GMD) of dry aggregates Hays, KS. Treatments with different letters indicate significant differences at the P=0.05 level. NS indicates no significant differences amoing treatments.

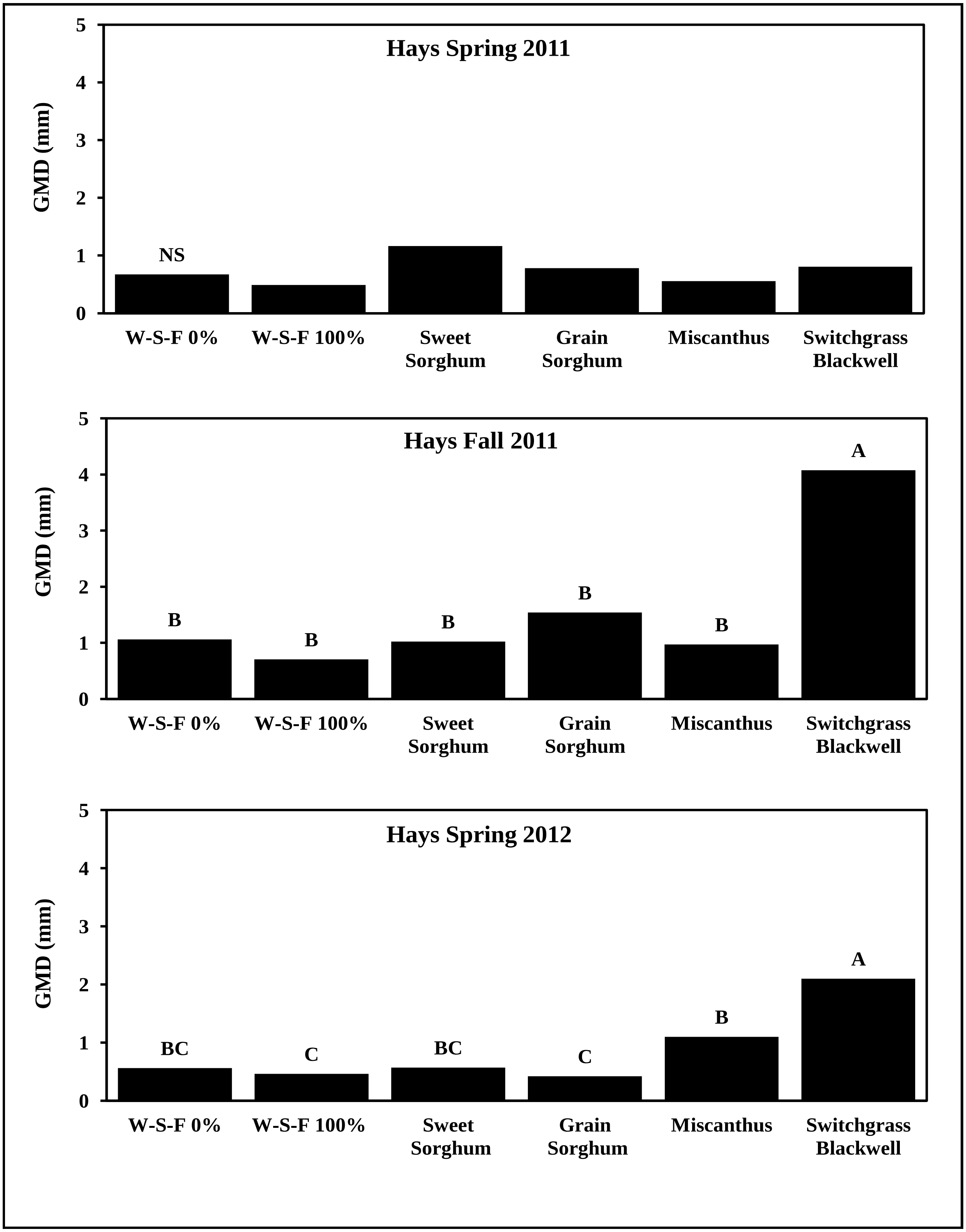


Figure 3.6 Geometric mean diameter (GMD) of dry aggregates Manhattan, KS. Treatments with different letters indicate significant differences at the P=0.05 level.

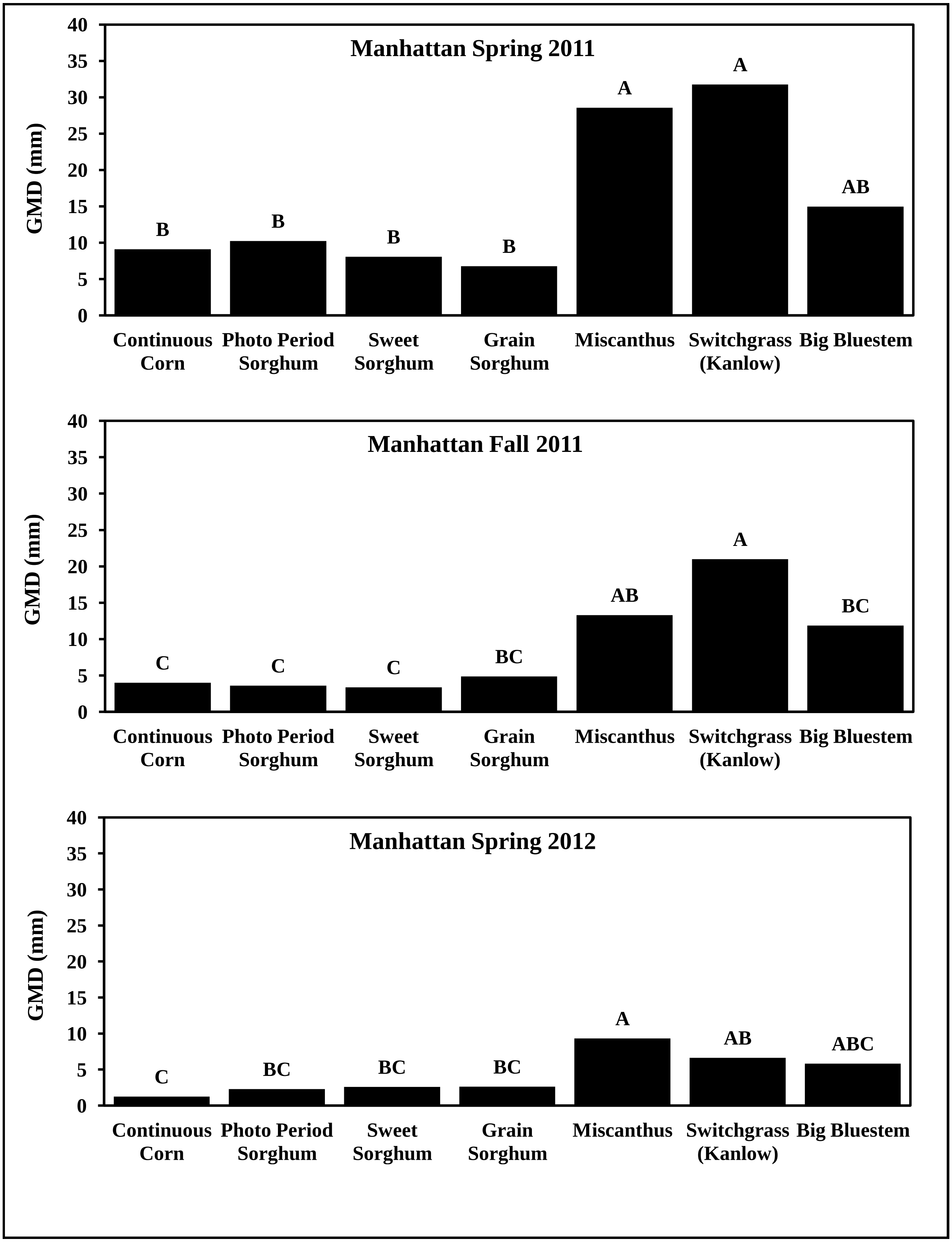


Figure 3.7 Aggregate stability at Colby, KS. Treatments with different letters indicate significant differences at the P=0.05 level. NS indicates no significant differences among treatments.

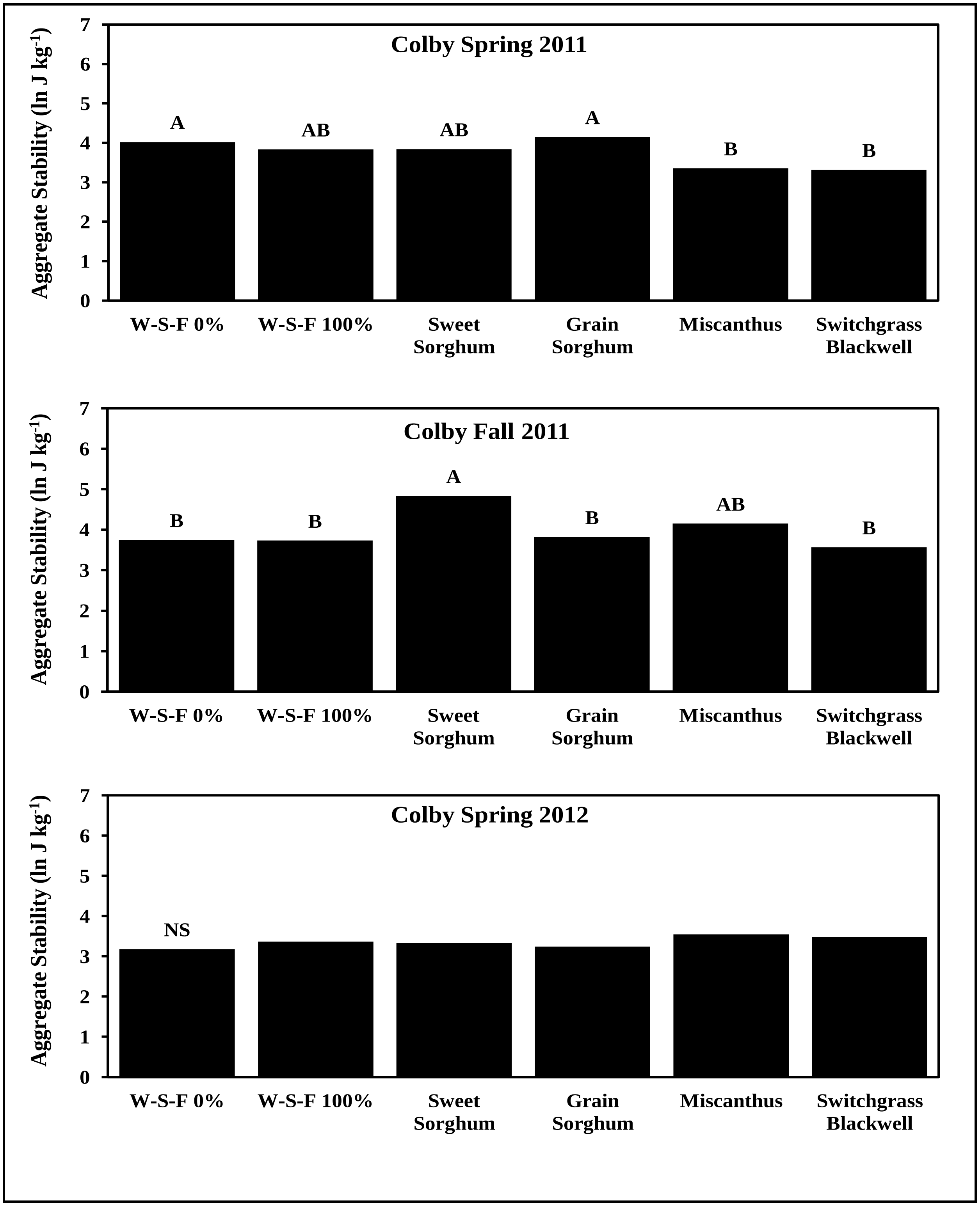


Figure 3.8 Aggregate stability at Hays, KS. Treatments with different letters indicate significant differences at the P=0.05 level. NS indicates no significant differences among treatments.

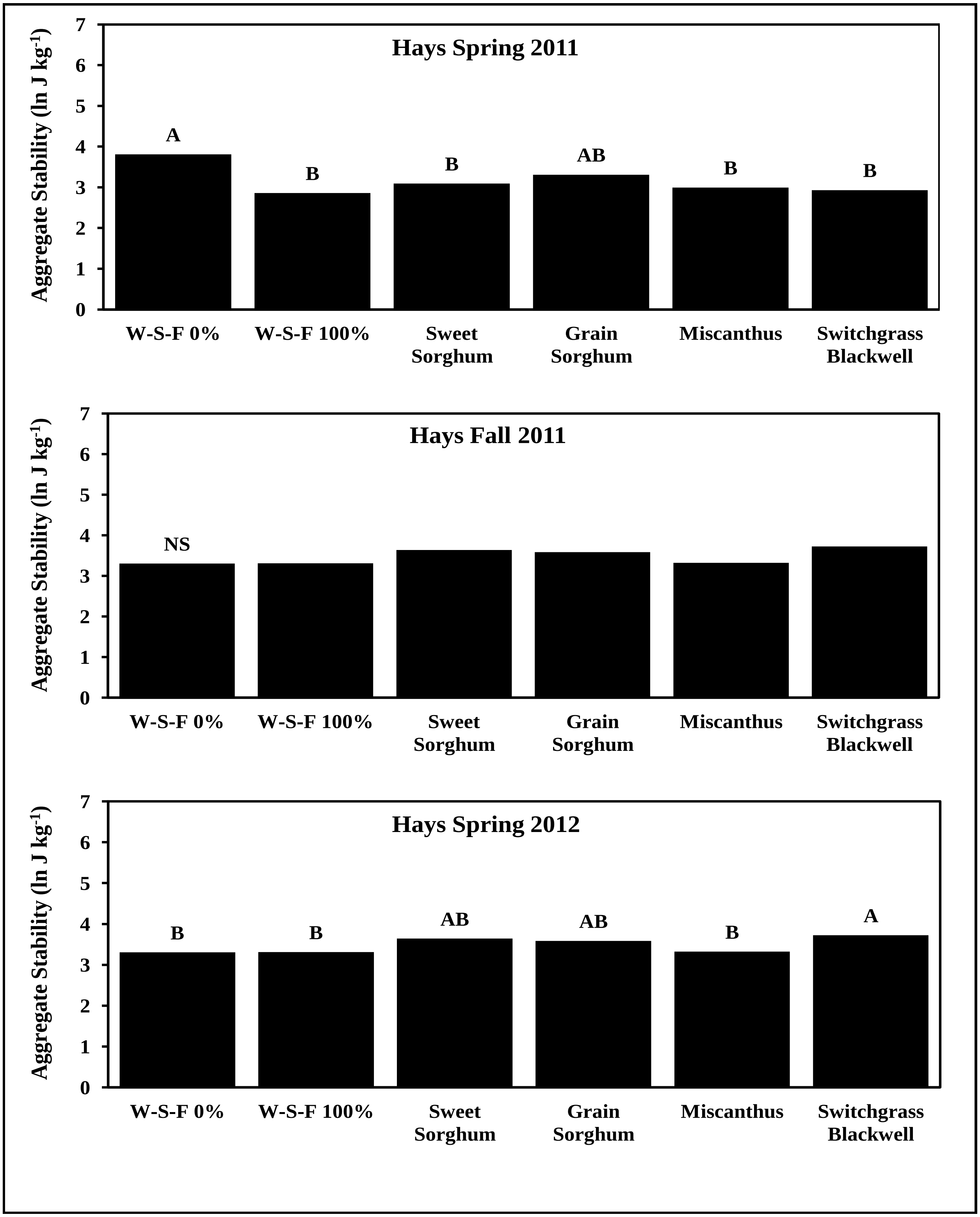


Figure 3.9 Aggregate stability at Manhattan, KS. Treatments with different letters indicate significant differences at the P=0.05 level.

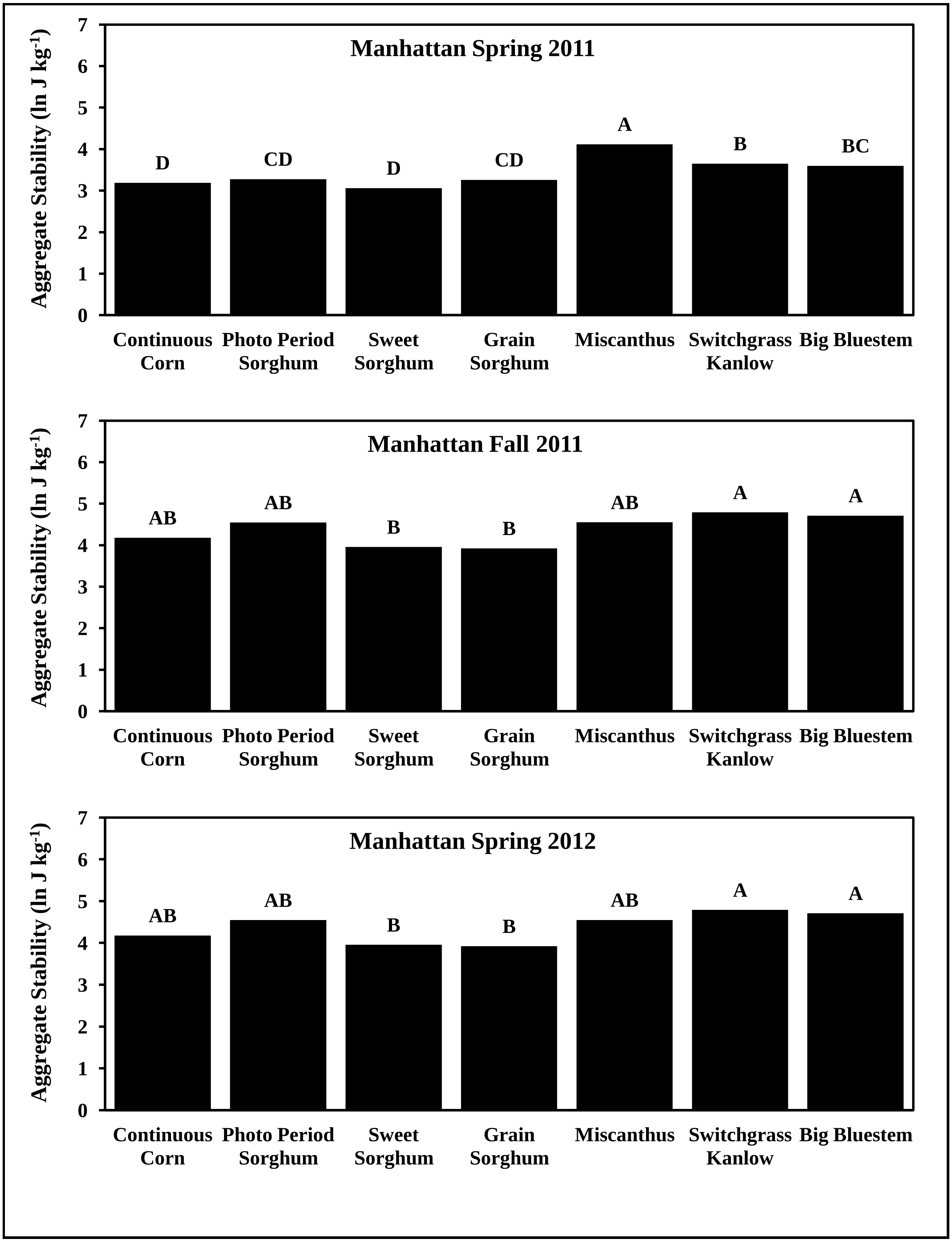
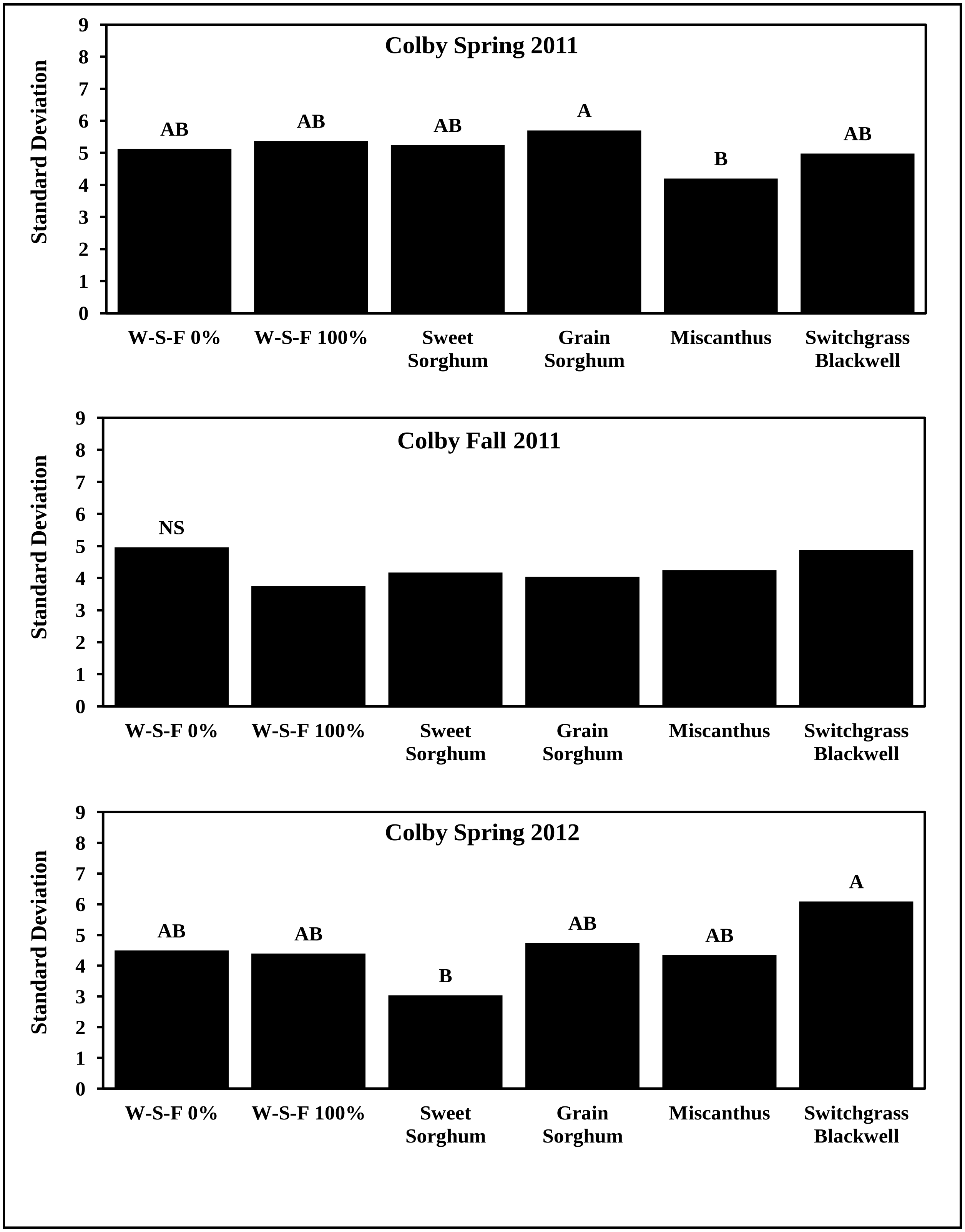


Figure 3.10 Surface roughness at Colby, KS. Treatments with different letters indicate significant differences at the P=0.05 level. NS indicates no significant differences among treatments.



Colby Spring 2011

Colby Fall 2011

Colby Spring 2012

Figure 3.11 Surface roughness at Hays, KS. Treatments with different letters indicate significant differences at the P=0.05 level. NS indicates no significant differences among treatments.

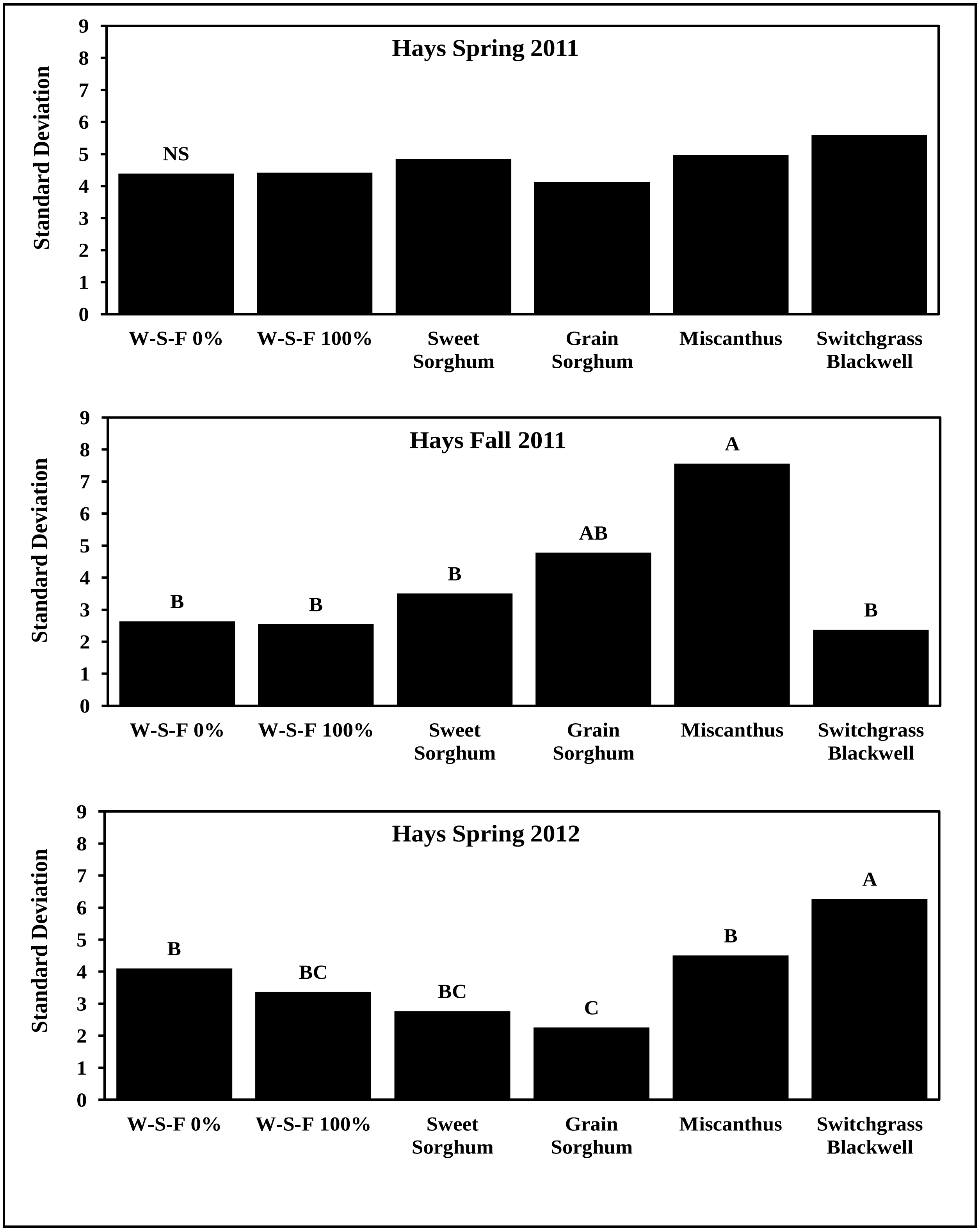
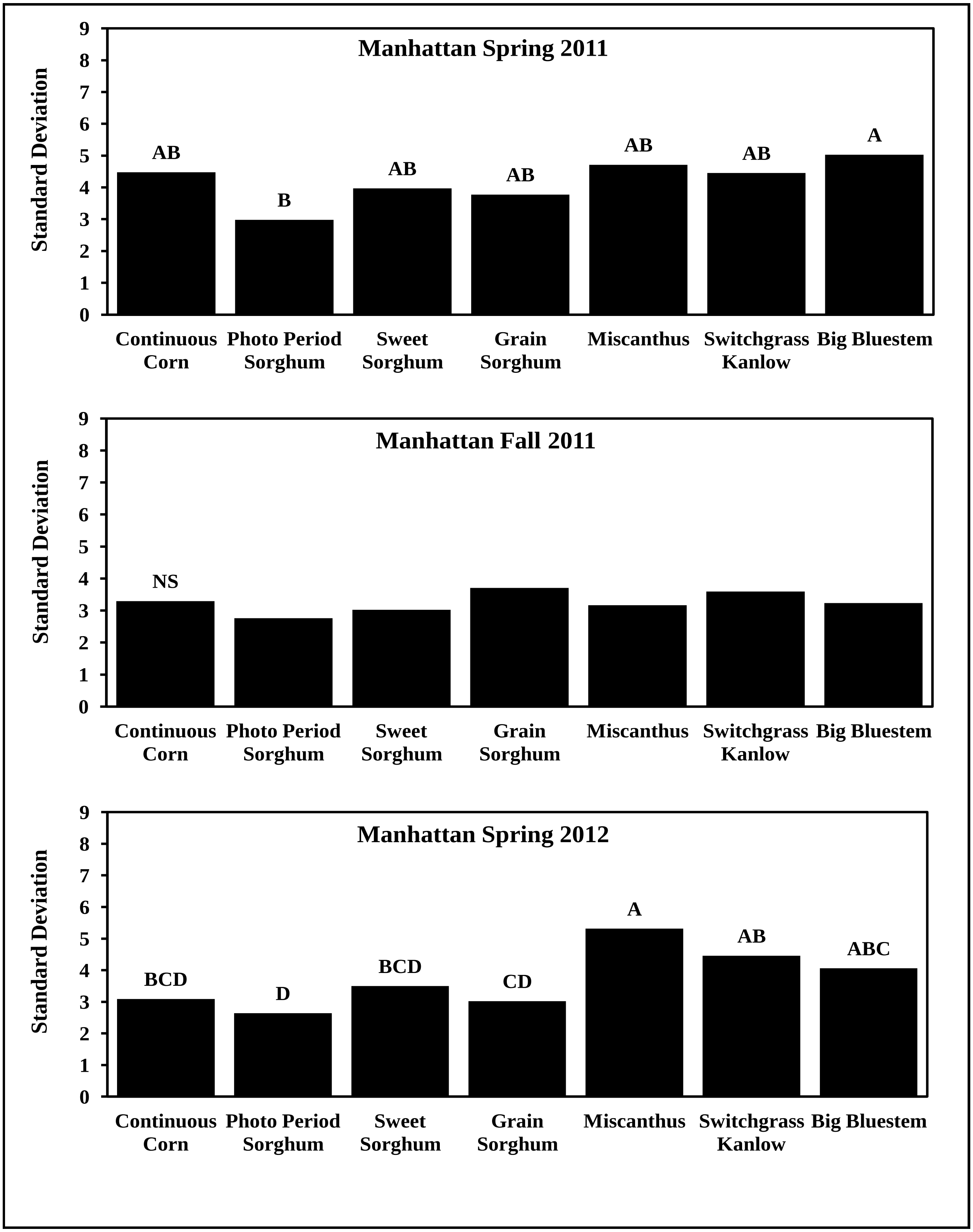


Figure 3.12 Surface roughness at Manhattan, KS. Treatments with different letters indicate significant differences at the P=0.05 level. NS indicates no significant differences among treatments.



Manhattan Spring 2011

Manhattan Fall 2011

Manhattan Spring 2012

Table 3.1 Schedule of wind erosion parameter sample dates.

Site	Time Period	Sample Date
Colby	Spring 2011	22 March 2011
Hays	Spring 2011	23 March 2011
Manhattan	Spring 2011	1 May 2011
Colby	Fall 2011	25 Nov. 2011
Hays	Fall 2011	25 Nov. 2011
Manhattan	Fall 2011	29 Nov. 2011
Colby	Spring 2012	18 March 2012
Hays	Spring 2012	19 March 2012
Manhattan	Spring 2012	14 March 2012

Table 3.2 Wind erodible fraction (%< 0.84 mm), mean geometric mean diameter (GMD) and geometric standard deviation (GSD) for the Colby site. Means accompanied by the same letter within the same column are not significantly different at the P=0.05 level.

Spring 2011

Site	Treatment	% <0.84 (mm)	GMD (mm)	GSD
Colby	Switchgrass (Blackwell)	21.5	9.0	10.7 a
Colby	Miscanthus	21.0	9.5	10.7 a
Colby	Grain Sorghum	25.2	3.7	7.3 b
Colby	Sweet Sorghum	29.0	5.4	11.4 a
Colby	W-S-F 0% residue removal	27.2	5.6	9.8 ab
Colby	W-S-F 100% residue removal	18.0	7.4	8.5 ab

Fall 2011

Site	Treatment	% <0.84 (mm)	GMD (mm)	GSD
Colby	Switchgrass (Blackwell)	29.2	3.7	14.0
Colby	Miscanthus	17.3	10.3	9.8
Colby	Grain Sorghum	30.1	3.2	15.1
Colby	Sweet Sorghum	26.3	2.7	12.6
Colby	W-S-F 0% residue removal	21.2	5.6	14.9
Colby	W-S-F 100% residue removal	23.9	4.3	12.0

Spring 2012

Site	Treatment	% <0.84 (mm)	GMD (mm)	GSD
Colby	Switchgrass (Blackwell)	30.7 c	2.7 a	11.1
Colby	Miscanthus	56.9 a	0.6 c	10.1
Colby	Grain Sorghum	54.7 ab	0.9 c	10.1
Colby	Sweet Sorghum	56.6 a	0.8 c	10.2
Colby	W-S-F 0% residue removal	51.4 abc	0.9 bc	9.6
Colby	W-S-F 100% residue removal	34.2 bc	2.2 ab	13.0

Table 3.3 Wind erodible fraction (%< 0.84 mm), mean geometric mean diameter (GMD) and geometric standard deviation (GSD) for the Hays site. Means accompanied by the same letter within the same column are not significantly different at the P=0.05 level.

Spring 2011

Site	Treatment	% <0.84 (mm)	GMD (mm)	GSD
Hays	Switchgrass (Blackwell)	57.4	0.81	10.2
Hays	Miscanthus	67.1	0.56	11.6
Hays	Grain Sorghum	58.7	0.78	12.5
Hays	Sweet Sorghum	50.0	1.17	13.2
Hays	W-S-F 0% residue removal	58.8	0.67	11.3
Hays	W-S-F 100% residue removal	66.5	0.49	8.8

Fall 2011

Site	Treatment	% <0.84 (mm)	GMD (mm)	GSD
Hays	Switchgrass (Blackwell)	25.8 b	4.08 a	10.0
Hays	Miscanthus	41.6 ab	0.97 b	9.6
Hays	Grain Sorghum	36.5 ab	1.54 b	11.0
Hays	Sweet Sorghum	45.3 ab	1.02 b	10.2
Hays	W-S-F 0% residue removal	38.0 ab	1.06 b	8.8
Hays	W-S-F 100% residue removal	59.1 a	0.70 b	10.1

Spring 2012

Site	Treatment	% <0.84 (mm)	GMD (mm)	GSD
Hays	Switchgrass (Blackwell)	42.2 b	2.1a	13.2 a
Hays	Miscanthus	55.9 ab	1.1 b	11.0 b
Hays	Grain Sorghum	67.8 a	0.42 c	8.3 c
Hays	Sweet Sorghum	68.0 a	0.57 bc	8.3 c
Hays	W-S-F 0% residue removal	64.3 a	0.56 bc	8.3 c
Hays	W-S-F 100% residue removal	68.3 a	0.46 c	8.1 c

Table 3.4 Wind erodible fraction (%< 0.84 mm), mean geometric mean diameter (GMD) and geometric standard deviation (GSD) for the Manhattan site. Means accompanied by the same letter within the same column are not significantly different at the P=0.05 level.

Spring 2011

Site	Treatment	% <0.84 (mm)	GMD (mm)	GSD
Manhattan	Continuous Corn	16.7 a	9.1 b	14.2 a
Manhattan	Photo Period Sorghum	18.6 a	10.2 b	12.3 abc
Manhattan	Sweet Sorghum	19.0 a	8.1 b	12.8 abc
Manhattan	Grain Sorghum	18.9 a	6.8 b	14.0 ab
Manhattan	Miscanthus	6.9 b	28.6 a	10.9 bc
Manhattan	Switchgrass (Kanlow)	7.9 ab	31.7 a	10.6 abc
Manhattan	Big Bluestem	15.4 ab	15.0 ab	13.6 c

Fall 2011

Site	Treatment	% <0.84 (mm)	GMD (mm)	GSD
Manhattan	Continuous Corn	25.6 a	4.0 c	14.3 a
Manhattan	Photo Period Sorghum	24.9 a	3.6 c	13.7 a
Manhattan	Sweet Sorghum	26.3 a	3.4 c	12.7 ab
Manhattan	Grain Sorghum	23.4 ab	4.9 bc	13.9 a
Manhattan	Miscanthus	13.2 bc	13.3 ab	11.9 ab
Manhattan	Switchgrass (Kanlow)	6.6 c	21.0 a	8.9 b
Manhattan	Big Bluestem	10.9 c	11.9 bc	9.8 ab

Spring 2012

Site	Treatment	% <0.84 (mm)	GMD (mm)	GSD
Manhattan	Continuous Corn	43.1 a	1.2 c	16.8 a
Manhattan	Photo Period Sorghum	34.8 ab	2.3 c	17.3 a
Manhattan	Sweet Sorghum	31.7 b	2.6 bc	18.6 a
Manhattan	Grain Sorghum	33.9 ab	2.6 bc	17.1 a
Manhattan	Miscanthus	13.6 c	9.3 a	9.9 b
Manhattan	Switchgrass (Kanlow)	17.0 c	6.6 ab	11.5 b
Manhattan	Big Bluestem	16.7 c	5.8 abc	11.3 b

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Chapter 4 - Biomass Yield and Forage Quality

Abstract

Perennial warm-season grasses (WSG) can be an alternative to crop residue removal for biofuel. Perennials may also be valuable for both biofuel and forage feedstock.. This versatility of WSG can be appealing to producers. However, cutting date and height can greatly influence the forage quality and value of the feedstock. Our objective was to assess the impacts of growing WSG on biomass and forage production and quality. Biomass production was assessed for the 2010 and 2011 growing seasons. However, forage quality and yield comparisons between a two cut hay system and one cut biofuel system was only conducted during the 2011 growing season. At Manhattan, the photo period sensitive and sweet sorghum varieties had the highest yields in both 2010 and 2011. Similar results were observed at Colby in 2010 and 2011 and at Hays in 2010. However, in 2011 at Hays, low precipitation caused the annual crops to be a complete loss and no yields were recorded. From this study, it is evident that annual crops generally produce higher biomass yields than perennial WSG in situations where adequate moisture is provided. However, this study also shows that WSG yields can be competitive with row crop production in areas with limited annual precipitation or years when below average precipitation is received. Furthermore, results indicate that a two cut forage system with a 0.1 m cutting height can produce more biomass compared with a one cut biofuel system. Additionally, the two cut system improved forage quality parameters.

Introduction

Biomass production from dedicated energy crops will be crucial to the viability of biofuel production in the United States as crop residues alone cannot sustainably meet the biomass demands (Blanco-Canqui, 2010). Both total biomass produced and quality of the biomass need to be evaluated in various regions of the U.S with varying climate and soil conditions. Ideal energy crops will vary across the U.S, as one crop is not likely to fit all systems (Parrish et al., 2005). Developed energy crops will need to be capable of producing biomass on marginal lands where intensive management systems, such as irrigation, are not available. It is estimated that a majority of dedicated energy crops will be grown on marginal lands (Kort et al., 1997). Throughout the central Great Plains, WSG may fit the dedicated energy crop niche for marginal lands and dry land conditions.

In addition to the potential WSG have as a dedicated energy crop, they may also serve as a valuable animal feedstock. This can be important particularly in years of drought or poor production from row crops. Growing WSG on marginal and dryland acres gives producers the flexibility of using these feedstocks on a need basis. Having this flexibility may make dedicated energy crops more economically appealing to producers and may encourage the conversion of marginal acres to more environmentally conservative WSG species.

The popularity of using switchgrass (*Panicum virgatum* L.) as an energy crop has only been second to corn. In previous studies, switchgrass was considered to be the "benchmark species" for non-woody herbaceous energy crops as it has consistently proved to be the most productive (Parrish et al., 2008). However, other perennial WSG species need to be developed for biofuel production across the U.S.

Materials and Methods

Field Experiment Locations and Treatments

This project is located on four energy crop experiments intended for long-term measurments at three locations in Kansas. The experimental sites were located at (1) the Kansas State University (KSU) Northwest Research-Extension Center in Colby, Kansas (39º23'N, 101º03’W), (2) the KSU Agricultural Research Center in Hays, Kansas (38º52’N, 99º19’W), and (3) two separate studies at the KSU Agronomy Research Farm at Manhattan, Kansas (39º11’N, 96º35’W). The two separate yield studies in Manhattan will be further explained and will here on be referred to as the biofuel study and forage study. All studies were conducted between August 2010 and April 2012, except for the forage study in Manhattan which was only conducted during the 2011 growing season. Soil types at each location were a Keith silt loam (fine-silty, mixed, super active, mesic Cumulic Hapludolls) at Colby, a Harney silt loam (fine, smectitic, mesic Typic Argiustolls) at Hays, and a Kahola silt loam (fine-silty, mixed, super active, mesic Cumulic Hapludolls) at Manhattan. The three sites were primarily selected due to the differences in historic mean annual precipitation. Historic mean annual precipitation included 465mm at Colby, 579mm at Hays, and 838mm at Manhattan, respectively (High Plains Regional Climate Center).

All sites and studies were designed as a randomized complete block experiment. The Colby, Hays and Manhattan forage study each had three replications, while the biofuel system at the Manhattan location contained four replications. In Manhattan the individual plot size for the biofuel study was 6.1 m wide by 10.7 m long, while the plot sizes for the forage system were 6.1 m wide and 9.0 m long. Plots in Colby and Hays were 6.1 m wide and 6.1 m long. The forage system experiment in Manhattan was established in 2007 and consisted only of ‘Kanlow’ switchgrass. The biofuel experiment at Manhattan was established in 2007 and consisted of three perennial warm-season grasses (‘Kanlow’ switchgrass, big bluestem (*Andropogon gerardii* L.), and miscanthus (Miscanthus × giganteus)), two native grass mixtures (indiangrass (*Sorghastrum nutans* L.) /switchgrass/big bluestem mix and a switchgrass/big bluestem mix), corn (*Zea mays* L.) grown continuously and rotated with soybean, and three sorghum (Sorghum bicolor L. [Moench.]) cultivars (photoperiod sensitive, sweet, and grain sorghum) in rotation with soybeans(*Glycine max* (L.) Merr.).

The corn hybrids grown at Manhattan in 2010 and 2011 were Pioneer ‘33K40’ (Bt) and Pioneer ‘33K44’ (Bt), respectively, both of the same parent family with relative maturity of 114 days (Pioneer Hi-Bred International, Johnston, IA). Sorghum cultivars included Land O’Lakes ‘DKS59-09’ (Land O’Lakes, St. Paul, MN) DP FS, Mississippi State University ‘M81E’ sweet sorghum, Sorghum Partners ‘NK300’ (Sorghum Partners, Inc., New Deal, TX) DP FS, and

Sorghum Partners ‘1990CA’ PS sorghum. The soybean variety planted at Manhattan both study years for rotational purposes was KSU Foundation ‘KS3406RR’ (Kansas State Univ., Manhattan, KS). The forage system experiment in Manhattan was established in 2007 and consisted only of ‘Kanlow’ switchgrass.

The experiments at Hays and Colby were established in spring 2009 and consisted of two varieties of switchgrass (‘Pathfinder’ and ‘Blackwell’), indiangrass, big bluestem, sand bluestem [*Schizachyrium scoparium* (Michx.) Nash], mixed native grasses, miscanthus, forage sorghum, grain sorghum, and no-till wheat (*Triticum aestivum* L.)-sorghum-fallow (W-S-F) with (100%) and without (0%) residue removal.

All sites in 2010 were harvested using a single cut biomass bulk harvest. The perennial grasses at Hays, in addition to a one cut system, included a two cut forage system in 2011. Additionally in 2011, data was collected from the forage study in Manhattan to compare the effects of a one cut and a two cut system. Plots in the forage study were also subjected to two different cutting heights; a high cut, 0.20 m, and a low cut, 0.10 m. The biofuel system plots in Manhattan and the biofuel plots in Colby were still harvested using a single cut system in 2011.

Establishment of WSG stands in Colby and Hays was challenging as low annual precipitation and high weed pressure limited growth of young plants. Additionally, annual row crop production was also reduced or eliminated during this time period at Colby and Hays due to lower than average annual rainfall and concentrated animal pest pressure. During the 2011 growing season, proper weed control at Colby and Hays improved stand quality and biomass production. This was accomplished by applying 0.56 kg ha^{-1} of quinclorac herbicide pre-emergence just prior to the 2011 growing season. Additional herbicide applications of Starane (flurozypyr) at 0.56 kg ha^{-1} and 0.56 kg ha^{-1} of 2, 4-D dimethylamine [(2, 4-dichlorophenoxy) acetic acid] were applied at the three leaf stage. Hand weeding was also done as necessary throughout the growing season both years.

Biomass Yield

Harvest of the biofuel study in Manhattan was completed in 2010 and 2011 using the same procedures. Annual crops were harvested after physiological maturity or just before the first killing frost if maturity was not reached (Table 4.1). Harvest of the annual crops was accomplished by hand harvesting a ten plant sample from the center of the plot. Plant length, number of ears/grain heads and mass were all recorded. Harvested grain and stover were separated and dried in a forced-air dryer at 65º C for 48 and 240 hours, respectively. In addition to the ten plant sample, a chopped harvest mass was also recorded. This was done using a self-propelled flail-type forage harvester to harvest an area 1.5 m wide by 10.7 m long from the center two rows (eight-row plots) of each plot, to minimize plot edge effects. The head of the forage harvester was set so it left an approximate stubble height of 10 cm. Perennial WSG for the biofuel study in Manhattan were harvested after the first killing frost (Table 4.1), using a walk-behind sickle mower leaving a 10 cm stubble height. Biomass yields were determined by harvesting the center 0.91 m by 10.7 m area of the plot. Harvested biomass was then hand raked, collected, and weighed. Additionally, heights were taken from ten random plants in the harvested area. A 225-325 g wet sub-sample was randomly extracted from the harvested biomass to determine the dry matter (DM) of the biomass. The sample was then weighed, dried in a forced-air dryer at 65º C for 240 hours, then weighed again. The wet and dry weights were then used to calculate sample DM concentration and plot DM yield using the following equations.

$$\mathrm{DM} = \frac{\text{Dry Sample Mass}}{\text{Wet Sample Mass}}$$

$$\text{DM Yield} = \text{Calculated DM x Wet Harvest Mass}$$

Stover yields included all above-ground harvested biomass.

Harvest at Colby, both 2010 and 2011, and Hays, 2010, was done after the first killing frost. Harvest of all plots was accomplished by harvesting the center 6.1m by 1.5 m area of each plot using a forage plot harvester (Carter Manufacturing Company Inc., Brookston, IN). The forage harvester was set to maintain a 10 cm stubble height across all plots. Biomass wet weights were recorded using a scale that was mounted to the forage harvester collection basket. In order to determine the DM content, a 225-325g wet subsample was randomly collected from the wet bulk harvested biomass and weighed. The sample was then dried and DM was calculated as previously shown.

In 2011, a forage study was implemented on the existing Hays experiment and the forage study at Manhattan. The forage study plots were intended to quantify the effects of a multiple cut system on biomass production and quality compared with a traditional one cut system. Furthermore, each cutting system was subjected to different cutting heights, including a high cut 0.20 m and a low cut 0.10 m residual height treatment. The different system and cutting heights were used to see what system would produce the highest biomass yield and forage quality. In the future, soil physical properties will also be measured to quantify the long-term effects of different stubble heights. The first harvest was taken during the summer of 2011 (Table 4.1) close to when the plants had reached boot stage. Only plants in the two-cut hay cut system were harvested at this time. This was done to simulate traditional hay cuttings in production agriculture. The 2011 fall harvest was done after the first killing frost and plants in both the one-cut biomass and two-cut hay cut system were harvested at this time (Table 4.1).

Harvests at Hays and Manhattan were done using different methods. However, the methods at each site were consistent for both the summer and fall harvest. In Manhattan, harvest was accomplished by using a walk-behind sickle mower with adjustable guides to leave either a 0.10 or 0.20 m stubble height. Biomass yields were determined by harvesting the center 0.91 m by 6.1 m area of the plot. Harvested biomass was then hand raked, collected, and weighed. A 225-325 g wet sub-sample was randomly extracted from the harvested biomass to determine the DM of the biomass. At Hays, harvest was done with a forage plot harvester (Carter Manufacturing Company Inc., Brookston, IN). The forage harvester was set to maintain either a 0.10 or 0.20 m stubble height, depending on the treatment. Wet weights were recorded using a scale that was mounted to the forage harvester collection basket. In order to determine the DM content, a 225-325g wet subsample from each harvested strip was randomly collected from the wet bulk harvested biomass and weighed. The subsample was then dried, and DM and yield were calculated as previously shown.

Forage Quality

In 2011, plant matter from the Hays and Manhattan forage study was analyzed for a variety of quality parameters. Theses parameters were used to determine the suitability of each WSG species as an animal feed and biofuel feedstock (Ball et al., 2001). When assessing a species' over all viability as a feedstock, the quantity and quality of that feedstock ultimately determines the value of the feedstock. Finding the best species that can produce the highest quality without sacrificing biomass yield is crucial to the long-term viability of WSG as biofuel and animal feedstock.

The dried biomass samples that were collected to determine DM were also used to determine forage quality. After DM was calculated, the dried biomass samples were ground with a Model 4 Thomas-Wiley Laboratory Mill equipped with a 2 mm screen (Thomas Scientific, Swedesboro, NJ). Samples were then ground to pass through a 1 mm screen using a laboratory cyclone mill. A subsample of the ground biomass was then bagged and sent to Ward Laboratories (Ward Laboratories, Kearney, NE 68848) for analysis. Samples were analyzed using Near Infrared Reflectance Spectroscopy (NIR) for a complete spectrum of quality parameters (Shenk and Westerhaus, 1994). For this study, forage quality parameters are all reported on a dry matter basis. Parameters analyzed include crude protein, neutral detergent fiber (NDF), neutral detergent fiber digestibility (NDFD), total digestible nutrients (TDN), calcium (Ca), phosphorus (P), potassium (K), and ash. The reported values of the biofuel system are on a dry matter basis as reported directly from the laboratory. However, the reported values of the hay system are a weighted average between the summer and fall cut, according to the proportion of the total yield. Weighted nutritive value proportions were derived using the following equation;

$$\text{Weighted nutritive value} = \frac{(1^{\text{st}}\text{Cut yield} * 1^{\text{st}}\text{Cut nutritive value}) + (2^{\text{nd}}\text{Cut yield} * 2^{\text{nd}}\text{Cut nutritive value})}{\text{Total yield}}$$

Each forage parameter is important to assess the overall quality of a feedstock. NDF is a measurement that quantifies the amount of hemicellulose, cellulose and lignin in the fibrous bulk of the forage. This measurement is important as it is negatively correlated with animal feed intake. Values high in NDF are more likely to reduce animal performance due to reduced intake (Waldo 1986). A portion of the NDF value is potentially available for digestion by ruminants. This portion is referred to as the NDFD. The NDFD values are expressed as a portion of the NDF and can be useful as a way to rank fiber digestibility of forages (Stokes and Prostko 1998). TDN is a calculation used to relate to the digestible energy of a feedstock. It is the sum of the digestible fiber, protein, lipid and carbohydrate components of the sample. TDN values are useful for formulating rations that are primarily forage based (Waldo, 1986). Minerals such as Ca, P, and K are important values when evaluating animal feedstocks, as they are essential to growth and maintenance functions such as bone formation, energy metabolism, milk production, and electrolyte balance (Spears, 1994). Additionally, mineral concentration can be an important factor in biofuel feedstocks as well. All of the minerals in the feedstock can be concentrated in the waste product following energy extraction. The biofuel byproducts are often spread in fields as beneficial fertilizer (Adler et al., 2006). However, knowing and understanding the components of the by product is important to eliminate the potential of applying excess nutrients. This is particularly true in situations where the feedstock is subjected to combustion. In this case, knowing the ash value, in addition to the mineral content, is important (Adler et al., 2006; Stokes and Prostko, 1998). As feedstocks with high ash values will foul scrubbers and build up on the exhaust portion of a combustion system.

Statistical Analysis

Data were statistically analyzed using PROC Mixed in SAS 9.2 (SAS Institute, 2008). Least square differences were used to determine differences at the 0.05 probability levels (SAS Institute, 2008). Significance of main effect differences and their interactions was determined, with species, and/or cutting height, and/or cutting system as fixed effects and replications as random effects.

Results and Discussion

Biomass Yield

A significant year × variety interaction was observed for the total biomass yield at the Manhattan site. In general, the total biomass yields of the annual crops were higher than that of the perennial WSG (Table 4.5). The photo period sensitive and sweet sorghum varieties had the highest yields in both 2010 and 2011, while sweet sorghum had the highest overall yield in 2010 (23.19 Mg ha^{-1}). In 2011, the perennial WSG yields were not different from grain sorghum and corn yields. This can be attributed to an observed yield increase of the perennial WSG in combination with a yield decline of the annual crops due to limited precipitation. The increased yield of the WSG is likely due to increased stand maturity in addition to the grasses ability to utilize stored profile water after winter and early season precipitation events. The difference in water use timing, discussed in Chapter 2, allowed for the perennial crops to produce biomass yields competitive to the row crop treatments in 2011.

Due to weed competition, only select plots were harvested at Colby in 2010 and 2011. A significant year × variety interaction was observed. Annual crops produced higher biomass yields than perennial WSG (Table 4.3). Sweet sorghum had the highest biomass yields in both 2010 and 2011. T the highest sweet sorghum yield was in 2011 (7.76 Mg ha^{-1}). However, late season storms caused extensive lodging of sweet sorghum in 2011, which would make harvest difficult. The grain sorghum yield in 2010 was lower than the sweet sorghum yields for both harvest years but higher than the yields of the perennial crops. However in 2011, grain sorghum yield displayed a similar yield to both harvests of Blackwell switchgrass. This is likely due to poor stand establishment of the grain sorghum in 2011 from poor early season precipitation. The higher observed yield in 2011 by Blackwell switchgrass was most likely due to improved weed control. This may indicate that mature stands of switchgrass have the potential to produce yields comparable to annual crops, particularly in years with below average precipitation. In both 2010 and 2011, miscanthus had the lowest biomass of all species. Even with proper weed management in 2011, miscanthus still performed poorly due to limited water, as it seems to be better suited for areas with higher average precipitation. In addition to the mentioned species, wheat was planted in the fall of 2010 and was scheduled to be harvested in the spring of 2011. However, a late planting date in combination with low precipitation and high pest pressure resulted in an un-harvestable stand.

In 2010, the Hays study was harvested as a fall cut biofuel system. The two annual crops, sweet sorghum and grain sorghum, had the highest biomass yields (Table 4.4). This is similar to the data from Colby and follows trends of past data from the Manhattan study (Propheter et al. 2010). However, the biomass yield of Pathfinder switchgrass was similar to the observed grain sorghum biomass yield (Table 4.4). The lowest yielding treatments included gamagrass, miscanthus, and sand bluestem. Like the study in Colby, weed competition likely affected the 2010 biomass yields of all perennial crops. In 2011, all of the WSG treatments were harvested as a forage study that compared a one cut versus two cut system, with the annual crops still being harvested at physiologic maturity. However, low precipitation caused the annual crops to be a complete loss and no yields were recorded in 2011. Even though all sites observed low precipitation in 2011, the Hays site was the lowest (Table 4.2). Furthermore, most of the precipitation occurred after August when the crop was already lost (Figure 3.5). In addition to the complete loss of the 2011 sorghum stands, the spring 2011 wheat crop was also un-harvestable due to limited precipitation and excess pest pressure, particularly jack rabbits. This shows that in years of extreme weather events, WSG have the potential for greater yield than annual crops as they are able to utilize early and late season precipitation events.

The WSG plots at Hays were managed as a forage study in 2011. Data from this study allowed for yields to be compared among species, harvest heights and between biofuel and hay cut systems. In 2011, all yield values among species and systems were similar. However, a significant height interaction was observed with the low harvest height having higher yields than the high harvest height (Table 4.8). The lack of species effect, despite a wide range of yields, is due to high variability in yield data. The high variability could be explained by a variety of factors. A small harvest area and high stand variability, caused by weed pressure and low precipitation, can attribute for most of the variability. Yields from the forage study in Manhattan showed a system × height interaction with the 0.10 m hay harvest having the highest total biomass yield (8.01 Mg ha^{-1}) (Table 4.10). In general, the hay cut system and the 0.10 m cut heights generated the highest yields.

Annual precipitation amounts for both the 2010 and 2011 growing seasons were below average across all study sites (Table 4.2). The below average precipitation amount in addition to poor distribution of rain events intensified the crop stress and increased losses. Production of the annual crops was reduced by stress more than the WSG, due to limited precipitation during critical physiological development stages. This not only reduced grain production but also reduced total biomass and resulted in complete crop loss at Hays. The WSG were capable of accumulating biomass at times when moisture was available and were able to survive during dry periods due to their established root system. It has been documented that, with adequate precipitation, annual row crops are capable of producing higher amounts of biomass (Propheter et al. 2010). However, from this data it is apparent that WSG are capable of producing higher yields when moisture is limited.

Forage Quality

The value of biofuel and forage feedstocks not only depends on biomass produced, but also on the quality of the feedstock. Feedstocks that are not easily digested or have high ash content upon combustion may not be suitable options (Adler, 2006). Additionally, finding the best feedstock that balances animal and biofuel feedstock production may be important to the adoption of dedicated energy crops in production agriculture.

Samples from the 2011 forage study at Hays differed in forage quality by species, cutting height, and cutting system. A species × system interaction also resulted depending on the measured parameter. In Hays, species effects were observed for NDF, NDFD, ash, TDN, Ca, P and K. Sand bluestem had the highest NDF value, with all other treatments having similar values (Table 4.6). As previously discussed, a high NDF value negatively correlates to feed intake. Additionally, sand bluestem had one of the lowest NDFD values and had similar values to the mixedgrass treatment which had the lowest numeric value (445.94 g kg^{-1}). Indiangrass had the highest NDFD value and was similar to big bluestem, eastern gamagrass, and miscanthus. Indiangrass also had the highest ash content, which was similar to eastern gamagrass, miscanthus, mixedgrass, and big bluestem treatments. Sand bluestem and both switchgrass varieties had the lowest ash contents. The two switchgrass varieties, Pathfinder and Blackwell, had the highest TDN values. However, eastern gamagrass and miscanthus TDN were also similar to Blackwell switchgrass TDN. Indiangrass, mixedgrass, and sand bluestem had the lowest TDN values. The highest Ca value was recorded by big bluestem and was similar to eastern gamagrass and mixedgrass. Sand bluestem had the lowest observed value and was similar to indiangrass, miscanthus, and the two switchgrass varieties. The highest P concentration was recorded by Blackwell switchgrass and was similar to P concentrations of eastern gamagrass, mixedgrass, and Pathfinder switchgrass. The lowest P values observed were from indiangrass, sand bluestem, and big bluestem. All K values were similar, except eastern gamagrass and mixedgrass K concentrations were higher than all other treatments.

System effects were also observed for NDF, K and P values (Table 4.8). The two cut hay system reported lower NDF values and higher K and P values than the one cut biomass system. In general, the forage quality of the hay system was better than the biomass system. Crude protein was the only parameter that displayed a species x system interaction (Table 4.9). Indiangrass had one of the lowest CP values with the two cut hay harvest but had one of the greatest CP values under the one cut biomass harvest. In general, the hay system recorded higher CP values than the biomass system. Eastern gamagrass, big bluestem, mixed grass and Blackwell switchgrass had the highest CP values with a two cut hay system. The lowest CP values were observed by the two switchgrass varieties, sand bluestem, miscanthus, and eastern gamagrass harvested as a biomass one cut system. From this data it can be concluded that harvest timing of WSG significantly affects the CP levels of the harvested biomass. This is particularly true for eastern gamagrass and Blackwell switchgrass, as the cutting system impacted them the most.

Kanlow switchgrass was the only grass used in the Manhattan forage study. No height interactions were observed, and only effects caused by the cutting system were observed for the 2011 forage quality parameters. Similar to the Hays data, the two cut hay system generally had higher forage quality than the one cut biomass system. The hay system resulted in higher CP and TDN concentrations than the biomass system, making it a higher energy animal feedstock (Table 4.11). Furthermore, the hay system recorded lower NDF and higher NDFD values, which increases intake and digestibility of the forage. The biomass produced by the hay system was more desirable as both an animal and biofuel feedstock. Mineral values for the hay system also tended to be higher than the biomass system as both P and K values were higher. However, no system effect was observed for the Ca and ash values in 2011.

Conclusions

This study indicates that annual crops generally produce higher biomass yields than perennial WSG in soils with adequate moisture. However, this study also shows that WSG yields can be competitive with row crop production in areas with limited annual precipitation or years when below average precipitation is received. Yields of WSG can be minimal during establishment years, particularly if adequate weed control is not accomplished. However, once the WSG stands are established, the extensive root system and early season growth have the capability to accumulate biomass when moisture is available making WSG less susceptible to scattered precipitation events. From this data, it is evident that WSG species such as switchgrass can become a viable biomass production option in the Great Plains. This may particularly be true in lands that are considered marginal due to slope, degraded soil quality, or limited water resources.

The value of WSG as both an animal and biofuel feedstock can also increase with additional management. From observed data, it is apparent that a low cut 0.10 m harvest height has the capability to increase biomass production without sacrificing the quality of the feedstock. However, continued long-term yield data in combination with long-term soil quality comparisons between heights is needed to verify the sustainability of a low residual height system. In addition to cutting height, different cutting systems also have the potential to add value to WSG. While this study showed mixed yield results when comparing a two cut and one cut system, it was obvious that the hay cut system has the potential to increase the quality of the harvested biomass. Although biofuel biomass quality has previously not received as much attention as biomass production, concerns over disposal of byproducts may give higher quality biofuel feedstocks an advantage over crop residue use as a biofuel. Furthermore, high quality feedstocks will add value to WSG biomass as it will give producers the flexibility to sell their crop as either a biofuel or animal feedstock, depending on which has higher value at the time. Species such as switchgrass, big bluestem, and native grass mixes have the potential to produce quality biomass that can be used in diverse applications.

Figures and Tables

Figure 4.1 Plot layout of forage study at Manhattan

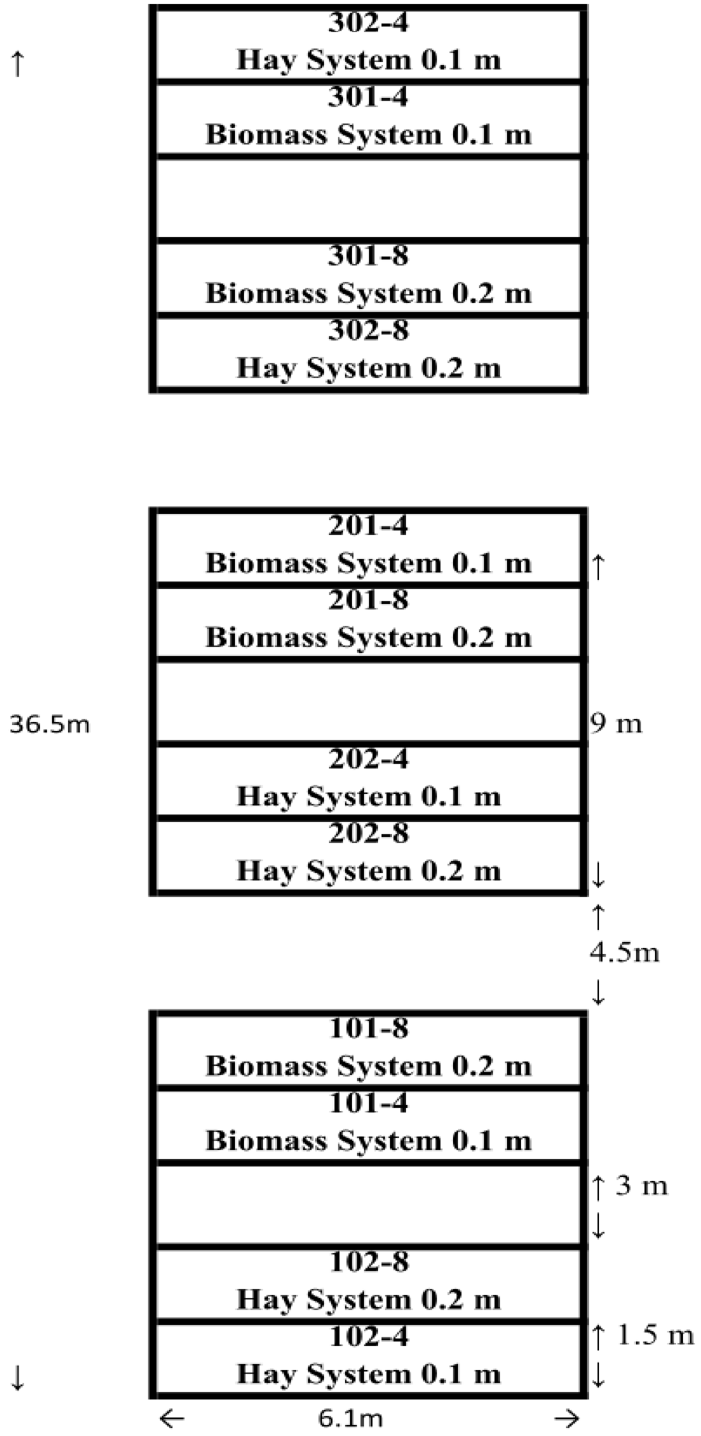

Table 4.1 Harvest dates.

Site	System	Year	Date
Colby	Biomass-Fall	2010	Nov. 22nd
Colby	Biomass-Fall	2011	Nov. 18th
Hays	Biomass-Fall	2010	Nov. 21st
Hays	Forage-Summer	2011	July 5th
Hays	Forage-Fall	2011	Nov. 11th
Hays	Biomass-Fall	2011	Nov. 11th
Manhattan	Biomass-Annual Crops	2010	Aug. 30th
Manhattan	Biomass-Perennial Crops	2010	Dec. 3rd
Manhattan	Biomass-Annual Crops	2011	Sept. 29th
Manhattan	Biomass-Perennial Crops	2011	Nov. 10th
Manhattan	Forage-Summer	2011	June 30th
Manhattan	Forage-Fall	2010	Nov. 7th
Manhattan	Biomass-Fall	2011	Nov. 7th

Table 4.2 Measured precipitation data, 2010 and 2011, compared to historic means (High Plains Regional Climate Center).

Site	Historic Annual Precipitation (mm)	2010 Measured Precipitation (mm) Jan.1st- Dec. 31st	2011 Measured Precipitation (mm) Jan.1st- Dec. 31st
Colby	465	380	406
Hays	579	452	326
Manhattan	838	704	522

Table 4.3 Total biomass dry matter yields at Colby in 2010 and 2011. Different letters indicate significant differences at the P=0.05 level

Treatment	2010	2011
	---Yield (Mg ha^{-1})---	
Switchgrass (Blackwell)	2.71 c	3.21 c
Miscanthus	1.13 d	1.64 d
Grain Sorghum	4.53 b	3.31 c
Sweet Sorghum	7.41 a	7.76 a

Table 4.4 Total biomass dry matter yields at Hays in 2010. Different letters indicate significant differences at the P=0.05 level

Treatment	Yield (Mg ha^{-1})
Switch Grass (Blackwell)	2.57 bc
Switch Grass (Pathfinder)	3.75 b
Miscanthus	1.94 c
Big Bluestem (Kaw)	2.42 bc
Sand Bluestem	1.86 c
Mixed Grass	2.55 bc
Indian Grass (Cheyenne)	3.90 b
Eastern Gamagrass	1.48 c
Grain Sorghum	5.55 a
Sweet Sorghum	6.88 a

Table 4.5 Total biomass dry matter yields at the Manhattan biofuel study in 2010 and 2011. Different letters indicate significant differences at the P=0.05 level

Treatment	2010	2011
	---Yield (Mg ha^{-1})---	
Continuous Corn	7.26 ef	8.46 de
Rotated Corn	12.59 bc	11.04 bcde
Photo Period Sorghum	20.77 a	20.77 a
Sweet Sorghum	23.19 a	19.44 a
Grain Sorghum	13.8 b	11.57 bcd
Big Bluestem	3.79 fg	10.93 bcde
Miscanthus	9.69 cde	13.78 b
Switchgrass (Kanlow)	7.9 de	10.89 bcde
Indiangrass Mix	2.56 g	10.97 bcd
Switchgrass Mix	2.94 fg	12.34 bcd

Table 4.6 Forage quality parameters by species effect at Hays in 2011. Different letters indicate significant differences at the P=0.05 level.

Species	Yield (Mg ha^{-1})	NDF (g kg^{-1})	NDFD proportion of NDF(g kg^{-1})	Ash (g kg^{-1})
Big Bluestem	2.38	713 b	490 ab	115 abc
Eastern Gamagrass	1.63	708 b	490 ab	126 a
Indiangrass	1.75	722 b	523 a	128 a
Miscanthus	1.61	718 b	502 ab	116 ab
Mixedgrass	2.33	716 b	446 c	118 ab
Sand Bluestem	1.57	749 a	467 bc	99 d
Switchgrass (Blackwell)	2.61	708 b	466 bc	101 cd
Switchgrass (Pathfinder)	2.70	705 b	480 bc	109 bcd
Species	**TDN (g kg^{-1})**	**Ca (g kg^{-1})**	**P (g kg^{-1})**	**K (g kg^{-1})**
Big Bluestem	523 cd	4.66 a	0.88 bcd	9.25 b
Eastern Gamagrass	539 bc	4.21 ab	0.93 abc	12.41 a
Indiangrass	520 d	3.93 bc	0.68 d	9.78 b
Miscanthus	540 bc	3.93 bc	0.88 bc	8.93 b
Mixedgrass	511 d	4.48 ab	0.95 abc	12.55 a
Sand Bluestem	521 d	3.63 c	0.79 cd	9.05 b
Switchgrass (Blackwell)	552 ab	4.09 bc	1.10 a	9.23 b
Switchgrass (Pathfinder)	558 a	4.10 bc	1.01 ab	8.18 b

Table 4.7 Forage quality parameters by system effect at Hays in 2011. Different letters indicate significant differences at the P=0.05 level.

System	NDF ($g\ kg^{-1}$)	K ($g\ kg^{-1}$)	P ($g\ kg^{-1}$)
Hay	681 b	12.34 a	1.19 a
Biomass	755 a	7.51 b	0.60 b

Table 4.8 Yield by height effect at Hays in 2011. Different letters indicate significant differences at the P=0.05 level.

Harvest Height (m)	Yield ($Mg\ ha^{-1}$)
0.1	2.96 a
0.2	1.18 b

Table 4.9 Crude protein, species by system interaction at Hays in 2011. Different letters indicate significant differences at the P=0.05 level.

Species	Hay System	Biomass System
	Crude Protein ($g\ kg^{-1}$)	
Big Bluestem	77 ab	57 efgh
Eastern Gamagrass	84 a	50 ghij
Indiangrass	67 bcde	54 fghi
Miscanthus	71 bcd	44 ij
Mixedgrass	74 abc	60 defg
Sand Bluestem	65 cdef	47 hij
Switchgrass (Blackwell)	76 abc	40 j
Switchgrass (Pathfinder)	72 bcd	42 j

Table 4.10 Cutting system comparison yield data at Manhattan in 2011. Different letters indicate significant differences at the P=0.05 level.

Treatment	Harvest Height (m)	System	Yield (Mg ha^{-1})		
			1st Cut	2nd Cut	Total
Switchgrass (Kanlow)	0.1	Biofuel	---	6.98	6.98 ab
Switchgrass (Kanlow)	0.2	Biofuel	---	6.68	6.68 b
Switchgrass (Kanlow)	0.1	Hay	2.18	5.83	8.01 a
Switchgrass (Kanlow)	0.2	Hay	1.32	5.51	6.83 ab

Table 4.11 Forage quality parameters by system effect at Manhattan in 2011. Different letters indicate significant differences at the P=0.05 level.

System	Crude Protein (g kg^{-1})	NDF (g kg^{-1})	NDFD proportion of NDF (g kg^{-1})	Ash (g kg^{-1})
Hay	75 a	649 b	466 a	84
Biomass	33 b	752 a	360 b	80
System	**TDN (g kg^{-1})**	**Ca (g kg^{-1})**	**P (g kg^{-1})**	**K (g kg^{-1})**
Hay	570 a	3.69	1.64 a	12.57 a
Biomass	496 b	3.33	0.80 b	5.80 b

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Appendix A - Raw Data; Wind Erosion, Soil Physical and Soil Hydraulic Properties

Table A.1 Bulk density values at Colby in 2010. Different letters indicate significant differences at the P=0.05 level.

Treatment	0-5 cm	5-10 cm
	---Bulk Density (Mg m^{-3})---	
Switchgrass (Blackwell)	1.19	1.19
Miscanthus	1.17	1.10
Grain Sorghum	1.15	1.09
Sweet Sorghum	1.23	1.22
S-F-W 0%	1.13	1.13
S-F-W 100%	1.15	1.18

Table A.2 Bulk density values at Colby in 2011 and 2012. Different letters indicate significant differences at the P=0.05 level.

Treatment	Spring 2011 0-7.5cm	Spring 2012 0-7.5cm	Spring 2012 7.5-15cm
	---Bulk Density (Mg m^{-3})---		
Switchgrass (Blackwell)	1.22	1.24	1.33
Miscanthus	1.25	1.31	1.33
Grain Sorghum	1.21	1.24	1.34
Sweet Sorghum	1.19	1.26	1.38
W-S-F 0% residue removal	1.15	1.19	1.36
W-S-F 100% residue removal	1.24	1.24	1.42

Table A.3 Bulk density values at Hays in 2010. Different letters indicate significant differences at the P=0.05 level.

Treatment	0-5 cm	5-10 cm
	---Bulk Density (Mg m^{-3})---	
Switchgrass (Blackwell)	1.12	1.15 ab
Switchgrass (Pathfinder)	1.16	1.17 ab
Miscanthus	1.16	1.22 ab
Big Bluestem	1.11	1.12 ab
Sand Bluestem	1.14	1.18 ab
Mixed Grass	1.19	1.19 ab
Indian Grass (Cheyenne)	1.11	1.26 a
Eastern Gamagrass	1.18	1.11 b
Grain Sorghum	1.17	1.22 ab
Sweet Sorghum	1.19	1.19 ab
S-F-W 0%	1.13	1.12 ab
S-F-W 100%	1.10	1.18 ab

Table A.4 Bulk density values at Hays in 2011 and 2012. Different letters indicate significant differences at the P=0.05 level.

Treatment	Spring 2011 0-7.5cm	Spring 2012 0-7.5cm	Spring 2012 7.5-15cm
		---Bulk Density (Mg m^{-3})---	
Switchgrass (Blackwell)	1.27	1.20 bcd	1.24 d
Switchgrass (Pathfinder)	1.27	1.25 abc	1.32 bc
Miscanthus	1.28	1.31 ab	1.40 a
Big Bluestem	1.30	1.13 d	1.23 d
Sand Bluestem	1.30	1.25 abc	1.31 c
Mixed Grass	1.29	1.15 cd	1.32 bc
Indiangrass	1.28	1.27 abc	1.34 abc
Eastern Gamagrass	1.35	1.31 ab	1.33 bc
Grain Sorghum	1.29	1.35 a	1.40 a
Sweet Sorghum	1.27	1.20 bcd	1.34 abc
W-S-F 0% residue removal	1.22	1.30 ab	1.36 abc
W-S-F 100% residue removal	1.25	1.28 ab	1.37 ab

Table A.5 Bulk density values at Manhattan in 2011 and 2012. Different letters indicate significant differences at the P=0.05 level.

Treatment	Spring 2011 0-7.5cm	Spring 2012 0-7.5cm	Spring 2012 7.5-15cm
	---Bulk Density (Mg m^{-3})---		
Continuous Corn	1.34 ab	1.40	1.42 ab
Photo Period Sorghum	1.39 a	1.37	1.39 ab
Sweet Sorghum	1.34 ab	1.39	1.38 bc
Grain Sorghum	1.33 ab	1.39	1.40 ab
Rotated Corn	1.32 ab	1.36	1.39 bc
Miscanthus	1.28 b	1.37	1.42 ab
Switchgrass (Kanlow)	1.32 ab	1.36	1.38 ab
Big Bluestem	1.36 a	1.36	1.37 c
Indiangrass Mix	1.31 ab	1.37	1.43 a
Switchgrass Mix	1.25 b	1.41	1.41 ab
Soy Beans (Photo Period Sorghum)	1.37 ab	1.40	1.40 ab
Soy Beans (Sweet Sorghum)	1.31 ab	1.37	1.40 ab
Soy Bean (Grain Sorghum)	1.30 ab	1.34	1.39 ab
Soy Bean (Rotated Corn)	1.30 ab	1.40	1.39 ab

Table A.6 Soil N and C concentrations at Colby in Fall 2010. Different letters within the same size fraction and depth interval indicates significant differences at the P=0.05 level.

Treatment	Depth (cm)	Total N	Total C
		---Mg ha^{-1}---	
Switchgrass (Blackwell)	5	0.92	8.58
Miscanthus	5	0.80	7.07
Grain Sorghum	5	0.92	8.61
Sweet Sorghum	5	0.95	9.10
S-F-W 0%	5	0.98	8.81
S-F-W 100%	5	0.98	9.00
Switchgrass (Blackwell)	10	0.72 b	6.73
Miscanthus	10	0.69 b	6.57
Grain Sorghum	10	0.73 b	6.58
Sweet Sorghum	10	0.88 a	8.48
W-S-F 0% residue removal	10	0.63 b	5.96
W-S-F 100% residue removal	10	0.71 b	6.80

Table A.7 Soil N and C concentrations at Colby in Spring 2012. Different letters within the same size fraction and depth interval indicates significant differences at the P=0.05 level.

Treatment	Depth (cm)	Total N	Total C
		---Mg ha^{-1}---	
Switchgrass (Blackwell)	7.5	1.33	12.06
Miscanthus	7.5	1.57	14.13
Grain Sorghum	7.5	1.27	11.63
Sweet Sorghum	7.5	1.49	13.11
W-S-F 0% residue removal	7.5	1.40	12.42
W-S-F 100% residue removal	7.5	1.66	15.14
Switchgrass (Blackwell)	15	1.33	11.59
Miscanthus	15	1.29	11.34
Grain Sorghum	15	1.45	13.22
Sweet Sorghum	15	1.48	13.36
W-S-F 0% residue removal	15	1.29	11.70
W-S-F 100% residue removal	15	1.30	12.06

Table A.8 Soil N and C concentrations at Hays in Fall 2010. Different letters within the same size fraction and depth interval indicates significant differences at the P=0.05 level.

Treatment	Depth (cm)	Total N	Total C
		---Mg ha^{-1}---	
Switchgrass (Blackwell)	5	0.71 ab	6.33
Switchgrass (Pathfinder)	5	0.65 ab	6.22
Miscanthus	5	0.72 ab	6.18
Big Bluestem	5	0.71 ab	6.90
Sand Bluestem	5	0.69 ab	6.60
Mixed Grass	5	0.82 a	7.44
Indian Grass (Cheyenne)	5	0.81 a	7.62
Eastern Gamagrass	5	0.80 a	6.75
Grain Sorghum	5	0.66 ab	5.64
Sweet Sorghum	5	0.62 b	5.79
S-F-W 0%	5	0.63 ab	5.66
S-F-W 100%	5	0.69 ab	5.93
Switchgrass (Blackwell)	10	0.70	6.20
Switchgrass (Pathfinder)	10	0.65	5.86
Miscanthus	10	0.81	7.19
Big Bluestem	10	0.69	6.64
Sand Bluestem	10	0.68	6.21
Mixed Grass	10	0.67	6.02
Indian Grass (Cheyenne)	10	0.76	6.60
Eastern Gamagrass	10	0.67	5.99
Grain Sorghum	10	0.67	6.14
Sweet Sorghum	10	0.62	5.91
S-F-W 0%	10	0.66	6.14
S-F-W 100%	10	0.70	5.92

Table A.9 Soil N and C concentrations at Hays in Spring 2012. Different letters within the same size fraction and depth interval indicates significant differences at the P=0.05 level.

Treatment	Depth (cm)	Total N	Total C
		---Mg ha^{-1}---	
Switchgrass (Blackwell)	5	1.03 ab	10.24 ab
Switchgrass (Pathfinder)	5	1.00 b	9.98 ab
Miscanthus	5	1.00 b	8.91 b
Big Bluestem	5	0.96 b	9.00 b
Sand Bluestem	5	0.98 b	9.78 ab
Mixed Grass	5	0.99 b	9.47 b
Indian Grass (Cheyenne)	5	1.18 a	11.29 a
Eastern Gamagrass	5	1.03 ab	9.82 ab
Grain Sorghum	5	1.04 ab	9.70 b
Sweet Sorghum	5	0.99 b	9.46 b
S-F-W 0%	5	1.07 ab	9.47 b
S-F-W 100%	5	1.08 ab	9.66 b
Switchgrass (Blackwell)	10	0.98	6.20
Switchgrass (Pathfinder)	10	0.99	5.86
Miscanthus	10	1.06	7.19
Big Bluestem	10	1.03	6.64
Sand Bluestem	10	1.05	6.21
Mixed Grass	10	0.97	6.02
Indian Grass (Cheyenne)	10	1.11	6.60
Eastern Gamagrass	10	1.01	5.99
Grain Sorghum	10	1.02	6.14
Sweet Sorghum	10	1.02	5.91
S-F-W 0%	10	1.10	6.14
S-F-W 100%	10	1.01	5.92

Table A.10 Soil N and C concentrations at Manhattan in Spring 2012. Different letters within the same size fraction and depth interval indicates significant differences at the P=0.05 level.

Treatment	Depth (cm)	Total N	Total C
		---Mg ha^{-1}---	
Continuous Corn	7.5	1.26 ab	13.30 ab
Photo Period Sorghum	7.5	1.33 ab	13.95 ab
Sweet Sorghum	7.5	1.16 ab	12.31 ab
Grain Sorghum	7.5	1.12 ab	11.84 b
Rotated Corn	7.5	1.33 ab	14.33 ab
Miscanthus	7.5	1.23 ab	14.71 ab
Switchgrass (Kanlow)	7.5	1.42 a	15.96 a
Big Bluestem	7.5	1.12 ab	12.24 ab
Indiangrass Mix	7.5	1.24 ab	13.70 ab
Switchgrass Mix	7.5	0.89 b	9.98 b
Continuous Corn	15	1.11	11.78
Photo Period Sorghum	15	1.08	11.27
Sweet Sorghum	15	1.29	12.82
Grain Sorghum	15	1.07	11.48
Rotated Corn	15	1.29	12.56
Miscanthus	15	1.30	13.89
Switchgrass (Kanlow)	15	1.37	14.77
Big Bluestem	15	1.22	13.18
Indiangrass Mix	15	1.04	10.40
Switchgrass Mix	15	1.21	12.26

Table A.11 Mean weight diameter (MWD) and distribution of water-stable aggregate factions at Colby, for the 0 to 5cm depth in Fall 2010.

			Aggregate Size Fraction (mm)					
Treatment	Rep	MWD (mm)	>4.75	2-4.75	1-2	0.5-1	0.25-0.5	<0.25
			---Water Stable Aggregates (%) ---					
Switchgrass (Blackwell)	1	1.76	18.3	9.6	7.4	9.9	9.7	45.1
Switchgrass (Blackwell)	2	1.24	11.7	10.3	1.0	3.4	6.3	69.0
Switchgrass (Blackwell)	3	1.29	12.4	9.4	2.4	4.7	7.2	65.8
Miscanthus	1	1.75	16.0	13.0	7.9	10.5	11.5	43.8
Miscanthus	2	1.89	17.4	13.6	8.8	13.3	15.6	32.6
Miscanthus	3	1.53	14.1	9.6	7.4	12.2	14.2	44.9
Sweet Sorghum	1	0.91	7.7	4.4	6.8	8.2	7.6	66.7
Sweet Sorghum	2	1.84	17.7	10.8	5.0	26.8	10.3	29.4
Sweet Sorghum	3	1.27	11.3	8.2	6.5	9.3	11	55.7
Grain Sorghum	1	1.37	9.9	14.0	6.0	10.2	10.6	49.4
Grain Sorghum	2	1.08	13.3	0.2	3.4	5.7	12.7	67.1
Grain Sorghum	3	1.06	4.1	14.8	8.8	8.1	10.1	55.2
W-S-F 0% residue removal	1	1.08	4.7	13.0	9.6	12.1	12.2	50.3
W-S-F 0% residue removal	2	0.81	7.5	4.2	2.9	3.7	4.2	77.5
W-S-F 0% residue removal	3	0.66	1.9	8.8	3.9	7.0	12.5	66.2
W-S-F 100% residue removal	1	0.7	4.1	6.5	4.4	5.1	6.6	76.1
W-S-F 100% residue removal	2	1.01	5.7	12.3	6.5	2.6	10.6	63.9
W-S-F 100% residue removal	3	1.14	6.7	12	10.2	7.3	7.8	58.4

Table A.12 Mean weight diameter (MWD) and distribution of water-stable aggregate factions at Colby, in Spring 2011.

				Aggregate Size Fraction (mm)					
Treatment	Rep	Depth (cm)	MWD (mm)	>4.75	2-4.75	1-2	0.5-1	0.25-0.5	<0.25
				---Water Stable Aggregates (%) ---					
Switchgrass (Blackwell)	1	7.5	2.68	27.6	21	6.2	7.1	6.7	31.5
Switchgrass (Blackwell)	2	7.5	2.18	21.8	14.3	9.1	11.5	13.5	30.0
Switchgrass (Blackwell)	3	7.5	0.40	0.1	4.2	3.4	9.7	9.9	74.2
Switchgrass (Pathfinder)	1	7.5	2.80	33.7	13.9	4.2	6.3	7.9	35.7
Switchgrass (Pathfinder)	2	7.5	4.29	59.7	10.5	4.6	4.0	2.2	20.0
Switchgrass (Pathfinder)	3	7.5	1.65	14.3	12.5	8.3	12.9	11.7	40.9
Miscanthus	1	7.5	2.91	32.9	16.3	9.3	8.7	7.1	26.2
Miscanthus	2	7.5	1.49	10.3	12.7	12.1	16.9	13.1	35.9
Miscanthus	3	7.5	1.09	7.7	8.5	5.8	18.5	6.5	54.2
Big Bluestem	1	7.5	2.59	27.2	19.6	4.8	5.6	8.5	35.9
Big Bluestem	2	7.5	2.53	27.6	14.9	8.7	7.7	9.5	33.5
Big Bluestem	3	7.5	0.91	0.4	11.9	17.1	15.9	14.7	40.3

Sand Bluestem	1	7.5	2.12	23.6	11.1	7.1	7.1	9.1	41.7
Sand Bluestem	2	7.5	2.34	25.8	12.3	8.3	11.9	5.6	37.5
Sand Bluestem	3	7.5	0.66	2.6	6.7	4.8	8.5	12.7	64.1
Mixed Grass	1	7.5	1.6	15.9	11.7	4.2	5.2	4.0	59.5
Mixed Grass	2	7.5	1.97	23.2	8.5	4.4	5.2	8.3	51.8
Mixed Grass	3	7.5	2.08	21.6	13.1	7.1	8.9	12.3	37.1
Indiangrass	1	7.5	1.82	20.4	9.3	4.0	6.0	10.9	49.6
Indiangrass	2	7.5	3.03	35.7	15.3	6.9	10.1	7.5	24.6
Indiangrass	3	7.5	2.11	19.8	16.5	8.3	12.1	10.9	33.1
Eastern Gamagrass	1	7.5	1.69	13.3	14.3	11.3	12.7	12.7	36.1
Eastern Gamagrass	2	7.5	1.34	2.0	25.6	8.5	16.1	15.7	32.7
Eastern Gamagrass	3	7.5	2.08	20.2	15.3	8.7	9.1	9.3	39.1
Grain Sorghum	1	7.5	0.67	1.2	9.1	6.2	8.3	12.3	65.3
Grain Sorghum	2	7.5	0.75	1.0	9.1	8.9	11.9	27.0	44.2
Grain Sorghum	3	7.5	0.74	4.4	4.2	6.2	11.9	15.7	58.3
Sweet Sorghum	1	7.5	0.57	4.0	1.4	5.2	7.5	10.5	73.0
Sweet Sorghum	2	7.5	0.58	3.6	2.4	3.0	11.9	10.9	70.2
Sweet Sorghum	3	7.5	1.55	13.5	10.1	8.7	15.1	14.7	37.3
W-S-F 0% residue removal	1	7.5	0.81	3.2	9.3	6.5	11.5	8.3	61.9
W-S-F 0% residue removal	2	7.5	0.60	1.0	8.3	5.2	9.7	5.0	72.4
W-S-F 0% residue removal	3	7.5	1.10	9.5	6.9	5.4	9.7	10.9	59.3
W-S-F 100% residue removal	1	7.5	0.40	1.6	3.8	1.2	2.2	8.3	82.7
W-S-F 100% residue removal	2	7.5	0.69	3.2	5.4	5.4	11.5	14.1	61.1
W-S-F 100% residue removal	3	7.5	0.21	0.1	0.8	0.2	2.0	15.5	82.9
Switchgrass (Blackwell)	1	15	1.14	8.1	11.7	4.6	7.1	9.9	59.9
Switchgrass (Blackwell)	2	15	1.91	19.4	13.1	3.0	16.3	1.8	47.8
Switchgrass (Blackwell)	3	15	0.48	0.6	5.4	2.8	11.3	10.1	71.4
Switchgrass (Pathfinder)	1	15	1.86	20.8	9.5	4.4	7.1	7.9	50.6
Switchgrass (Pathfinder)	2	15	1.13	10.7	6.5	4.2	6.9	8.9	64.5
Switchgrass (Pathfinder)	3	15	2.03	19.6	12.9	11.3	13.9	10.5	31.5
Miscanthus	1	15	1.66	14.9	12.5	7.9	9.1	10.3	46.6
Miscanthus	2	15	0.73	5.8	3.0	4.4	9.1	10.7	67.9
Miscanthus	3	15	0.22	0.2	0.8	1.6	4.4	3.8	88.3
Big Bluestem	1	15	1.58	16.9	8.7	4.6	5.8	6.9	57.1
Big Bluestem	2	15	1.75	17.3	11.3	7.5	8.1	9.3	46.8
Big Bluestem	3	15	2.00	13.5	23.2	10.7	19.8	2.8	29.6
Sand Bluestem	1	15	1.45	10.5	13.3	9.7	11.3	13.3	41.7
Sand Bluestem	2	15	2.70	27.2	19.6	8.7	12.7	13.9	18.1
Sand Bluestem	3	15	0.27	0.4	1.4	1.8	4.8	7.5	84.9
Mixed Grass	1	15	1.56	17.3	8.3	3.6	3.8	3.4	64.9
Mixed Grass	2	15	2.21	26.0	11.1	4.0	4.8	7.1	46.4
Mixed Grass	3	15	1.30	12.5	8.3	4.6	5.4	10.3	59.3

Indiangrass	1	15	2.05	24.0	8.9	5.2	6.5	8.7	46.2
Indiangrass	2	15	0.97	8.3	6.3	4.4	6.7	10.3	65.1
Indiangrass	3	15	2.85	33.7	11.5	12.3	10.3	6.0	28.0
Eastern Gamagrass	1	15	1.78	13.5	16.7	11.7	12.3	12.7	32.9
Eastern Gamagrass	2	15	1.31	1.4	20	25.8	11.3	9.3	32.7
Eastern Gamagrass	3	15	2.33	24.8	14.9	7.3	8.5	7.7	37.3
Grain Sorghum	1	15	0.51	1.8	2.8	6.9	8.7	11.5	68.3
Grain Sorghum	2	15	0.92	4.2	8.1	9.5	13.9	19.4	45.2
Grain Sorghum	3	15	0.87	5.4	5.4	6.2	15.3	16.9	52.2
Sweet Sorghum	1	15	0.79	7.3	2.8	2.2	8.3	13.7	67.3
Sweet Sorghum	2	15	0.49	3.4	1.0	2.6	7.5	14.9	70.2
Sweet Sorghum	3	15	0.79	4.2	6.2	6.0	11.1	16.5	55.8
W-S-F 0% residue removal	1	15	1.05	9.1	5.4	5.2	12.7	10.3	58.3
W-S-F 0% residue removal	2	15	0.82	1.2	9.5	13.3	11.9	22.4	41.3
W-S-F 0% residue removal	3	15	0.48	0.4	5.0	5.8	8.3	11.9	70.2
W-S-F 100% residue removal	1	15	0.34	1.2	2.2	2.2	3.8	4.8	86.7
W-S-F 100% residue removal	2	15	0.73	4.2	5.4	2.8	12.3	17.1	58.7
W-S-F 100% residue removal	3	15	0.46	1.8	3.4	3.4	6.0	11.3	73.6

Table A.13 Mean weight diameter (MWD) and distribution of water-stable aggregate factions at Colby, in Fall 2011.

				Aggregate Size Fraction (mm)					
Treatment	**Rep**	**Depth (cm)**	**MWD (mm)**	**>4.75**	**2-4.75**	**1-2**	**0.5-1**	**0.25-0.5**	**<0.25**
				---Water Stable Aggregates (%) ---					
Switchgrass (Blackwell)	1	7.5	1.37	2.2	23.6	16.2	13.2	15.4	29.5
Switchgrass (Blackwell)	2	7.5	3.57	47.6	11.4	3.8	5.0	8.4	24.1
Switchgrass (Blackwell)	3	7.5	2.29	27.2	9.5	4.8	7.4	11.7	39.2
Miscanthus	1	7.5	1.49	31.6	10.5	6.8	11.1	13.3	26.2
Miscanthus	2	7.5	2.27	32.7	11.4	3.2	4.8	9.8	38.5
Miscanthus	3	7.5	2.96	33.8	10.4	3.6	5.8	10.0	36.8
Grain Sorghum	1	7.5	1.96	59.3	10.8	1.8	2.8	5.6	20.2
Grain Sorghum	2	7.5	0.77	10.2	10.0	8.8	12.6	14.4	44.2
Grain Sorghum	3	7.5	2.62	30.6	10.0	4.6	6.8	11.4	36.8
Sweet Sorghum	1	7.5	1.83	6.2	33.6	10.1	9.7	12.5	27.8
Sweet Sorghum	2	7.5	2.68	32.2	12.6	4.6	7.8	12.2	30.6
Sweet Sorghum	3	7.5	1.27	10.6	9.4	6.2	10.4	13.4	50.1
W-S-F 0% residue removal	1	7.5	2.65	2.4	27.5	15.2	12.8	14.0	28.1
W-S-F 0% residue removal	2	7.5	2.63	24.2	12.8	8.6	11.2	12.4	30.8
W-S-F 0% residue removal	3	7.5	2.67	37.5	11.4	4.2	6.4	10.4	29.9
W-S-F 100% residue removal	1	7.5	4.22	10.5	27.4	11.7	11.9	13.9	23.9
W-S-F 100% residue removal	2	7.5	1.32	3.6	8.0	5.6	8.2	11.4	63.1

W-S-F 100% residue removal	3	7.5	2.50	32.9	9.8	4.0	6.8	10.4	36.3
Switchgrass (Blackwell)	1	15	0.94	2.2	15.7	4.4	10.7	14.3	52.7
Switchgrass (Blackwell)	2	15	1.44	14.0	8.6	6.2	8.8	12.0	50.3
Switchgrass (Blackwell)	3	15	1.14	10.8	5.2	5.6	9.8	14.3	54.0
Miscanthus	1	15	2.44	21.4	10.0	6.8	8.6	12.4	41.1
Miscanthus	2	15	0.98	30.0	10.3	5.4	6.6	9.3	38.4
Miscanthus	3	15	0.85	19.4	10.6	6.2	9.0	11.0	43.9
Grain Sorghum	1	15	2.17	0.8	17.2	25.2	19.4	10.8	26.8
Grain Sorghum	2	15	1.89	12.4	15.0	13.4	15.6	14.4	29.2
Grain Sorghum	3	15	1.90	13.5	7.0	4.8	7.4	13.5	53.4
Sweet Sorghum	1	15	1.45	6.2	22.2	9.2	9.2	14.0	39.2
Sweet Sorghum	2	15	1.34	13.9	6.2	4.2	7.6	13.3	54.6
Sweet Sorghum	3	15	2.51	27.6	14.1	7.6	9.1	10.5	30.6
W-S-F 0% residue removal	1	15	1.95	22.2	17.0	19.2	15.4	6.4	20.4
W-S-F 0% residue removal	2	15	2.48	5.4	9.0	8.0	13.4	15.6	49.0
W-S-F 0% residue removal	3	15	1.85	5.8	7.4	4.2	6.8	9.4	66.5
W-S-F 100% residue removal	1	15	1.23	13.7	28.3	12.5	8.8	12.5	23.9
W-S-F 100% residue removal	2	15	1.70	23.6	5.0	4.4	7.8	11.6	47.7
W-S-F 100% residue removal	3	15	1.35	20.3	11.7	4.2	7.0	9.9	46.9

Table A.14 Mean weight diameter (MWD) and distribution of water-stable aggregate factions at Colby, in Spring 2012.

				Aggregate Size Fraction (mm)					
Treatment	**Rep**	**Depth (cm)**	**MWD (mm)**	**>4.75**	**2-4.75**	**1-2**	**0.5-1**	**0.25-0.5**	**<0.25**
				---Water Stable Aggregates (%) ---					
Switchgrass (Blackwell)	1	7.5	0.68	0.8	10.6	3.8	9.2	20.6	55.1
Switchgrass (Blackwell)	2	7.5	1.84	0.4	6.2	4.8	15.1	17.3	56.2
Switchgrass (Blackwell)	3	7.5	1.33	3.8	23.4	5.0	7.8	15.2	45.6
Miscanthus	1	7.5	0.88	0.4	5.6	5.4	14.2	11.2	63.3
Miscanthus	2	7.5	1.12	0.2	2.8	6.6	18.6	18.8	53.2
Miscanthus	3	7.5	0.92	3.4	16.3	6.8	15.9	26.0	30.8
Grain Sorghum	1	7.5	3.00	0.6	4.6	3.6	9.8	19.6	62.1
Grain Sorghum	2	7.5	0.56	1.4	20.4	11.2	21.2	15.4	31.2
Grain Sorghum	3	7.5	1.07	7.2	14.1	8.2	11.7	16.9	42.1
Sweet Sorghum	1	7.5	3.43	1.6	3.6	5.6	18.3	10.1	60.1
Sweet Sorghum	2	7.5	0.52	7.2	7.0	15.4	39.5	4.4	26.1
Sweet Sorghum	3	7.5	0.47	6.7	20.4	6.5	17.8	13.8	33.8
W-S-F 0% residue removal	1	7.5	1.20	2.4	11.9	5.0	8.7	16.5	55.3
W-S-F 0% residue removal	2	7.5	1.44	9.0	18.6	22.6	21.2	7.0	22.2
W-S-F 0% residue removal	3	7.5	0.83	2.8	13.1	6.4	9.6	18.3	50.0
W-S-F 100% residue removal	1	7.5	1.28	2.2	12.5	7.4	8.2	22.5	48.0
W-S-F 100% residue removal	2	7.5	1.17	9.3	18.5	10.7	19.3	15.5	25.8

W-S-F 100% residue removal	3	7.5	1.26	5.5	15.8	7.1	12.3	14.4	44.9
Switchgrass (Blackwell)	1	15	0.55	0.4	7.4	8.4	11.4	23.0	50.3
Switchgrass (Blackwell)	2	15	0.90	41.6	14.6	10.2	12.8	4.2	17.2
Switchgrass (Blackwell)	3	15	0.58	15.4	7.6	4.8	5.8	13.0	53.7
Miscanthus	1	15	1.62	1.0	6.7	11.3	16.3	25.8	38.1
Miscanthus	2	15	0.73	4.4	13.2	10.6	26.3	12.4	33.1
Miscanthus	3	15	0.39	2.0	11.0	6.8	13.1	21.1	45.6
Grain Sorghum	1	15	2.47	0.2	5.0	4.8	7.9	19.6	61.8
Grain Sorghum	2	15	1.27	10.4	5.6	3.4	6.0	14.0	60.7
Grain Sorghum	3	15	1.12	5.8	13.4	4.6	12.2	22.6	41.4
Sweet Sorghum	1	15	1.47	1.2	12.5	6.3	7.9	14.1	57.5
Sweet Sorghum	2	15	0.48	10.5	25.2	7.3	17.9	10.7	28.2
Sweet Sorghum	3	15	1.20	5.6	8.1	6.2	6.7	12.5	61.1
W-S-F 0% residue removal	1	15	0.96	0.8	2.8	3.0	6.4	17.0	70.8
W-S-F 0% residue removal	2	15	0.78	5.4	18.1	9.7	17.3	14.3	35.0
W-S-F 0% residue removal	3	15	1.75	3.8	3.8	3.0	5.0	10.0	74.1
W-S-F 100% residue removal	1	15	0.64	4.2	11.0	9.0	9.4	13.4	53.9
W-S-F 100% residue removal	2	15	0.83	30.3	17.9	25.1	6.0	6.2	14.7
W-S-F 100% residue removal	3	15	0.46	29.8	11.9	4.0	4.4	8.3	41.1

Table A.15 Mean weight diameter (MWD) and distribution of water-stable aggregate factions at Hays, for the 0 to 5cm depth in Fall 2010.

			Aggregate Size Fraction (mm)					
Treatment	Rep	MWD (mm)	>4.75	2-4.75	1-2	0.5-1	0.25-0.5	<0.25
			---Water Stable Aggregates (%) ---					
Switchgrass (Blackwell)	1	1.79	6.4	33.3	6.4	9.7	12.2	32.0
Switchgrass (Blackwell)	2	1.24	13.8	4.6	3.3	5.4	7.4	65.0
Switchgrass (Blackwell)	3	1.73	19.6	8.6	4.0	1.1	16.2	50.1
Switchgrass (Pathfinder)	1	0.43	0.1	3.4	6.8	11.5	10.7	68.0
Switchgrass (Pathfinder)	2	1.22	13.1	5.7	2.8	4.3	9.8	64.0
Switchgrass (Pathfinder)	3	2.55	27.3	14.7	10.1	10.8	11.4	26.2
Miscanthus	1	1.34	13.7	9.0	2.8	3.2	5.6	65.5
Miscanthus	2	1.01	10.2	3.9	3.6	7.0	10.2	64.3
Miscanthus	3	1.34	7.9	13.5	9.2	18.4	16.4	34.3
Big Bluestem	1	1.08	9.2	6.8	3.9	7.9	24.6	46.9
Big Bluestem	2	0.85	8.3	2.8	4.0	5.8	9.8	68.9
Big Bluestem	3	1.18	10.6	6.3	5.4	11.5	15.1	52.4
Sand Bluestem	1	1.56	14.9	11.1	6.5	5.5	7.8	53.9
Sand Bluestem	2	1.00	9.8	4.7	3.5	6.1	8.3	68.2
Sand Bluestem	3	0.73	3.9	6.7	3.8	5.8	20.9	58.8
Mixed Grass	1	0.76	0.2	12.3	14.3	0.7	9.4	63.3
Mixed Grass	2	1.24	13.7	5.1	3.3	5.5	8.0	64.2
Mixed Grass	3	2.23	22.5	14.3	9.3	10.9	13.5	30.0
Indiangrass	1	0.86	5.4	7.7	3.8	6.3	19.9	57.1
Indiangrass	2	1.11	10.8	5.6	3.3	7.7	12.1	60.4
Indiangrass	3	0.97	5.6	8.7	11.2	7.9	6.7	59.0
Sweet Sorghum	1	0.38	0.2	12.3	14.3	0.7	9.4	63.3
Sweet Sorghum	2	0.73	13.7	5.1	3.3	5.5	8.0	64.2
Sweet Sorghum	3	0.62	22.5	14.3	9.3	10.9	13.5	30.0
Eastern Gamagrass	1	1.26	12.9	0.7	11.6	5.7	6.9	62.7
Eastern Gamagrass	2	1.54	1.9	1.9	1.1	3.6	5.3	85.0
Eastern Gamagrass	3	1.28	1.8	3.4	2.8	7.0	10.5	73.1
Grain Sorghum	1	1.17	1.5	0.4	1.5	3.1	14.3	79.3
Grain Sorghum	2	0.36	1.5	1.6	1.9	6.1	11.8	76.3
Grain Sorghum	3	0.46	4.8	5.4	6.3	9.3	16.3	58.3
W-S-F 0% residue removal	1	0.31	1.5	0.4	1.5	3.1	14.3	79.3
W-S-F 0% residue removal	2	0.36	1.5	1.6	1.9	6.1	11.8	76.3
W-S-F 0% residue removal	3	0.79	4.8	5.4	6.3	9.3	16.3	58.3
W-S-F 100% residue removal	1	1.43	12.6	10.8	7.3	6.4	9.8	52.5
W-S-F 100% residue removal	2	0.29	0.3	1.9	2.2	5.9	10.2	79.7
W-S-F 100% residue removal	3	1.08	7.8	7.6	7.6	11.2	17.5	47.2

Table A.16 Mean weight diameter (MWD) and distribution of water-stable aggregate factions at Hays, in Spring 2011.

				Aggregate Size Fraction (mm)					
Treatment	Rep	Depth (cm)	MWD (mm)	>4.75	2-4.75	1-2	0.5-1	0.25-0.5	<0.25
				---Water Stable Aggregates (%) ---					
Switchgrass (Blackwell)	1	7.5	1.08	6.3	13.0	6.3	5.1	7.5	61.8
Switchgrass (Blackwell)	2	7.5	0.96	5.9	7.9	8.5	9.3	13.2	54.3
Switchgrass (Blackwell)	3	7.5	0.95	8.1	4.1	7.3	10.4	9.3	58.5
Switchgrass (Pathfinder)	1	7.5	1.05	3.3	14.8	11.4	9.3	6.9	53.7
Switchgrass (Pathfinder)	2	7.5	1.02	7.3	8.9	5.1	8.1	13.8	55.7
Switchgrass (Pathfinder)	3	7.5	0.94	8.9	4.3	5.3	5.9	7.3	65.6
Miscanthus	1	7.5	1.40	13.4	8.3	6.3	9.4	11.4	49.4
Miscanthus	2	7.5	0.88	5.9	6.3	6.5	9.6	15.2	54.3
Miscanthus	3	7.5	0.67	4.1	4.7	3.9	8.1	13.2	65.2
Big Bluestem	1	7.5	1.16	7.1	12.0	9.1	9.3	8.7	51.0
Big Bluestem	2	7.5	0.83	6.3	4.9	5.9	7.5	10.8	62.4
Big Bluestem	3	7.5	1.27	5.3	15.6	14.4	13.2	11.2	37.4
Sand Bluestem	1	7.5	0.89	2.6	11.4	9.8	12.2	9.3	54.3
Sand Bluestem	2	7.5	0.73	4.5	5.1	4.9	8.3	13.8	61.8
Sand Bluestem	3	7.5	0.99	5.9	6.7	9.6	16.5	18.5	40.4
Mixed Grass	1	7.5	0.87	7.9	4.1	4.1	7.5	7.3	68.1
Mixed Grass	2	7.5	0.82	4.3	9.6	4.9	4.9	7.9	65.9
Mixed Grass	3	7.5	1.34	12.8	5.3	10.2	11.6	12.4	46.5
Indiangrass	1	7.5	1.68	19.5	7.7	3.5	4.9	3.1	61.0
Indiangrass	2	7.5	0.91	9.1	3.0	3.3	8.9	8.9	66.3
Indiangrass	3	7.5	0.66	6.3	2.2	2.0	3.7	8.9	75.8
Eastern Gamagrass	1	7.5	1.38	10.0	11.8	11.0	10.6	10.6	45.1
Eastern Gamagrass	2	7.5	1.04	8.9	5.3	8.5	6.1	12.2	58.7
Eastern Gamagrass	3	7.5	0.86	4.5	6.9	9.1	11.6	11.2	56.3
Grain Sorghum	1	7.5	1.27	3.9	2.8	5.3	18.5	16.1	50.8
Grain Sorghum	2	7.5	0.33	0.6	2.6	1.6	2.8	19.3	70.3
Grain Sorghum	3	7.5	0.53	1.8	3.7	4.7	10.4	17.7	60.8
Sweet Sorghum	1	7.5	0.78	3.7	3.9	3.0	6.3	11.2	70.3
Sweet Sorghum	2	7.5	0.22	1.2	2.4	1.2	10.8	16.1	66.7
Sweet Sorghum	3	7.5	0.58	0.2	0.0	0.6	1.2	13.4	81.5
W-S-F 0% residue removal	1	7.5	0.94	0.6	2.6	3.5	8.5	14.6	67.1

W-S-F 0% residue removal	2	7.5	0.40	0.1	0.8	1.0	4.7	11.8	81.3
W-S-F 0% residue removal	3	7.5	0.18	3.1	2.2	2.6	7.7	14.8	69.5
W-S-F 100% residue removal	1	7.5	0.77	1.8	4.5	4.9	7.3	13.6	65.4
W-S-F 100% residue removal	2	7.5	0.40	1.4	2.0	0.2	11.4	15.4	68.1
W-S-F 100% residue removal	3	7.5	0.25	0.6	0.6	1.2	3.5	11.2	82.7
Switchgrass (Blackwell)	1	15	1.13	11.8	5.3	3.3	4.3	8.7	66.5
Switchgrass (Blackwell)	2	15	0.86	4.3	6.7	10.2	12.8	12.2	53.3
Switchgrass (Blackwell)	3	15	1.10	5.5	9.8	14.2	14.2	11.8	43.9
Switchgrass (Pathfinder)	1	15	0.85	5.1	5.1	8.7	13.8	13.6	52.6
Switchgrass (Pathfinder)	2	15	0.89	4.3	7.5	9.1	12.8	21.7	42.1
Switchgrass (Pathfinder)	3	15	0.93	4.7	9.3	8.7	11.0	8.7	56.1
Miscanthus	1	15	0.70	1.0	6.5	12.8	15.2	15.2	48.2
Miscanthus	2	15	0.89	2.6	9.4	13.0	14.4	13.2	46.1
Miscanthus	3	15	0.43	0.6	3.1	5.7	9.3	12.8	67.9
Big Bluestem	1	15	0.91	5.5	9.4	4.3	7.9	11.6	60.8
Big Bluestem	2	15	0.81	5.3	4.1	5.5	13.2	22.8	47.4
Big Bluestem	3	15	0.93	4.7	8.9	9.1	11.2	13.8	50.2
Sand Bluestem	1	15	0.73	0.6	6.9	14.2	18.5	14.4	43.5
Sand Bluestem	2	15	1.10	6.7	7.9	10.2	18.1	19.5	35.6
Sand Bluestem	3	15	1.00	4.9	7.3	12.4	17.7	18.9	37.2
Mixed Grass	1	15	0.90	5.7	4.9	10.8	11.0	17.5	47.6
Mixed Grass	2	15	0.54	1.0	4.5	6.9	11.2	15.7	60.6
Mixed Grass	3	15	0.63	1.0	6.1	9.4	12.8	13.2	55.1
Indiangrass	1	15	1.13	5.5	10.6	15.9	12.4	8.7	44.1
Indiangrass	2	15	0.74	0.8	6.9	10.2	25.2	18.1	38.2
Indiangrass	3	15	0.66	3.7	4.5	3.9	11.2	11.8	63.0
Eastern Gamagrass	1	15	1.73	9.6	18.7	19.7	15.6	10.0	23.8
Eastern Gamagrass	2	15	0.44	2.8	1.8	4.3	1.8	4.9	82.3
Eastern Gamagrass	3	15	0.61	2.2	1.6	12.4	15.6	13.8	53.7
Grain Sorghum	1	15	1.55	2.6	7.5	8.1	16.7	13.4	50.4
Grain Sorghum	2	15	0.56	0.6	4.9	8.3	13.2	18.3	53.1
Grain Sorghum	3	15	0.55	1.8	3.9	2.4	9.8	14.4	65.7
Sweet Sorghum	1	15	1.61	1.8	2.2	8.5	19.5	12.0	54.3
Sweet Sorghum	2	15	0.43	0.2	0.4	5.1	14.6	21.3	57.5
Sweet Sorghum	3	15	0.69	1.2	4.3	6.1	10.6	13.6	62.4
W-S-F 0% residue removal	1	15	1.27	2.6	8.5	5.9	14.2	11.8	56.3
W-S-F 0% residue removal	2	15	0.37	1.2	2.6	3.9	15.6	14.6	62.4
W-S-F 0% residue removal	3	15	0.37	2.2	1.0	4.9	13.2	20.5	58.3
W-S-F 100% residue removal	1	15	1.34	2.4	2.4	10.8	18.3	15.9	49.8

W-S-F 100% residue removal	2	15	0.54	0.1	3.5	5.5	21.3	15.6	53.7
W-S-F 100% residue removal	3	15	0.37	2.4	0.8	3.9	9.1	19.1	64.4

Table A.17 Mean weight diameter (MWD) and distribution of water-stable aggregate factions at Hays, in Fall 2011.

				Aggregate Size Fraction (mm)					
Treatment	**Rep**	**Depth (cm)**	**MWD (mm)**	**>4.75**	**2-4.75**	**1-2**	**0.5-1**	**0.25-0.5**	**<0.25**
				---Water Stable Aggregates (%) ---					
Switchgrass (Blackwell)	1	7.5	1.85	1.6	41.7	11.7	12.9	10.7	21.3
Switchgrass (Blackwell)	2	7.5	2.02	17.8	15.8	12.6	11.0	12.2	29.2
Switchgrass (Blackwell)	3	7.5	2.97	36.0	12.8	9.4	10.0	6.6	26.4
Switchgrass (Pathfinder)	1	7.5	1.77	2.4	35.8	18.1	10.1	7.6	25.6
Switchgrass (Pathfinder)	2	7.5	2.05	9.2	34.6	11.2	6.8	9.0	28.8
Switchgrass (Pathfinder)	3	7.5	2.26	14.8	28.3	12.6	8.1	7.1	26.8
Miscanthus	1	7.5	1.15	1.8	17.9	16.3	10.4	15.5	38.2
Miscanthus	2	7.5	0.57	1.2	3.6	9.3	5.8	34.5	46.0
Miscanthus	3	7.5	0.60	0.2	9.9	3.0	4.9	26.0	56.2
Big Bluestem	1	7.5	3.05	33.6	16.6	15.0	11.0	3.2	20.6
Big Bluestem	2	7.5	1.82	16.4	11.2	15.6	10.8	11.2	35.1
Big Bluestem	3	7.5	0.97	1.4	16.8	5.8	12.4	23.6	40.3
Sand Bluestem	1	7.5	1.83	19.7	8.2	9.6	7.8	9.0	45.6
Sand Bluestem	2	7.5	1.68	16.7	11.0	5.4	9.4	15.3	43.2
Sand Bluestem	3	7.5	1.37	5.7	19.6	11.9	10.5	8.5	43.9
Mixed Grass	1	7.5	1.66	5.4	25.1	21.2	11.6	9.0	28.1
Mixed Grass	2	7.5	2.27	12.5	30.3	16.9	12.9	8.2	17.3
Mixed Grass	3	7.5	2.21	8.8	39.3	14.0	5.8	9.4	22.4
Indiangrass	1	7.5	1.95	9.2	28.5	15.5	14.5	11.6	21.5
Indiangrass	2	7.5	2.65	28.7	16.5	7.6	8.8	10.8	27.5
Indiangrass	3	7.5	2.14	10.1	32.5	16.2	7.7	7.3	24.1
Eastern Gamagrass	1	7.5	1.39	3.3	19.1	24.6	15.9	11.0	27.8
Eastern Gamagrass	2	7.5	1.92	6.3	32.4	15.6	10.5	6.7	25.9
Eastern Gamagrass	3	7.5	1.46	1.6	29.3	16.6	6.7	11.3	36.0
Grain Sorghum	1	7.5	1.00	8.2	6.0	5.8	9.2	12.4	58.7
Grain Sorghum	2	7.5	1.25	0.1	21.2	23.4	13.9	14.9	27.8
Grain Sorghum	3	7.5	0.90	0.6	9.3	20.5	16.3	20.3	32.8
Sweet Sorghum	1	7.5	1.40	2.4	22.3	20.3	13.9	15.1	26.1
Sweet Sorghum	2	7.5	1.08	2.2	15.2	14.6	14.4	15.2	38.8
Sweet Sorghum	3	7.5	1.07	6.7	9.9	6.7	10.3	12.0	52.7
W-S-F 0% residue removal	1	7.5	0.84	0.1	7.8	25.2	13.3	15.9	38.8

W-S-F 0% residue removal	2	7.5	0.77	2.6	7.6	6.2	16.1	20.9	46.4
W-S-F 0% residue removal	3	7.5	0.55	0.8	5.6	3.2	7.2	42.2	40.0
W-S-F 100% residue removal	1	7.5	1.07	0.8	16.4	16.4	13.8	16.6	34.8
W-S-F 100% residue removal	2	7.5	1.06	2.4	8.8	29.9	6.6	12.4	38.1
W-S-F 100% residue removal	3	7.5	0.55	0.8	6.9	5.3	7.1	13.8	65.5
Switchgrass (Blackwell)	1	15	1.50	1.0	20.9	38.1	16.2	9.7	15.4
Switchgrass (Blackwell)	2	15	0.89	4.2	8.2	6.6	16.5	15.5	48.9
Switchgrass (Blackwell)	3	15	1.32	0.2	23.8	21.8	15.4	11.3	28.5
Switchgrass (Pathfinder)	1	15	1.80	1.6	34.4	25.3	12.3	7.5	18.0
Switchgrass (Pathfinder)	2	15	1.29	5.5	16.4	13.4	12.0	14.6	38.7
Switchgrass (Pathfinder)	3	15	1.55	8.8	19.1	13.7	8.2	10.4	40.2
Miscanthus	1	15	1.01	5.4	8.0	12.2	14.8	14.6	45.5
Miscanthus	2	15	0.97	0.6	3.4	38.7	25.0	7.9	25.0
Miscanthus	3	15	0.64	1.4	7.8	7.2	10.3	13.2	64.5
Big Bluestem	1	15	1.74	2.0	28.3	33.7	13.5	7.6	14.7
Big Bluestem	2	15	1.99	9.5	30.4	15.0	6.3	13.4	25.3
Big Bluestem	3	15	1.35	9.5	6.6	9.7	47.7	2.8	25.6
Sand Bluestem	1	15	1.49	0.8	28.3	21.3	14.5	9.6	26.1
Sand Bluestem	2	15	1.38	12.8	3.4	9.3	17.0	42.5	16.4
Sand Bluestem	3	15	1.19	0.2	19.1	24.7	12.2	8.6	36.1
Mixed Grass	1	15	1.55	1.0	25.2	30.4	14.9	8.0	19.9
Mixed Grass	2	15	1.09	4.0	11.2	14.0	20.8	6.0	42.9
Mixed Grass	3	15	0.95	4.7	9.3	12.0	10.1	9.3	57.4
Indiangrass	1	15	1.63	5.8	21.4	23.4	17.3	12.1	21.0
Indiangrass	2	15	1.46	12.0	10.0	6.8	16.9	17.5	35.1
Indiangrass	3	15	1.16	3.6	17.8	3.9	25.4	8.7	40.6
Eastern Gamagrass	1	15	1.96	21.2	8.3	10.1	10.1	10.5	39.5
Eastern Gamagrass	2	15	1.61	1.6	33.3	8.6	25.3	5.6	25.0
Eastern Gamagrass	3	15	1.84	5.4	36.7	3.6	27.2	2.8	26.6
Grain Sorghum	1	15	0.91	3.0	8.7	12.8	17.4	17.6	42.2
Grain Sorghum	2	15	0.77	1.2	8.3	7.0	21.5	21.7	38.8
Grain Sorghum	3	15	0.86	0.4	9.0	20.7	13.1	19.3	37.1
Sweet Sorghum	1	15	0.96	2.0	5.8	27.1	18.2	13.8	33.1
Sweet Sorghum	2	15	0.88	0.4	7.6	19.0	32.9	8.0	33.1
Sweet Sorghum	3	15	0.87	5.0	7.4	8.4	8.6	12.0	58.9
W-S-F 0% residue removal	1	15	1.04	0.1	7.0	38.2	22.0	11.8	21.2
W-S-F 0% residue removal	2	15	0.54	0.6	3.6	6.8	18.7	19.5	49.8
W-S-F 0% residue removal	3	15	0.50	0.2	2.6	8.8	13.6	30.1	44.9
W-S-F 100% residue removal	1	15	1.03	0.4	11.2	26.3	17.6	17.4	27.1

W-S-F 100% residue removal	2	15	0.72	0.6	7.1	12.5	17.2	14.4	45.7
W-S-F 100% residue removal	3	15	0.46	0.4	3.2	7.0	9.9	15.5	60.4

Table A.18 Mean weight diameter (MWD) and distribution of water-stable aggregate factions at Hays, in Spring 2012.

				Aggregate Size Fraction (mm)					
Treatment	**Rep**	**Depth (cm)**	**MWD (mm)**	**>4.75**	**2-4.75**	**1-2**	**0.5-1**	**0.25-0.5**	**<0.25**
				---Water Stable Aggregates (%) ---					
Switchgrass (Blackwell)	1	7.5	2.39	24.3	15.3	11.5	10.1	10.5	28.2
Switchgrass (Blackwell)	2	7.5	1.76	1.0	7.6	11.0	19.7	21.5	38.8
Switchgrass (Blackwell)	3	7.5	1.58	2.2	22.9	15.3	15.5	16.3	27.6
Switchgrass (Pathfinder)	1	7.5	2.50	3.0	36.6	15.9	10.7	8.2	25.0
Switchgrass (Pathfinder)	2	7.5	1.81	4.4	5.7	6.7	13.5	22.6	46.1
Switchgrass (Pathfinder)	3	7.5	1.14	19.6	26.4	10.2	19.2	7.4	17.6
Miscanthus	1	7.5	1.10	11.6	17.3	15.1	16.3	14.9	24.3
Miscanthus	2	7.5	0.88	13.5	13.7	7.4	16.1	14.9	34.4
Miscanthus	3	7.5	1.57	3.4	7.8	8.2	19.5	20.9	39.8
Big Bluestem	1	7.5	2.69	0.2	11.2	24.6	15.4	15.8	33.4
Big Bluestem	2	7.5	2.55	8.0	31.2	17.8	11.8	6.4	24.4
Big Bluestem	3	7.5	1.79	5.1	22.8	16.2	16.6	13.1	25.0
Sand Bluestem	1	7.5	1.55	13.5	8.7	5.2	8.5	18.7	45.5
Sand Bluestem	2	7.5	1.58	2.8	18.8	10.3	10.1	11.1	46.0
Sand Bluestem	3	7.5	1.43	36.9	17.8	15.8	10.6	3.2	15.8
Mixed Grass	1	7.5	1.97	4.8	12.2	10.6	11.8	15.0	46.2
Mixed Grass	2	7.5	1.62	0.2	0.2	2.2	6.8	15.3	75.1
Mixed Grass	3	7.5	1.08	10.3	11.1	11.5	22.4	12.9	31.9
Indiangrass	1	7.5	1.35	0.8	16.4	16.4	17.4	21.2	27.9
Indiangrass	2	7.5	2.49	1.0	5.0	5.6	9.1	21.6	57.5
Indiangrass	3	7.5	0.84	2.8	16.2	22.6	21.6	13.8	23.4
Eastern Gamagrass	1	7.5	1.31	17.1	12.0	8.0	10.0	14.3	38.2
Eastern Gamagrass	2	7.5	2.08	2.4	4.0	5.0	11.2	18.1	59.0
Eastern Gamagrass	3	7.5	3.30	9.5	17.9	10.1	16.1	10.5	35.1
Grain Sorghum	1	7.5	0.98	7.0	23.1	11.3	13.5	12.3	32.6
Grain Sorghum	2	7.5	1.37	2.2	16.9	8.3	19.6	16.3	36.1
Grain Sorghum	3	7.5	1.43	3.8	15.8	36.8	4.6	8.3	29.5
Sweet Sorghum	1	7.5	0.81	3.4	29.2	13.4	19.2	10.2	24.4
Sweet Sorghum	2	7.5	1.65	9.0	7.8	20.2	22.0	5.2	36.4
Sweet Sorghum	3	7.5	1.09	1.6	32.2	13.6	14.2	13.2	26.0
W-S-F 0% residue removal	1	7.5	0.54	1.6	9.4	9.0	12.4	21.3	46.0
W-S-F 0% residue removal	2	7.5	0.82	5.0	41.1	15.9	11.9	6.7	19.6

W-S-F 0% residue removal	3	7.5	0.59	18.9	28.4	16.3	13.7	4.8	18.5
W-S-F 100% residue removal	1	7.5	0.76	26.6	17.4	19.8	5.0	12.0	19.4
W-S-F 100% residue removal	2	7.5	0.78	0.6	10.6	11.8	15.1	18.1	44.0
W-S-F 100% residue removal	3	7.5	0.25	16.3	35.1	10.2	9.0	8.0	22.1
Switchgrass (Blackwell)	1	15	1.05	0.4	8.4	31.8	24.2	16.4	19.2
Switchgrass (Blackwell)	2	15	2.14	1.0	4.4	9.0	19.4	24.2	42.7
Switchgrass (Blackwell)	3	15	1.65	4.2	13.9	30.1	16.5	15.5	19.9
Switchgrass (Pathfinder)	1	15	1.74	1.0	21.4	20.2	18.6	10.6	28.3
Switchgrass (Pathfinder)	2	15	1.30	0.8	7.1	11.5	17.7	22.8	40.1
Switchgrass (Pathfinder)	3	15	1.11	17.4	10.2	9.6	13.2	17.6	32.1
Miscanthus	1	15	1.63	21.4	10.1	13.7	16.5	22.6	15.5
Miscanthus	2	15	0.80	0.4	10.6	9.8	15.6	22.8	41.0
Miscanthus	3	15	0.66	0.4	7.4	14.5	23.9	24.7	30.1
Big Bluestem	1	15	1.47	0.4	13.3	13.9	22.1	15.5	34.4
Big Bluestem	2	15	2.95	7.6	10.0	13.4	16.2	15.2	37.0
Big Bluestem	3	15	2.17	5.0	22.4	16.0	18.8	13.4	24.8
Sand Bluestem	1	15	1.54	0.4	7.4	9.4	20.6	16.2	47.1
Sand Bluestem	2	15	0.87	2.6	16.4	13.7	12.7	11.3	42.6
Sand Bluestem	3	15	0.97	0.6	12.1	23.0	19.4	12.3	32.5
Mixed Grass	1	15	1.25	1.0	11.2	25.3	32.2	6.9	25.9
Mixed Grass	2	15	1.22	0.2	2.0	17.1	22.1	25.9	32.1
Mixed Grass	3	15	1.12	2.2	5.8	10.1	17.9	19.1	45.1
Indiangrass	1	15	1.40	3.0	27.4	21.5	19.3	5.4	23.3
Indiangrass	2	15	1.80	0.2	4.0	18.6	24.0	21.6	32.0
Indiangrass	3	15	1.46	1.4	16.9	16.3	19.3	15.9	30.5
Eastern Gamagrass	1	15	1.15	20.4	9.6	16.4	31.7	16.6	5.2
Eastern Gamagrass	2	15	1.29	0.2	2.6	13.2	21.2	26.5	34.1
Eastern Gamagrass	3	15	1.02	3.2	5.4	5.6	8.2	13.6	64.3
Grain Sorghum	1	15	0.95	3.2	27.7	22.2	15.4	8.4	23.4
Grain Sorghum	2	15	0.72	1.2	9.6	14.0	17.6	18.2	40.4
Grain Sorghum	3	15	0.69	3.0	10.4	13.8	14.6	15.4	43.4
Sweet Sorghum	1	15	0.78	7.8	9.0	10.4	18.6	20.6	34.0
Sweet Sorghum	2	15	0.78	1.4	5.6	11.2	19.1	20.9	41.6
Sweet Sorghum	3	15	0.86	1.6	9.2	12.2	20.0	22.2	35.3
W-S-F 0% residue removal	1	15	0.73	0.8	9.8	13.7	20.9	20.9	33.5
W-S-F 0% residue removal	2	15	0.73	5.2	16.0	12.6	17.6	15.8	33.7
W-S-F 0% residue removal	3	15	0.60	35.5	11.4	10.4	11.6	10.2	20.7
W-S-F 100% residue removal	1	15	0.64	10.1	10.7	14.1	20.5	16.9	27.0
W-S-F 100% residue removal	2	15	0.86	2.4	6.6	10.3	15.3	20.7	44.5
W-S-F 100% residue removal	3	15	0.64	4.4	29.5	20.4	13.4	8.6	23.4

Table A.19 Mean weight diameter (MWD) and distribution of water-stable aggregate factions at Manhattan, in Spring 2011.

Treatment	Rep	Depth (cm)	MWD (mm)	>4.75	2-4.75	1-2	0.5-1	0.25-0.5	<0.25
				Aggregate Size Fraction (mm)					
				---Water Stable Aggregates (%) ---					
Continuous Corn	1	7.5	1.2	8.7	9.9	5.4	13.5	14.3	48.2
Continuous Corn	2	7.5	0.6	3.0	4.0	3.2	5.6	12.9	71.4
Continuous Corn	3	7.5	0.5	0.2	1.4	4.0	32.9	1.4	58.9
Continuous Corn	4	7.5	0.8	6.2	2.6	6.5	8.3	11.7	63.1
Photo Period Sorghum	1	7.5	0.7	7.1	3.0	1.4	5.6	8.7	74.0
Photo Period Sorghum	2	7.5	0.2	0.2	1.2	0.4	5.4	10.5	82.3
Photo Period Sorghum	3	7.5	1.2	8.7	10.5	8.5	10.9	15.9	43.7
Photo Period Sorghum	4	7.5	0.6	2.4	6.7	3.6	7.3	8.7	69.4
Sweet Sorghum	1	7.5	0.8	8.9	3.0	0.6	4.0	11.1	70.6
Sweet Sorghum	2	7.5	0.9	5.2	6.9	4.2	14.5	14.9	53.8
Sweet Sorghum	3	7.5	0.7	4.8	4.6	6.2	8.5	12.9	62.9
Sweet Sorghum	4	7.5	1.1	10.9	7.9	2.0	5.0	8.9	63.9
Grain Sorghum	1	7.5	0.5	0.8	6.3	3.4	5.4	14.9	69.4
Grain Sorghum	2	7.5	0.6	1.4	5.8	5.0	19.4	6.9	59.5
Grain Sorghum	3	7.5	0.7	5.2	3.4	5.8	10.3	12.3	60.9
Grain Sorghum	4	7.5	---	---	---	---	---	---	---
Rotated Corn	1	7.5	0.8	3.2	7.9	7.9	10.9	10.9	56.9
Rotated Corn	2	7.5	0.6	1.8	3.2	8.3	14.1	10.9	61.3
Rotated Corn	3	7.5	1.1	12.9	2.4	2.8	7.9	12.5	61.7
Rotated Corn	4	7.5	0.6	4.4	2.2	5.2	7.9	11.3	69.4
Miscanthus	1	7.5	2.5	28.6	11.3	7.1	10.7	9.7	31.9
Miscanthus	2	7.5	2.4	25.2	15.3	8.1	10.1	9.5	30.6
Miscanthus	3	7.5	1.8	20.2	8.7	4.4	5.2	10.7	49.0
Miscanthus	4	7.5	1.0	10.9	2.4	2.2	4.2	10.5	69.2
Switchgrass (Kanlow)	1	7.5	2.2	22.2	12.9	11.9	13.9	11.1	26.4
Switchgrass (Kanlow)	2	7.5	3.4	38.9	20.8	6.9	5.2	5.2	23.2
Switchgrass (Kanlow)	3	7.5	2.2	21.8	16.7	6.5	8.1	7.7	36.9

Switchgrass (Kanlow)	4	7.5	0.7	4.4	6.5	5.2	4.0	12.7	67.3
Big Bluestem	1	7.5	1.6	16.3	9.9	4.2	13.5	14.1	41.5
Big Bluestem	2	7.5	1.1	7.9	12.9	3.2	2.0	4.8	68.1
Big Bluestem	3	7.5	1.5	15.9	6.9	4.6	13.3	8.9	48.4
Big Bluestem	4	7.5	2.3	24.6	18.3	2.8	5.4	7.3	39.7
Indiangrass Mix	1	7.5	3.0	37.3	13.5	4.8	6.0	7.5	29.2
Indiangrass Mix	2	7.5	3.1	34.3	19.8	6.9	8.3	7.5	22.2
Indiangrass Mix	3	7.5	1.4	16.5	4.2	3.2	4.2	7.3	62.9
Indiangrass Mix	4	7.5	3.0	38.1	11.3	7.3	5.4	5.4	32.1
Switchgrass Mix	1	7.5	1.3	11.9	10.3	6.5	6.2	9.3	55.0
Switchgrass Mix	2	7.5	1.4	12.1	11.1	6.0	10.7	11.9	47.6
Switchgrass Mix	3	7.5	2.3	28.8	9.9	3.6	5.0	7.1	44.6
Switchgrass Mix	4	7.5	2.9	36.5	12.3	4.0	4.8	6.7	36.5
Soy Bean (Photo Period Sorghum)	1	7.5	0.4	1.0	1.8	4.0	8.7	17.1	66.3
Soy Bean (Photo Period Sorghum)	2	7.5	0.3	1.6	0.1	1.0	2.4	7.1	88.1
Soy Bean (Photo Period Sorghum)	3	7.5	0.5	0.8	4.4	6.2	8.1	13.7	65.3
Soy Bean (Photo Period Sorghum)	4	7.5	---	---	---	---	---	---	---
Soy Bean (Sweet Sorghum)	1	7.5	0.8	18.8	19.6	13.7	17.9	21.0	8.3
Soy Bean (Sweet Sorghum)	2	7.5	0.9	6.7	4.4	4.2	9.1	21.0	54.8
Soy Bean (Sweet Sorghum)	3	7.5	0.7	7.3	6.5	3.6	7.1	14.1	60.3
Soy Bean (Sweet Sorghum)	4	7.5	1.1	1.4	3.2	2.4	4.2	8.7	80.6
Soy Bean (Grain Sorghum)	1	7.5	0.5	2.0	2.4	6.2	12.5	19.8	56.7
Soy Bean (Grain Sorghum)	2	7.5	0.8	4.2	6.5	4.6	8.7	31.9	42.3
Soy Bean (Grain Sorghum)	3	7.5	0.6	2.8	6.2	3.2	4.4	8.3	74.6
Soy Bean (Grain Sorghum)	4	7.5	0.5	2.4	4.8	4.0	5.6	10.3	72.4
Soy Bean (Rotated Corn)	1	7.5	0.8	5.2	5.2	5.2	10.9	14.5	57.5
Soy Bean (Rotated Corn)	2	7.5	0.6	0.6	1.6	0.4	3.8	7.5	85.3
Soy Bean (Rotated Corn)	3	7.5	0.5	0.4	0.2	1.6	3.4	12.3	82.1
Soy Bean (Rotated Corn)	4	7.5	0.4	0.2	0.4	1.0	3.8	13.5	79.6
Continuous Corn	1	15	0.7	1.4	5.2	8.7	19.0	18.8	46.2
Continuous Corn	2	15	1.0	7.9	7.3	5.4	6.9	13.7	57.3
Continuous Corn	3	15	0.6	2.8	4.6	5.4	11.1	12.7	62.1

Continuous Corn	4	15	0.5	2.0	3.0	3.2	9.3	9.3	72.4
Photo Period Sorghum	1	15	0.4	0.1	2.4	4.4	10.3	17.3	64.7
Photo Period Sorghum	2	15	0.3	1.6	1.0	0.2	4.2	12.3	80.2
Photo Period Sorghum	3	15	0.4	0.8	2.6	3.6	7.1	18.7	66.7
Photo Period Sorghum	4	15	0.3	0.2	1.4	4.4	10.7	12.3	71.2
Sweet Sorghum	1	15	0.3	0.2	2.0	1.6	3.4	6.2	86.3
Sweet Sorghum	2	15	0.2	0.2	0.4	1.4	3.4	11.3	81.7
Sweet Sorghum	3	15	0.3	0.8	1.8	2.4	6.0	11.1	77.6
Sweet Sorghum	4	15	0.4	1.6	3.8	2.2	0.1	6.2	86.3
Grain Sorghum	1	15	0.4	1.0	3.6	4.2	4.6	12.9	72.4
Grain Sorghum	2	15	0.3	0.4	1.8	1.2	7.1	15.7	73.2
Grain Sorghum	3	15	0.3	0.4	1.6	1.8	5.4	13.7	77.2
Grain Sorghum	4	15	---	---	---	---	---	---	---
Rotated Corn	1	15	0.8	5.8	5.6	6.7	5.8	15.3	59.7
Rotated Corn	2	15	0.3	0.2	0.8	3.2	7.3	13.7	73.6
Rotated Corn	3	15	0.3	1.2	0.8	1.4	0.6	6.2	88.7
Rotated Corn	4	15	0.3	0.8	0.6	2.8	4.6	11.1	79.8
Miscanthus	1	15	1.5	11.3	12.5	10.9	15.9	14.5	34.5
Miscanthus	2	15	0.9	8.5	5.0	3.6	6.2	13.9	63.3
Miscanthus	3	15	1.4	12.9	8.7	5.8	9.3	13.5	49.4
Miscanthus	4	15	0.8	4.4	8.1	5.2	7.9	10.5	64.5
Switchgrass (Kanlow)	1	15	1.6	15.7	7.5	7.7	12.3	18.8	38.3
Switchgrass (Kanlow)	2	15	1.3	12.1	8.7	5.0	6.0	9.1	58.1
Switchgrass (Kanlow)	3	15	1.0	10.7	1.8	3.8	9.3	15.3	59.3
Switchgrass (Kanlow)	4	15	2.3	27.2	10.7	4.2	14.3	5.2	36.9
Big Bluestem	1	15	1.1	9.1	7.1	4.4	8.9	13.1	55.6
Big Bluestem	2	15	0.9	6.9	7.7	5.2	6.9	4.6	68.8
Big Bluestem	3	15	0.7	4.2	5.2	6.9	8.5	12.5	61.5
Big Bluestem	4	15	1.0	9.1	5.6	3.6	8.7	14.5	58.1
Indiangrass Mix	1	15	1.3	13.1	5.8	4.0	7.1	14.5	53.4
Indiangrass Mix	2	15	0.7	4.8	4.0	3.6	5.6	13.7	68.7
Indiangrass Mix	3	15	0.5	4.2	2.0	2.2	4.2	9.5	75.6

Indiangrass Mix	4	15	0.6	3.4	2.6	4.0	13.1	6.9	69.8
Switchgrass Mix	1	15	1.4	12.5	7.5	1.4	16.7	12.3	47.6
Switchgrass Mix	2	15	1.4	12.5	10.1	6.3	11.3	12.3	46.8
Switchgrass Mix	3	15	0.9	7.9	3.8	4.2	7.9	9.7	64.3
Switchgrass Mix	4	15	0.9	7.7	5.6	4.2	7.5	11.9	63.5
Soy Bean (Photo Period Sorghum)	1	15	0.3	0.8	1.2	0.2	6.5	22.0	69.4
Soy Bean (Photo Period Sorghum)	2	15	0.4	1.2	1.0	4.6	9.7	9.3	72.4
Soy Bean (Photo Period Sorghum)	3	15	0.3	0.1	1.8	4.0	8.3	16.5	67.5
Soy Bean (Photo Period Sorghum)	4	15	0.3	0.6	1.8	2.6	3.6	9.3	81.0
Soy Bean (Sweet Sorghum)	1	15	1.7	15.5	11.1	10.7	10.5	21.6	29.0
Soy Bean (Sweet Sorghum)	2	15	0.6	4.4	1.4	3.0	5.4	13.5	71.4
Soy Bean (Sweet Sorghum)	3	15	0.6	3.4	2.6	5.6	11.1	17.7	59.3
Soy Bean (Sweet Sorghum)	4	15	0.4	0.6	1.2	5.2	10.9	13.5	69.2
Soy Bean (Grain Sorghum)	1	15	0.3	1.0	1.2	1.8	6.3	18.3	71.2
Soy Bean (Grain Sorghum)	2	15	0.2	0.2	0.2	0.2	0.8	11.7	86.3
Soy Bean (Grain Sorghum)	3	15	0.4	2.6	1.2	5.0	4.0	10.7	75.8
Soy Bean (Grain Sorghum)	4	15	0.4	0.1	3.4	2.8	7.5	11.9	72.6
Soy Bean (Rotated Corn)	1	15	0.3	4.8	2.4	3.4	4.4	12.9	70.8
Soy Bean (Rotated Corn)	2	15	0.2	1.4	2.2	6.5	8.3	11.7	70.0
Soy Bean (Rotated Corn)	3	15	0.2	3.4	1.4	0.6	5.6	7.7	81.2
Soy Bean (Rotated Corn)	4	15	---	---	---	---	---	---	---

Table A.20 Mean weight diameter (MWD) and distribution of water-stable aggregate factions at Manhattan, in Fall 2011.

				Aggregate Size Fraction (mm)					
Treatment	**Rep**	**Depth (cm)**	**MWD (mm)**	**>4.75**	**2-4.75**	**1-2**	**0.5-1**	**0.25-0.5**	**<0.25**
				---Water Stable Aggregates (%) ---					
Continuous Corn	1	7.5	1.4	6.2	21.5	6.0	7.6	12.0	46.4
Continuous Corn	2	7.5	0.9	0.2	12.7	11.0	15.1	18.5	42.4
Continuous Corn	3	7.5	1.5	10.2	15.5	10.0	13.9	18.3	31.7
Continuous Corn	4	7.5	2.4	23.7	18.7	8.0	9.8	13.1	26.3
Photo Period Sorghum	1	7.5	1.9	17.9	15.5	4.8	10.8	11.8	39.0
Photo Period Sorghum	2	7.5	1.5	4.2	21.5	16.3	16.1	16.7	24.7

Photo Period Sorghum	3	7.5	1.1	9.8	6.8	5.8	7.6	12.2	57.8
Photo Period Sorghum	4	7.5	2.2	20.7	17.5	7.8	9.6	12.0	32.1
Sweet Sorghum	1	7.5	2.6	29.1	14.7	4.6	7.6	11.8	31.9
Sweet Sorghum	2	7.5	2.0	21.7	10.4	5.8	8.0	15.7	38.4
Sweet Sorghum	3	7.5	1.0	6.2	9.0	5.0	10.2	17.7	51.8
Sweet Sorghum	4	7.5	0.9	0.2	9.0	21.3	15.1	23.1	31.3
Grain Sorghum	1	7.5	1.9	19.5	11.8	4.2	5.2	8.5	51.1
Grain Sorghum	2	7.5	0.8	0.2	11.2	12.4	10.4	20.9	44.6
Grain Sorghum	3	7.5	2.1	23.7	10.8	6.0	7.2	12.7	39.4
Grain Sorghum	4	7.5	0.5	0.2	2.8	8.2	17.5	17.9	53.2
Rotated Corn	1	7.5	1.6	6.2	22.1	14.7	14.5	13.9	28.1
Rotated Corn	2	7.5	1.1	4.6	13.1	6.4	13.5	26.7	35.5
Rotated Corn	3	7.5	1.0	1.2	10.8	17.1	19.7	20.9	29.9
Rotated Corn	4	7.5	1.8	9.6	28.1	9.2	5.6	13.7	33.7
Miscanthus	1	7.5	2.1	6.0	35.7	23.1	13.5	10.0	11.4
Miscanthus	2	7.5	3.7	47.0	14.3	5.2	6.4	7.8	19.1
Miscanthus	3	7.5	2.3	26.9	10.0	4.4	5.8	9.4	43.6
Miscanthus	4	7.5	1.0	1.4	14.3	13.7	11.2	18.9	40.4
Switchgrass (Kanlow)	1	7.5	1.9	5.6	32.3	18.9	13.3	11.8	18.3
Switchgrass (Kanlow)	2	7.5	2.3	20.3	20.1	8.4	8.6	17.1	25.5
Switchgrass (Kanlow)	3	7.5	1.3	12.5	7.8	4.4	9.0	12.9	53.2
Switchgrass (Kanlow)	4	7.5	1.7	4.0	25.9	26.1	14.9	11.8	16.9
Big Bluestem	1	7.5	4.9	69.1	10.2	2.4	2.4	3.6	12.4
Big Bluestem	2	7.5	1.3	7.2	15.1	7.4	8.8	13.3	48.0
Big Bluestem	3	7.5	2.3	22.9	18.9	5.0	6.8	8.4	37.8
Big Bluestem	4	7.5	1.9	8.2	29.5	12.2	11.0	13.7	25.5
Indiangrass Mix	1	7.5	---	---	---	---	---	---	---
Indiangrass Mix	2	7.5	1.6	8.8	22.1	3.8	8.8	22.7	33.7
Indiangrass Mix	3	7.5	3.1	39.6	11.8	2.4	3.4	6.2	36.3
Indiangrass Mix	4	7.5	1.8	7.0	33.9	7.2	7.2	12.4	32.1
Switchgrass Mix	1	7.5	---	---	---	---	---	---	---
Switchgrass Mix	2	7.5	---	---	---	---	---	---	---

Switchgrass Mix	3	7.5	0.9	8.8	4.2	3.6	5.2	12.7	65.1
Switchgrass Mix	4	7.5	2.4	17.3	29.3	8.2	11.8	7.6	25.5
Soy Bean (Grain Sorghum)	1	7.5	1.0	5.0	12.9	5.0	7.2	12.2	57.8
Soy Bean (Grain Sorghum)	2	7.5	1.3	3.2	23.7	21.3	17.3	15.7	18.7
Soy Bean (Grain Sorghum)	3	7.5	0.4	16.9	25.9	12.5	8.6	12.5	23.3
Soy Bean (Grain Sorghum)	4	7.5	1.3	0.8	3.8	12.9	10.0	22.3	49.8
Soy Bean (Photo Period Sorghum)	1	7.5	1.2	11.4	5.6	4.0	10.8	16.9	51.0
Soy Bean (Photo Period Sorghum)	2	7.5	1.4	12.9	9.0	6.2	11.2	17.5	43.4
Soy Bean (Photo Period Sorghum)	3	7.5	1.2	1.6	19.9	16.3	15.3	17.5	29.1
Soy Bean (Photo Period Sorghum)	4	7.5	0.5	0.8	3.8	3.4	9.8	15.9	65.9
Soy Bean (Sweet Sorghum)	1	7.5	1.0	44.2	13.3	6.0	7.4	10.2	18.7
Soy Bean (Sweet Sorghum)	2	7.5	1.5	7.0	16.5	8.4	10.8	16.3	40.6
Soy Bean (Sweet Sorghum)	3	7.5	2.3	0.2	1.4	11.8	8.2	13.9	64.7
Soy Bean (Sweet Sorghum)	4	7.5	0.6	5.2	17.9	9.0	10.6	17.9	39.0
Soy Bean (Rotated Corn)	1	7.5	1.0	4.2	13.7	6.8	9.4	11.6	54.4
Soy Bean (Rotated Corn)	2	7.5	1.3	9.2	13.1	4.8	5.6	9.0	58.6
Soy Bean (Rotated Corn)	3	7.5	1.9	13.1	20.5	13.3	11.0	16.3	25.3
Soy Bean (Rotated Corn)	4	7.5	0.3	0.1	2.2	2.8	10.2	13.1	71.5
Continuous Corn	1	15	0.9	2.2	7.0	21.1	5.4	21.7	42.2
Continuous Corn	2	15	0.9	0.2	8.8	20.1	21.1	21.5	28.3
Continuous Corn	3	15	1.4	1.0	21.0	27.7	13.5	15.7	20.6
Continuous Corn	4	15	1.2	10.2	6.6	5.6	12.9	15.5	49.0
Photo Period Sorghum	1	15	0.8	6.2	4.6	3.8	7.4	15.3	62.9
Photo Period Sorghum	2	15	0.6	0.6	5.4	4.6	13.5	30.7	44.8
Photo Period Sorghum	3	15	0.4	0.8	3.8	3.6	6.6	18.3	67.1
Photo Period Sorghum	4	15	0.9	0.1	7.6	28.5	19.3	13.9	30.7
Sweet Sorghum	1	15	1.0	10.0	5.0	3.2	7.4	15.7	58.4
Sweet Sorghum	2	15	0.4	0.1	4.4	4.4	8.0	18.9	64.1
Sweet Sorghum	3	15	1.5	6.4	19.3	16.1	12.9	17.7	27.5
Sweet Sorghum	4	15	1.8	8.2	25.9	10.6	13.3	15.5	26.1
Grain Sorghum	1	15	3.8	47.0	15.5	7.8	10.4	11.2	8.2
Grain Sorghum	2	15	1.2	1.8	21.7	10.8	11.2	18.9	35.5

Grain Sorghum	3	15	1.6	19.3	4.0	2.0	6.6	14.3	53.8
Grain Sorghum	4	15	1.0	0.4	17.7	13.3	10.8	13.3	44.0
Rotated Corn	1	15	0.6	0.6	5.6	8.4	8.2	18.1	58.8
Rotated Corn	2	15	2.5	22.5	22.7	8.6	12.0	11.8	22.1
Rotated Corn	3	15	2.4	19.7	23.3	12.9	14.3	10.8	19.1
Rotated Corn	4	15	0.9	5.6	7.2	6.6	9.8	13.5	57.0
Miscanthus	1	15	1.5	4.8	19.1	25.5	15.1	14.1	21.1
Miscanthus	2	15	0.9	4.8	8.6	6.2	14.3	18.5	47.4
Miscanthus	3	15	2.5	19.5	28.3	8.0	7.0	7.4	29.7
Miscanthus	4	15	1.9	6.6	33.3	10.4	11.0	11.4	27.3
Switchgrass (Kanlow)	1	15	1.6	12.4	12.4	11.6	16.1	17.1	30.1
Switchgrass (Kanlow)	2	15	2.1	20.1	14.9	7.4	10.8	11.0	35.7
Switchgrass (Kanlow)	3	15	3.6	48.6	8.8	3.0	3.8	7.6	28.3
Switchgrass (Kanlow)	4	15	2.5	16.7	30.5	12.2	18.5	6.6	15.5
Big Bluestem	1	15	4.2	57.0	13.3	3.4	3.6	4.6	17.9
Big Bluestem	2	15	1.5	5.2	25.5	9.2	8.6	11.8	39.4
Big Bluestem	3	15	1.5	15.7	8.4	3.8	5.0	9.4	57.8
Big Bluestem	4	15	0.9	1.6	11.0	12.2	10.2	21.9	42.8
Indiangrass Mix	1	15	---	---	---	---	---	---	---
Indiangrass Mix	2	15	0.7	4.2	4.6	3.6	5.4	14.7	67.3
Indiangrass Mix	3	15	0.7	0.0	11.0	11.0	10.0	14.5	53.4
Indiangrass Mix	4	15	0.8	0.4	10.4	13.3	14.3	13.5	47.6
Switchgrass Mix	1	15	---	---	---	---	---	---	---
Switchgrass Mix	2	15	---	---	---	---	---	---	---
Switchgrass Mix	3	15	2.7	32.7	11.4	4.0	5.2	10.0	36.9
Switchgrass Mix	4	15	1.7	19.9	5.4	4.2	7.2	14.9	48.8
Soy Bean (Photo Period Sorghum)	1	15	1.1	9.2	7.0	5.8	10.6	20.3	46.8
Soy Bean (Photo Period Sorghum)	2	15	0.5	0.8	2.6	5.2	10.2	20.5	60.8
Soy Bean (Photo Period Sorghum)	3	15	0.4	0.8	1.4	3.4	9.2	22.9	62.2
Soy Bean (Photo Period Sorghum)	4	15	2.5	31.7	8.6	3.2	6.0	14.7	35.5
Soy Bean (Sweet Sorghum)	1	15	0.3	0.4	1.8	3.0	6.2	16.5	72.1
Soy Bean (Sweet Sorghum)	2	15	1.0	0.8	11.4	24.5	15.5	17.3	30.1

Soy Bean (Sweet Sorghum)	3	15	1.1	10.2	3.6	5.4	13.1	18.7	49.0
Soy Bean (Sweet Sorghum)	4	15	0.8	3.0	8.6	7.4	6.6	12.4	62.0
Soy Bean (Grain Sorghum)	1	15	0.9	5.6	5.6	6.6	13.9	21.5	46.4
Soy Bean (Grain Sorghum)	2	15	0.7	0.0	9.0	9.0	13.5	27.1	41.2
Soy Bean (Grain Sorghum)	3	15	0.9	2.6	12.0	10.4	10.6	15.1	49.2
Soy Bean (Grain Sorghum)	4	15	1.0	6.6	7.0	5.6	9.2	18.1	53.4
Soy Bean (Sweet Sorghum)	1	15	1.2	10.4	5.4	6.2	11.0	21.3	45.8
Soy Bean (Sweet Sorghum)	2	15	0.8	0.2	10.0	12.2	14.9	24.7	37.8
Soy Bean (Sweet Sorghum)	3	15	0.6	0.2	4.4	15.5	11.4	18.5	50.0
Soy Bean (Sweet Sorghum)	4	15	0.6	0.4	6.4	11.6	8.4	13.5	59.4

Table A.21 Mean weight diameter (MWD) and distribution of water-stable aggregate factions at Manhattan, in Spring 2012.

				Aggregate Size Fraction (mm)					
Treatment	**Rep**	**Depth (cm)**	**MWD (mm)**	**>4.75**	**2-4.75**	**1-2**	**0.5-1**	**0.25-0.5**	**<0.25**
				---Water Stable Aggregates (%) ---					
Continuous Corn	1	7.5	1.9	18.0	14.4	12.6	5.0	8.6	41.3
Continuous Corn	2	7.5	1.0	3.8	12.2	12.2	11.6	17.4	43.1
Continuous Corn	3	7.5	0.9	1.2	10.8	14.4	18.4	24.4	31.1
Continuous Corn	4	7.5	1.4	13.2	10.4	5.6	6.8	11.0	53.3
Photo Period Sorghum	1	7.5	1.2	3.0	19.6	11.8	14.6	15.4	35.7
Photo Period Sorghum	2	7.5	2.1	18.0	12.6	23.6	20.4	2.4	23.4
Photo Period Sorghum	3	7.5	1.8	18.2	12.0	7.6	9.6	12.2	40.9
Photo Period Sorghum	4	7.5	1.3	6.4	18.0	9.4	10.8	14.6	40.7
Sweet Sorghum	1	7.5	1.1	2.0	17.8	12.4	10.1	18.4	39.4
Sweet Sorghum	2	7.5	1.8	20.6	8.6	5.4	7.4	16.0	42.3
Sweet Sorghum	3	7.5	1.9	11.0	15.0	32.5	18.2	7.2	16.6
Sweet Sorghum	4	7.5	0.8	0.6	8.0	14.0	17.6	27.5	32.3
Grain Sorghum	1	7.5	1.6	5.0	30.1	5.8	13.4	20.4	25.7
Grain Sorghum	2	7.5	1.2	11.4	6.0	4.0	6.8	16.6	55.5
Grain Sorghum	3	7.5	2.3	26.9	10.2	5.6	7.0	14.6	36.1
Grain Sorghum	4	7.5	1.0	3.0	14.0	8.4	12.2	20.2	43.1

Rotated Corn	1	7.5	2.1	10.0	7.6	20.0	14.2	11.8	36.3
Rotated Corn	2	7.5	1.4	2.6	18.6	5.8	20.6	21.2	31.9
Rotated Corn	3	7.5	1.2	8.0	23.4	4.8	18.8	18.2	27.1
Rotated Corn	4	7.5	1.6	28.7	12.2	5.2	7.8	13.2	33.3
Miscanthus	1	7.5	2.5	15.2	20.0	12.6	16.8	15.8	19.8
Miscanthus	2	7.5	2.0	10.0	30.3	11.0	12.0	12.6	24.4
Miscanthus	3	7.5	2.0	32.7	13.0	10.8	9.6	10.2	24.4
Miscanthus	4	7.5	2.8	19.8	12.0	15.0	11.2	23.2	19.6
Switchgrass (Kanlow)	1	7.5	2.1	4.8	28.3	10.2	18.6	14.4	23.8
Switchgrass (Kanlow)	2	7.5	1.6	11.8	6.0	3.4	6.0	12.2	61.5
Switchgrass (Kanlow)	3	7.5	1.2	21.0	6.4	7.2	9.2	17.0	39.5
Switchgrass (Kanlow)	4	7.5	1.8	25.7	11.0	8.0	16.6	16.8	22.6
Big Bluestem	1	7.5	2.3	8.4	14.0	7.2	10.0	20.8	39.7
Big Bluestem	2	7.5	1.3	31.9	7.4	5.2	11.6	15.0	29.7
Big Bluestem	3	7.5	2.5	3.2	23.6	11.2	11.2	14.8	36.7
Big Bluestem	4	7.5	1.4	7.6	26.5	10.2	11.0	15.8	29.3
Indiangrass Mix	1	7.5	---	---	---	---	---	---	---
Indiangrass Mix	2	7.5	1.7	13.6	12.4	4.6	5.8	6.8	57.3
Indiangrass Mix	3	7.5	1.5	22.0	19.6	6.0	8.8	11.0	33.3
Indiangrass Mix	4	7.5	2.3	44.7	14.0	3.6	3.6	5.6	29.3
Switchgrass Mix	1	7.5	---	---	---	---	---	---	---
Switchgrass Mix	2	7.5	---	---	---	---	---	---	---
Switchgrass Mix	3	7.5	3.4	11.8	9.0	8.8	13.6	20.0	37.5
Switchgrass Mix	4	7.5	1.4	17.4	25.3	7.6	5.4	17.4	27.5
Soy Bean (Grain Sorghum)	1	7.5	2.2	12.6	27.9	9.0	13.2	14.2	23.2
Soy Bean (Grain Sorghum)	2	7.5	2.1	16.2	5.8	9.0	14.4	17.4	37.3
Soy Bean (Grain Sorghum)	3	7.5	1.6	3.0	19.8	10.2	10.4	17.4	39.3
Soy Bean (Grain Sorghum)	4	7.5	1.2	6.0	16.8	6.8	10.4	21.8	39.3
Soy Bean (Photo Period Sorghum)	1	7.5	1.3	27.1	16.2	22.6	16.6	3.8	13.6
Soy Bean (Photo Period Sorghum)	2	7.5	2.8	4.6	17.2	11.8	16.2	21.2	29.1
Soy Bean (Photo Period Sorghum)	3	7.5	1.3	6.8	26.1	15.6	12.2	13.6	26.1
Soy Bean (Photo Period Sorghum)	4	7.5	1.7	8.6	7.4	3.4	4.8	11.2	64.9

Soy Bean (Sweet Sorghum)	1	7.5	1.0	13.8	25.7	9.4	12.2	15.4	24.2
Soy Bean (Sweet Sorghum)	2	7.5	2.1	21.2	6.8	6.0	10.6	21.0	35.1
Soy Bean (Sweet Sorghum)	3	7.5	1.9	5.8	12.8	7.6	8.6	13.8	51.5
Soy Bean (Sweet Sorghum)	4	7.5	1.1	3.4	17.0	8.8	11.4	16.8	43.1
Soy Bean (Rotated Corn)	1	7.5	1.1	11.6	36.1	18.0	11.6	10.8	12.0
Soy Bean (Rotated Corn)	2	7.5	2.4	17.4	31.9	14.6	12.6	10.8	13.2
Soy Bean (Rotated Corn)	3	7.5	2.5	8.2	20.4	7.0	10.4	17.8	36.5
Soy Bean (Rotated Corn)	4	7.5	1.5	0.4	4.0	5.6	9.0	16.4	64.7
Continuous Corn	1	15	0.5	4.2	12.0	5.4	9.6	18.4	50.5
Continuous Corn	2	15	1.0	3.0	6.6	8.8	17.4	22.0	42.7
Continuous Corn	3	15	0.8	2.2	6.6	11.2	17.4	20.8	42.5
Continuous Corn	4	15	0.8	5.8	7.4	11.4	12.6	14.6	49.3
Photo Period Sorghum	1	15	1.0	0.6	7.8	14.4	11.4	18.4	47.5
Photo Period Sorghum	2	15	0.7	3.0	4.2	3.4	5.6	18.2	65.9
Photo Period Sorghum	3	15	0.6	0.6	5.6	8.8	17.4	19.8	48.1
Photo Period Sorghum	4	15	0.6	0.2	5.6	18.4	23.8	16.8	35.9
Sweet Sorghum	1	15	0.8	7.4	3.8	5.8	9.4	20.6	53.3
Sweet Sorghum	2	15	0.9	2.0	4.0	6.8	12.4	23.2	52.7
Sweet Sorghum	3	15	0.6	29.5	8.8	4.8	7.6	12.6	37.1
Sweet Sorghum	4	15	2.4	4.4	21.8	9.6	11.2	19.6	33.5
Grain Sorghum	1	15	1.4	2.8	9.4	8.4	15.2	23.6	41.1
Grain Sorghum	2	15	0.9	28.7	8.0	3.6	5.4	12.2	42.7
Grain Sorghum	3	15	2.3	18.0	7.6	11.4	8.2	15.4	39.7
Grain Sorghum	4	15	1.7	0.8	2.8	6.2	15.8	22.4	52.3
Rotated Corn	1	15	0.5	1.8	8.4	11.0	24.0	20.8	33.9
Rotated Corn	2	15	0.9	51.5	14.8	6.6	8.0	8.8	10.4
Rotated Corn	3	15	4.0	8.0	4.2	4.6	9.2	19.6	54.5
Rotated Corn	4	15	0.9	4.2	3.8	4.2	7.0	15.8	65.3
Miscanthus	1	15	0.7	2.6	16.8	12.6	22.8	23.4	22.2
Miscanthus	2	15	1.2	0.8	8.2	10.6	10.8	28.1	42.1
Miscanthus	3	15	0.7	37.1	11.2	4.2	4.6	7.8	35.9
Miscanthus	4	15	2.9	12.6	34.5	7.8	14.2	9.8	21.2

Switchgrass (Kanlow)	1	15	2.2	11.6	9.2	9.8	14.6	20.4	34.5
Switchgrass (Kanlow)	2	15	1.4	9.4	30.1	6.2	13.8	16.0	25.1
Switchgrass (Kanlow)	3	15	1.9	7.4	18.1	5.6	9.6	12.4	47.1
Switchgrass (Kanlow)	4	15	1.3	35.3	15.2	8.4	11.0	12.6	18.0
Big Bluestem	1	15	3.0	5.2	13.6	9.2	24.0	16.8	31.7
Big Bluestem	2	15	1.2	10.6	21.2	10.0	15.0	9.0	34.3
Big Bluestem	3	15	1.7	10.4	10.6	21.2	14.4	10.0	33.5
Big Bluestem	4	15	1.5	0.6	7.8	4.2	17.8	18.4	51.9
Indiangrass Mix	1	15	---	---	---	---	---	---	---
Indiangrass Mix	2	15	0.6	6.2	20.0	13.8	12.8	18.2	29.3
Indiangrass Mix	3	15	1.5	0.8	7.0	7.2	8.2	17.4	59.7
Indiangrass Mix	4	15	0.6	0.6	7.8	3.8	20.0	23.8	44.3
Switchgrass Mix	1	15	---	---	---	---	---	---	---
Switchgrass Mix	2	15	---	---	---	---	---	---	---
Switchgrass Mix	3	15	0.7	36.3	14.0	16.0	7.2	9.4	17.6
Switchgrass Mix	4	15	3.1	6.0	11.6	6.4	11.0	16.0	49.5
Soy Bean (Photo Period Sorghum)	1	15	1.1	3.6	10.2	9.0	16.0	21.2	40.3
Soy Bean (Photo Period Sorghum)	2	15	1.0	2.0	4.0	6.0	13.0	24.6	51.1
Soy Bean (Photo Period Sorghum)	3	15	0.6	0.4	3.4	17.6	13.4	25.7	39.7
Soy Bean (Photo Period Sorghum)	4	15	0.7	0.8	4.0	5.8	10.6	33.3	46.1
Soy Bean (Sweet Sorghum)	1	15	0.5	1.0	1.6	3.4	7.0	19.6	67.8
Soy Bean (Sweet Sorghum)	2	15	0.4	8.6	5.2	5.8	11.6	22.6	46.7
Soy Bean (Sweet Sorghum)	3	15	1.0	2.2	6.6	11.2	17.4	20.8	42.5
Soy Bean (Sweet Sorghum)	4	15	0.8	2.8	2.6	4.2	7.6	15.2	68.5
Soy Bean (Grain Sorghum)	1	15	0.5	0.6	8.0	26.7	13.4	22.0	30.5
Soy Bean (Grain Sorghum)	2	15	0.9	6.2	4.4	4.4	9.2	20.8	54.9
Soy Bean (Grain Sorghum)	3	15	0.8	1.8	11.8	15.1	21.0	21.8	29.0
Soy Bean (Grain Sorghum)	4	15	1.0	0.6	10.0	11.8	15.8	22.8	39.5
Soy Bean (Sweet Sorghum)	1	15	0.8	3.0	8.6	12.2	36.5	15.0	25.1
Soy Bean (Sweet Sorghum)	2	15	1.0	7.8	3.8	9.0	10.2	23.2	46.3
Soy Bean (Sweet Sorghum)	3	15	1.0	4.4	2.4	4.0	7.6	18.8	63.3
Soy Bean (Sweet Sorghum)	4	15	0.6	0.8	1.6	10.4	11.8	16.8	59.1

Table A.22 Infiltration values, at Colby in 2011.

Treatment	Rep	Cum. Infiltration (cm)
Switchgrass (Blackwell)	1	17.69
Switchgrass (Blackwell)	2	35.47
Switchgrass (Blackwell)	3	18.79
Miscanthus	1	46.87
Miscanthus	2	25.33
Miscanthus	3	39.73
Grain Sorghum	1	54.90
Grain Sorghum	2	16.58
Grain Sorghum	3	44.00
Sweet Sorghum	1	72.17
Sweet Sorghum	2	17.05
Sweet Sorghum	3	121.74
W-S-F 0% residue removal	1	80.67
W-S-F 0% residue removal	2	27.40
W-S-F 0% residue removal	3	46.39
W-S-F 100% residue removal	1	21.20
W-S-F 100% residue removal	2	46.77
W-S-F 100% residue removal	3	19.49

Table A.23 Infiltration values, at Hays in 2011.

Treatment	Rep	Cum. Infiltration (cm)
Switchgrass (Blackwell)	101	44.26
Switchgrass (Blackwell)	101	19.63
Switchgrass (Blackwell)	101	26.39
Switchgrass (Pathfinder)	106	46.01
Switchgrass (Pathfinder)	106	37.39
Switchgrass (Pathfinder)	106	37.94
Miscanthus	107	27.81
Miscanthus	107	80.40
Miscanthus	107	67.47
Big Bluestem	104	29.70
Big Bluestem	104	41.23
Big Bluestem	104	28.71
Sand Bluestem	112	30.86
Sand Bluestem	112	39.55
Sand Bluestem	112	28.49
Mixed grass	111	57.00
Mixed grass	111	55.29
Mixed grass	111	18.47
Indiangrass	103	31.44
Indiangrass	103	44.81
Indiangrass	103	35.80
Eastern Gamagrass	109	38.79
Eastern Gamagrass	109	36.43
Eastern Gamagrass	109	38.22
Grain Sorghum	105	14.13
Grain Sorghum	105	12.77
Grain Sorghum	105	34.70
Sweet Sorghum	110	47.54
Sweet Sorghum	110	40.76
Sweet Sorghum	110	15.43
W-S-F 0% residue removal	108	39.34
W-S-F 0% residue removal	108	32.06
W-S-F 0% residue removal	108	25.47
W-S-F 100% residue removal	102	25.94
W-S-F 100% residue removal	102	23.05
W-S-F 100% residue removal	102	42.14

Table A.24 Infiltration values, at Manhattan in 2011.

TRT	Rep	Cum. Infiltration (cm)
Continuous Corn	1	4.84
Continuous Corn	2	6.58
Continuous Corn	3	6.10
Continuous Corn	4	8.46
Photo Period Sorghum	1	2.29
Photo Period Sorghum	2	10.18
Photo Period Sorghum	3	1.65
Photo Period Sorghum	4	5.69
Sweet Sorghum	1	14.60
Sweet Sorghum	2	15.59
Sweet Sorghum	3	4.02
Sweet Sorghum	4	27.09
Grain Sorghum	1	6.16
Grain Sorghum	2	9.73
Grain Sorghum	3	9.09
Grain Sorghum	4	10.92
Rotated Corn	1	8.15
Rotated Corn	2	23.82
Rotated Corn	3	4.17
Rotated Corn	4	9.70
Miscanthus	1	20.79
Miscanthus	2	6.63
Miscanthus	3	5.52
Miscanthus	4	4.31
Switchgrass (Kanlow)	1	9.62
Switchgrass (Kanlow)	2	6.50
Switchgrass (Kanlow)	3	10.22
Switchgrass (Kanlow)	4	9.75
Big Bluestem	1	45.16
Big Bluestem	2	7.05
Big Bluestem	3	7.55
Big Bluestem	4	7.11
Indiangrass Mix	1	8.91
Indiangrass Mix	2	---
Indiangrass Mix	3	8.68
Indiangrass Mix	4	11.11
Switchgrass Mix	1	---
Switchgrass Mix	2	---
Switchgrass Mix	3	10.09
Switchgrass Mix	4	5.18
Soy Beans (Photo Period Sorghum)	1	4.35

Soy Beans (Photo Period Sorghum)	2	2.98
Soy Beans (Photo Period Sorghum)	3	3.68
Soy Beans (Photo Period Sorghum)	4	15.00
Soy Bean (Grain Sorghum)	1	3.24
Soy Bean (Grain Sorghum)	2	4.12
Soy Bean (Grain Sorghum)	3	6.18
Soy Bean (Grain Sorghum)	4	4.48
Soy Beans (Sweet Sorghum)	1	22.67
Soy Beans (Sweet Sorghum)	2	19.50
Soy Beans (Sweet Sorghum)	3	14.63
Soy Beans (Sweet Sorghum)	4	7.69
Soy Bean (Rotated Corn)	1	23.45
Soy Bean (Rotated Corn)	2	3.35
Soy Bean (Rotated Corn)	3	10.15
Soy Bean (Rotated Corn)	4	5.28

Table A.25 Water retention values, at Colby in 2011.

		Matric Potential (-kPa)								
Treatment	**Rep**	**Sat**	**0.05**	**0.1**	**3**	**6**	**10**	**33.3**	**500**	**1500**
				---Water Content ($m^3 m^{-3}$)---						
Switchgrass (Blackwell)	1	0.478	0.436	0.409	0.370	0.362	0.289	0.269	0.134	0.117
Switchgrass (Blackwell)	2	0.475	0.438	0.413	0.360	0.326	0.292	0.256	0.150	0.120
Switchgrass (Blackwell)	3	0.466	0.429	0.391	0.342	0.319	0.270	0.227	0.181	0.141
Switchgrass (Pathfinder)	1	0.485	0.445	0.429	0.412	0.407	0.384	0.361	0.164	0.150
Switchgrass (Pathfinder)	2	0.468	0.438	0.412	0.339	0.307	0.278	0.252	0.142	0.115
Switchgrass (Pathfinder)	3	0.472	0.422	0.415	0.398	0.371	0.342	0.327	0.162	0.149
Miscanthus	1	0.448	0.441	0.333	0.265	0.240	0.188	0.168	0.123	0.116
Miscanthus	2	0.468	0.422	0.385	0.336	0.313	0.265	0.222	0.187	0.179
Miscanthus	3	0.469	0.419	0.401	0.393	0.382	0.371	0.360	0.185	0.163
Big Bluestem	1	0.475	0.408	0.407	0.378	0.376	0.319	0.285	0.191	0.164
Big Bluestem	2	0.455	0.426	0.388	0.339	0.316	0.267	0.224	0.152	0.145
Big Bluestem	3	0.460	0.436	0.404	0.358	0.337	0.291	0.251	0.144	0.140
Sand Bluestem	1	0.477	0.436	0.381	0.322	0.310	0.260	0.239	0.142	0.110
Sand Bluestem	2	0.479	0.409	0.389	0.331	0.302	0.273	0.249	0.162	0.124
Sand Bluestem	3	0.481	0.418	0.406	0.360	0.338	0.292	0.252	0.142	0.132
Mixed Grass	1	0.505	0.396	0.361	0.336	0.331	0.304	0.288	0.140	0.101
Mixed Grass	2	0.481	0.447	0.427	0.361	0.319	0.289	0.265	0.176	0.139
Mixed Grass	3	0.471	0.430	0.409	0.377	0.350	0.315	0.279	0.180	0.169
Indiangrass	1	0.503	0.447	0.413	0.362	0.351	0.286	0.258	0.132	0.107
Indiangrass	2	0.490	0.448	0.438	0.397	0.359	0.325	0.289	0.161	0.161
Indiangrass	3	0.497	0.449	0.422	0.363	0.330	0.303	0.266	0.161	0.134
Eastern Gamagrass	1	0.475	0.439	0.399	0.376	0.375	0.343	0.325	0.197	0.131
Eastern Gamagrass	2	0.485	0.440	0.404	0.357	0.335	0.287	0.246	0.168	0.137
Eastern Gamagrass	3	0.485	0.437	0.399	0.350	0.326	0.277	0.233	0.169	0.131
Grain Sorghum	1	0.470	0.432	0.412	0.385	0.377	0.331	0.298	0.172	0.143
Grain Sorghum	2	0.493	0.457	0.433	0.403	0.372	0.341	0.299	0.172	0.117

Grain Sorghum	3	0.492	0.442	0.429	0.402	0.326	0.297	0.292	0.140	0.138
Sweet Sorghum	1	0.491	0.427	0.412	0.390	0.380	0.347	0.319	0.179	0.174
Sweet Sorghum	2	0.516	0.438	0.405	0.370	0.335	0.324	0.281	0.163	0.115
Sweet Sorghum	3	0.486	0.437	0.398	0.347	0.323	0.272	0.228	0.191	0.168
W-S-F 0% residue removal	1	0.498	0.438	0.406	0.364	0.353	0.311	0.288	0.111	0.106
W-S-F 0% residue removal	2	0.499	0.448	0.426	0.353	0.311	0.282	0.265	0.177	0.143
W-S-F 0% residue removal	3	0.492	0.441	0.410	0.285	0.245	0.216	0.208	0.155	0.151
W-S-F 100% residue removal	1	0.489	0.445	0.418	0.393	0.353	0.323	0.298	0.171	0.159
W-S-F 100% residue removal	2	0.506	0.435	0.411	0.366	0.342	0.312	0.308	0.152	0.150
W-S-F 100% residue removal	3	0.471	0.436	0.423	0.384	0.348	0.313	0.278	0.168	0.143

Table A.26 Water retention values, at Colby in 2012.

					Matric Potential (-kPa)					
Treatment	**Rep**	**Sat**	**0.05**	**0.1**	**3**	**6**	**10**	**33.3**	**500**	**1500**
					---Water Content (m^3 m^{-3})---					
Switchgrass (Blackwell)	1	0.548	0.478	0.453	0.422	0.400	0.338	0.287	0.138	0.124
Switchgrass (Blackwell)	2	0.469	0.434	0.419	0.399	0.384	0.344	0.290	0.164	0.129
Switchgrass (Blackwell)	3	0.514	0.475	0.458	0.424	0.394	0.344	0.232	0.169	0.132
Miscanthus	1	0.590	0.533	0.522	0.496	0.477	0.455	0.316	0.145	0.106
Miscanthus	2	0.554	0.524	0.501	0.459	0.426	0.364	0.259	0.118	0.106
Miscanthus	3	0.458	0.431	0.406	0.354	0.318	0.253	0.240	0.167	0.145
Grain Sorghum	1	0.493	0.459	0.444	0.424	0.405	0.353	0.341	0.160	0.141
Grain Sorghum	2	0.550	0.507	0.483	0.426	0.393	0.354	0.337	0.132	0.092
Grain Sorghum	3	0.504	0.474	0.452	0.417	0.390	0.334	0.273	0.135	0.105
Sweet Sorghum	1	0.536	0.504	0.482	0.448	0.418	0.364	0.326	0.141	0.132
Sweet Sorghum	2	0.567	0.517	0.502	0.456	0.417	0.329	0.305	0.165	0.104
Sweet Sorghum	3	0.544	0.521	0.496	0.437	0.400	0.330	0.226	0.168	0.113
W-S-F 0% residue removal	1	0.536	0.508	0.490	0.448	0.410	0.356	0.186	0.155	0.120
W-S-F 0% residue removal	2	0.522	0.472	0.450	0.414	0.387	0.353	0.228	0.171	0.129
W-S-F 0% residue removal	3	0.552	0.518	0.472	0.395	0.356	0.321	0.310	0.141	0.102

W-S-F 100% residue removal	1	0.516	0.455	0.420	0.344	0.310	0.289	0.302	0.158	0.103
W-S-F 100% residue removal	2	0.548	0.505	0.484	0.450	0.417	0.359	0.298	0.145	0.103
W-S-F 100% residue removal	3	0.478	0.443	0.418	0.378	0.352	0.309	0.289	0.141	0.105

Table A.27 Water retention values, at Hays in 2011.

			Matric Potential (-kPa)							
Treatment	**Rep**	**Sat**	**0.05**	**0.1**	**3**	**6**	**10**	**33.3**	**500**	**1500**
					---Water Content (m^3 m^{-3})---					
Switchgrass (Blackwell)	1	0.458	0.416	0.393	0.377	0.347	0.344	0.316	0.157	0.108
Switchgrass (Blackwell)	2	0.484	0.406	0.371	0.324	0.303	0.257	0.217	0.133	0.130
Switchgrass (Blackwell)	3	0.476	0.405	0.369	0.322	0.300	0.253	0.212	0.165	0.145
Switchgrass (Pathfinder)	1	0.525	0.448	0.423	0.399	0.392	0.355	0.328	0.160	0.156
Switchgrass (Pathfinder)	2	0.510	0.447	0.426	0.378	0.355	0.307	0.265	0.140	0.132
Switchgrass (Pathfinder)	3	0.491	0.442	0.410	0.364	0.342	0.296	0.256	0.140	0.126
Miscanthus	1	0.514	0.445	0.419	0.392	0.388	0.340	0.321	0.147	0.144
Miscanthus	2	0.520	0.477	0.435	0.380	0.354	0.299	0.251	0.174	0.141
Miscanthus	3	0.450	0.396	0.358	0.308	0.284	0.234	0.190	0.145	0.123
Big Bluestem	1	0.514	0.455	0.425	0.376	0.354	0.305	0.263	0.173	0.157
Big Bluestem	2	0.518	0.448	0.416	0.366	0.342	0.292	0.248	0.199	0.155
Big Bluestem	3	0.498	0.415	0.379	0.333	0.311	0.265	0.224	0.161	0.151
Sand Bluestem	1	0.483	0.445	0.401	0.317	0.270	0.227	0.194	0.148	0.119
Sand Bluestem	2	0.485	0.438	0.401	0.353	0.330	0.282	0.240	0.147	0.137
Sand Bluestem	3	0.520	0.438	0.399	0.349	0.325	0.275	0.231	0.155	0.138
Mixed Grass	1	0.475	0.432	0.387	0.353	0.344	0.301	0.268	0.168	0.153
Mixed Grass	2	0.521	0.408	0.374	0.330	0.309	0.264	0.226	0.148	0.137
Mixed Grass	3	0.497	0.452	0.422	0.370	0.346	0.295	0.250	0.179	0.143
Indiangrass	1	0.496	0.449	0.412	0.364	0.342	0.293	0.251	0.194	0.179
Indiangrass	2	0.516	0.400	0.365	0.319	0.297	0.251	0.211	0.207	0.166
Indiangrass	3	0.497	0.405	0.372	0.329	0.308	0.265	0.227	0.158	0.128
Eastern Gamagrass	1	0.521	0.446	0.431	0.415	0.410	0.389	0.367	0.167	0.145

Eastern Gamagrass	2	0.486	0.438	0.386	0.373	0.363	0.311	0.267	0.163	0.147
Eastern Gamagrass	3	0.521	0.409	0.375	0.332	0.311	0.268	0.230	0.164	0.156
Grain Sorghum	1	0.469	0.430	0.417	0.408	0.400	0.398	0.380	0.170	0.150
Grain Sorghum	2	0.467	0.397	0.384	0.337	0.315	0.267	0.226	0.141	0.138
Grain Sorghum	3	0.504	0.424	0.387	0.339	0.317	0.268	0.227	0.161	0.160
Sweet Sorghum	1	0.471	0.424	0.417	0.400	0.394	0.359	0.331	0.184	0.162
Sweet Sorghum	2	0.499	0.426	0.391	0.344	0.322	0.276	0.235	0.169	0.154
Sweet Sorghum	3	0.513	0.421	0.382	0.331	0.307	0.255	0.210	0.174	0.164
W-S-F 0% residue removal	1	0.515	0.426	0.397	0.370	0.366	0.321	0.281	0.158	0.155
W-S-F 0% residue removal	2	0.498	0.447	0.430	0.373	0.346	0.288	0.239	0.193	0.170
W-S-F 0% residue removal	3	0.512	0.449	0.412	0.363	0.341	0.292	0.250	0.148	0.134
W-S-F 100% residue removal	1	0.471	0.423	0.386	0.337	0.314	0.265	0.222	0.180	0.175
W-S-F 100% residue removal	2	0.514	0.403	0.386	0.339	0.317	0.270	0.229	0.186	0.139
W-S-F 100% residue removal	3	0.521	0.422	0.383	0.333	0.310	0.260	0.217	0.179	0.137

Table A.28 Water retention values, at Hays in 2012.

		Matric Potential (-kPa)								
Treatment	**Rep**	**Sat**	**0.05**	**0.1**	**3**	**6**	**10**	**33.3**	**500**	**1500**
		---Water Content (m^3 m^{-3})---								
Switchgrass (Blackwell)	1	0.418	0.380	0.359	0.344	0.317	0.314	0.289	0.138	0.125
Switchgrass (Blackwell)	2	0.445	0.373	0.341	0.299	0.279	0.236	0.200	0.145	0.139
Switchgrass (Blackwell)	3	0.477	0.406	0.370	0.323	0.301	0.254	0.213	0.171	0.133
Switchgrass (Pathfinder)	1	0.514	0.439	0.415	0.391	0.384	0.348	0.322	0.149	0.117
Switchgrass (Pathfinder)	2	0.475	0.417	0.397	0.352	0.331	0.286	0.247	0.157	0.115
Switchgrass (Pathfinder)	3	0.508	0.458	0.424	0.377	0.354	0.307	0.265	0.174	0.119
Miscanthus	1	0.441	0.382	0.359	0.336	0.333	0.292	0.275	0.134	0.112
Miscanthus	2	0.463	0.425	0.387	0.338	0.315	0.266	0.223	0.155	0.115
Miscanthus	3	0.383	0.337	0.304	0.261	0.241	0.198	0.161	0.145	0.134
Big Bluestem	1	0.461	0.408	0.381	0.338	0.317	0.273	0.236	0.160	0.126
Big Bluestem	2	0.480	0.416	0.386	0.339	0.317	0.270	0.230	0.169	0.157
Big Bluestem	3	0.533	0.444	0.406	0.356	0.333	0.283	0.240	0.163	0.161

Sand Bluestem	1	0.562	0.518	0.467	0.369	0.315	0.265	0.226	0.165	0.134
Sand Bluestem	2	0.494	0.447	0.409	0.360	0.337	0.288	0.245	0.152	0.124
Sand Bluestem	3	0.524	0.441	0.402	0.351	0.328	0.277	0.233	0.158	0.143
Mixed Grass	1	0.455	0.414	0.371	0.338	0.330	0.288	0.256	0.154	0.143
Mixed Grass	2	0.563	0.441	0.404	0.356	0.334	0.286	0.244	0.165	0.155
Mixed Grass	3	0.516	0.469	0.438	0.384	0.359	0.306	0.259	0.161	0.124
Indiangrass	1	0.395	0.358	0.328	0.290	0.272	0.233	0.200	0.126	0.108
Indiangrass	2	0.398	0.309	0.282	0.246	0.230	0.194	0.163	0.137	0.118
Indiangrass	3	0.567	0.463	0.425	0.375	0.352	0.302	0.259	0.175	0.142
Eastern Gamagrass	1	0.475	0.406	0.392	0.378	0.373	0.354	0.335	0.154	0.143
Eastern Gamagrass	2	0.472	0.425	0.376	0.363	0.353	0.303	0.260	0.129	0.125
Eastern Gamagrass	3	0.507	0.398	0.365	0.323	0.303	0.260	0.224	0.142	0.142
Grain Sorghum	1	0.394	0.361	0.350	0.343	0.335	0.334	0.319	0.136	0.100
Grain Sorghum	2	0.473	0.402	0.389	0.341	0.319	0.271	0.229	0.163	0.159
Grain Sorghum	3	0.581	0.488	0.446	0.391	0.365	0.310	0.262	0.175	0.173
Sweet Sorghum	1	0.452	0.407	0.400	0.384	0.378	0.344	0.318	0.156	0.147
Sweet Sorghum	2	0.535	0.457	0.419	0.369	0.346	0.296	0.252	0.166	0.155
Sweet Sorghum	3	0.532	0.437	0.396	0.343	0.318	0.265	0.218	0.159	0.134
W-S-F 0% residue removal	1	0.499	0.412	0.384	0.358	0.354	0.311	0.272	0.148	0.133
W-S-F 0% residue removal	2	0.486	0.435	0.419	0.363	0.337	0.281	0.233	0.180	0.175
W-S-F 0% residue removal	3	0.566	0.495	0.455	0.401	0.376	0.323	0.277	0.157	0.153
W-S-F 100% residue removal	1	0.522	0.469	0.428	0.373	0.348	0.293	0.246	0.150	0.148
W-S-F 100% residue removal	2	0.506	0.397	0.380	0.334	0.313	0.266	0.226	0.175	0.148
W-S-F 100% residue removal	3	0.549	0.445	0.404	0.352	0.327	0.274	0.228	0.166	0.136

Table A.29 Water retention values, at Manhattan in 2011.

			Matric Potential (-kPa)							
Treatment	**Rep**	**Sat**	**0.05**	**0.1**	**3**	**6**	**10**	**33.3**	**500**	**1500**
			---Water Content (m^3 m^{-3})---							
Continuous Corn	1	0.488	0.431	0.422	0.386	0.380	0.365	0.341	0.106	0.105
Continuous Corn	2	0.485	0.431	0.424	0.408	0.395	0.368	0.340	0.135	0.118
Continuous Corn	3	0.526	0.424	0.405	0.368	0.361	0.315	0.219	0.152	0.135
Continuous Corn	4	0.506	0.440	0.422	0.409	0.398	0.356	0.283	0.132	0.116
Photo Period Sorghum	1	0.508	0.419	0.414	0.386	0.378	0.340	0.310	0.214	0.137
Photo Period Sorghum	2	0.499	0.432	0.423	0.388	0.385	0.346	0.335	0.153	0.130
Photo Period Sorghum	3	0.521	0.415	0.396	0.386	0.377	0.293	0.263	0.118	0.109
Photo Period Sorghum	4	0.519	0.429	0.415	0.370	0.347	0.275	0.231	0.153	0.131
Sweet Sorghum	1	0.520	0.413	0.410	0.408	0.396	0.340	0.308	0.164	0.131
Sweet Sorghum	2	0.513	0.444	0.437	0.403	0.383	0.345	0.298	0.143	0.136
Sweet Sorghum	3	0.499	0.436	0.426	0.424	0.416	0.352	0.277	0.156	0.128
Sweet Sorghum	4	0.472	0.433	0.420	0.413	0.405	0.312	0.291	0.115	0.101
Grain Sorghum	1	0.485	0.418	0.416	0.414	0.405	0.336	0.296	0.153	0.109
Grain Sorghum	2	0.462	0.435	0.430	0.411	0.386	0.374	0.275	0.166	0.134
Grain Sorghum	3	0.484	0.404	0.398	0.394	0.388	0.341	0.099	0.169	0.115
Grain Sorghum	4	0.494	0.437	0.433	0.427	0.414	0.352	0.322	0.178	0.119
Rotated Corn	1	0.525	0.416	0.414	0.396	0.388	0.343	0.273	0.150	0.127
Rotated Corn	2	0.484	0.445	0.441	0.428	0.418	0.357	0.282	0.120	0.106
Rotated Corn	3	0.468	0.412	0.403	0.397	0.388	0.338	0.278	0.131	0.129
Rotated Corn	4	0.485	0.448	0.439	0.431	0.423	0.345	0.307	0.173	0.173
Miscanthus	1	0.519	0.471	0.469	0.436	0.423	0.444	0.267	0.139	0.120
Miscanthus	2	0.481	0.436	0.429	0.402	0.394	0.381	0.256	0.153	0.099
Miscanthus	3	0.495	0.434	0.401	0.363	0.327	0.254	0.217	0.154	0.117
Miscanthus	4	0.511	0.445	0.438	0.431	0.412	0.385	0.266	0.115	0.093
Switchgrass (Kanlow)	1	0.488	0.432	0.430	0.404	0.403	0.394	0.249	0.154	0.143
Switchgrass (Kanlow)	2	0.497	0.410	0.406	0.404	0.380	0.359	0.291	0.174	0.155

Switchgrass (Kanlow)	3	0.494	0.448	0.441	0.438	0.430	0.385	0.269	0.152	0.138
Switchgrass (Kanlow)	4	0.466	0.428	0.419	0.409	0.378	0.308	0.253	0.140	0.108
Big Bluestem	1	0.492	0.450	0.444	0.422	0.421	0.400	0.172	0.155	0.144
Big Bluestem	2	0.496	0.448	0.441	0.419	0.406	0.392	0.256	0.168	0.149
Big Bluestem	3	0.510	0.443	0.435	0.432	0.408	0.374	0.293	0.107	0.088
Big Bluestem	4	0.480	0.445	0.441	0.428	0.420	0.389	0.277	0.156	0.126
Indiangrass Mix	1	0.518	0.436	0.435	0.420	0.397	0.376	0.272	0.160	0.118
Indiangrass Mix	2	---	---	---	---	---	---	---	---	---
Indiangrass Mix	3	0.455	0.422	0.418	0.416	0.410	0.355	0.304	0.143	0.130
Indiangrass Mix	4	0.464	0.412	0.405	0.403	0.397	0.375	0.288	0.141	0.129
Switchgrass Mix	1	---	---	---	---	---	---	---	---	---
Switchgrass Mix	2	---	---	---	---	---	---	---	---	---
Switchgrass Mix	3	0.456	0.435	0.424	0.422	0.418	0.366	0.331	0.118	0.104
Switchgrass Mix	4	0.488	0.443	0.441	0.427	0.421	0.407	0.257	0.132	0.121
Soy Beans (Photo Period Sorghum)	1	0.516	0.414	0.407	0.396	0.382	0.302	0.255	0.151	0.144
Soy Beans (Photo Period Sorghum)	2	0.516	0.414	0.407	0.396	0.382	0.302	0.255	0.151	0.144
Soy Beans (Photo Period Sorghum)	3	0.516	0.414	0.407	0.396	0.382	0.302	0.255	0.151	0.144
Soy Beans (Photo Period Sorghum)	4	0.516	0.414	0.407	0.396	0.382	0.302	0.255	0.151	0.144
Soy Beans (Sweet Sorghum)	1	0.516	0.414	0.407	0.396	0.382	0.302	0.255	0.151	0.144
Soy Beans (Sweet Sorghum)	2	0.516	0.414	0.407	0.396	0.382	0.302	0.255	0.151	0.144
Soy Beans (Sweet Sorghum)	3	0.516	0.414	0.407	0.396	0.382	0.302	0.255	0.151	0.144
Soy Beans (Sweet Sorghum)	4	0.516	0.414	0.407	0.396	0.382	0.302	0.255	0.151	0.144
Soy Bean (Grain Sorghum)	1	0.516	0.414	0.407	0.396	0.382	0.302	0.255	0.151	0.144
Soy Bean (Grain Sorghum)	2	0.516	0.414	0.407	0.396	0.382	0.302	0.255	0.151	0.144
Soy Bean (Grain Sorghum)	3	0.516	0.414	0.407	0.396	0.382	0.302	0.255	0.151	0.144
Soy Bean (Grain Sorghum)	4	0.516	0.414	0.407	0.396	0.382	0.302	0.255	0.151	0.144
Soy Bean (Rotated Corn)	1	0.516	0.414	0.407	0.396	0.382	0.302	0.255	0.151	0.144
Soy Bean (Rotated Corn)	2	0.516	0.414	0.407	0.396	0.382	0.302	0.255	0.151	0.144
Soy Bean (Rotated Corn)	3	0.516	0.414	0.407	0.396	0.382	0.302	0.255	0.151	0.144
Soy Bean (Rotated Corn)	4	0.516	0.414	0.407	0.396	0.382	0.302	0.255	0.151	0.144

Table A.30 Water retention values, at Manhattan in 2012.

			Matric Potential (-kPa)							
Treatment	**Rep**	**Sat**	**0.05**	**0.1**	**3**	**6**	**10**	**33.3**	**500**	**1500**
				---Water Content (m^3 m^{-3})---						
Continuous Corn	1	0.463	0.429	0.419	0.392	0.364	0.329	0.294	0.159	0.144
Continuous Corn	2	0.493	0.429	0.412	0.371	0.326	0.287	0.248	0.150	0.154
Continuous Corn	3	0.526	0.408	0.395	0.379	0.366	0.339	0.271	0.132	0.116
Continuous Corn	4	0.524	0.413	0.403	0.383	0.369	0.350	0.278	0.147	0.122
Photo Period Sorghum	1	0.475	0.435	0.425	0.404	0.386	0.368	0.327	0.162	0.126
Photo Period Sorghum	2	0.493	0.421	0.410	0.391	0.373	0.355	0.287	0.132	0.110
Photo Period Sorghum	3	0.500	0.450	0.437	0.419	0.397	0.362	0.348	0.165	0.144
Photo Period Sorghum	4	0.553	0.424	0.411	0.395	0.374	0.359	0.301	0.175	0.131
Sweet Sorghum	1	0.529	0.438	0.428	0.410	0.394	0.378	0.327	0.176	0.131
Sweet Sorghum	2	0.540	0.445	0.437	0.416	0.395	0.376	0.307	0.138	0.118
Sweet Sorghum	3	0.519	0.431	0.418	0.388	0.363	0.343	0.332	0.169	0.122
Sweet Sorghum	4	0.496	0.437	0.424	0.403	0.385	0.367	0.324	0.150	0.114
Grain Sorghum	1	0.518	0.447	0.433	0.417	0.401	0.384	0.315	0.154	0.110
Grain Sorghum	2	0.425	0.489	0.477	0.450	0.420	0.391	0.348	0.161	0.128
Grain Sorghum	3	0.497	0.428	0.413	0.393	0.377	0.361	0.298	0.156	0.138
Grain Sorghum	4	0.557	0.439	0.431	0.415	0.398	0.373	0.311	0.171	0.131
Rotated Corn	1	0.522	0.473	0.441	0.406	0.367	0.335	0.307	0.151	0.109
Rotated Corn	2	0.512	0.456	0.430	0.400	0.369	0.330	0.311	0.170	0.120
Rotated Corn	3	0.491	0.456	0.440	0.419	0.395	0.376	0.355	0.166	0.132
Rotated Corn	4	0.486	0.438	0.417	0.398	0.378	0.361	0.346	0.156	0.109
Miscanthus	1	0.555	0.424	0.415	0.389	0.371	0.360	0.342	0.172	0.149
Miscanthus	2	0.495	0.439	0.431	0.415	0.398	0.373	0.327	0.167	0.130
Miscanthus	3	0.574	0.456	0.446	0.431	0.419	0.411	0.361	0.152	0.114
Miscanthus	4	0.594	0.409	0.403	0.388	0.376	0.367	0.343	0.157	0.072
Switchgrass (Kanlow)	1	0.506	0.424	0.392	0.359	0.334	0.311	0.289	0.150	0.126
Switchgrass (Kanlow)	2	0.456	0.440	0.433	0.405	0.381	0.336	0.292	0.159	0.135
Switchgrass (Kanlow)	3	0.513	0.467	0.463	0.455	0.444	0.422	0.403	0.165	0.129
Switchgrass (Kanlow)	4	0.515	0.420	0.411	0.388	0.357	0.326	0.305	0.164	0.161

Big Bluestem	1	0.492	0.461	0.451	0.438	0.423	0.404	0.385	0.161	0.121
Big Bluestem	2	0.466	0.465	0.453	0.424	0.398	0.377	0.311	0.154	0.111
Big Bluestem	3	0.495	0.437	0.424	0.396	0.367	0.341	0.317	0.159	0.123
Big Bluestem	4	0.470	0.398	0.384	0.352	0.329	0.311	0.274	0.171	0.125
Indiangrass Mix	1	0.603	0.428	0.407	0.392	0.380	0.371	0.355	0.187	0.178
Indiangrass Mix	2	---	---	---	---	---	---	---	---	---
Indiangrass Mix	3	0.506	0.445	0.426	0.406	0.381	0.371	0.357	0.187	0.162
Indiangrass Mix	4	0.464	0.412	0.405	0.403	0.397	0.375	0.369	0.141	0.129
Switchgrass Mix	1	---	---	---	---	---	---	---	---	---
Switchgrass Mix	2	---	---	---	---	---	---	---	---	---
Switchgrass Mix	3	0.524	0.432	0.408	0.392	0.372	0.361	0.326	0.170	0.133
Switchgrass Mix	4	0.525	0.435	0.410	0.390	0.371	0.356	0.318	0.154	0.138
Soy Beans (Photo Period Sorghum)	1	0.477	0.400	0.364	0.297	0.263	0.245	0.161	0.143	0.110
Soy Beans (Photo Period Sorghum)	2	0.498	0.436	0.413	0.390	0.366	0.347	0.230	0.177	0.129
Soy Beans (Photo Period Sorghum)	3	0.528	0.427	0.407	0.394	0.376	0.356	0.230	0.166	0.152
Soy Beans (Photo Period Sorghum)	4	0.554	0.447	0.425	0.403	0.385	0.362	0.248	0.145	0.118
Soy Beans (Sweet Sorghum)	1	0.437	0.468	0.438	0.403	0.375	0.354	0.256	0.139	0.129
Soy Beans (Sweet Sorghum)	2	0.494	0.468	0.447	0.412	0.373	0.330	0.230	0.161	0.145
Soy Beans (Sweet Sorghum)	3	0.514	0.445	0.425	0.404	0.379	0.344	0.218	0.163	0.154
Soy Beans (Sweet Sorghum)	4	0.515	0.465	0.439	0.417	0.399	0.363	0.247	0.143	0.111
Soy Bean (Grain Sorghum)	1	0.463	0.447	0.418	0.383	0.352	0.329	0.229	0.142	0.125
Soy Bean (Grain Sorghum)	2	0.494	0.434	0.410	0.379	0.350	0.320	0.208	0.155	0.096
Soy Bean (Grain Sorghum)	3	0.535	0.414	0.397	0.382	0.367	0.353	0.240	0.149	0.145
Soy Bean (Grain Sorghum)	4	0.519	0.443	0.427	0.410	0.388	0.359	0.249	0.127	0.121
Soy Bean (Rotated Corn)	1	0.494	0.459	0.424	0.395	0.369	0.342	0.239	0.160	0.143
Soy Bean (Rotated Corn)	2	0.511	0.461	0.436	0.420	0.406	0.387	0.265	0.158	0.137
Soy Bean (Rotated Corn)	3	0.523	0.438	0.406	0.383	0.351	0.322	0.211	0.157	0.152
Soy Bean (Rotated Corn)	4	0.525	0.423	0.405	0.388	0.372	0.358	0.224	0.171	0.129

Table A.31 Neutron probe volumetric water content (VWC) data, at Manhattan in 2011.

		Depth (cm)												
Treatment	**Rep**	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**	**150**	**170**	**180**	**200**
								5/16/2011						
								---VWC (m^3 m^{-3})---						
Continuous Corn	1	0.259	0.296	0.404	0.299	0.302	0.306	0.307	0.315	0.327	0.332	0.323	0.322	0.323
Continuous Corn	2	0.296	0.295	0.297	0.306	0.312	0.314	0.309	0.314	0.322	0.317	0.327	0.328	0.332
Continuous Corn	3	0.288	0.308	0.310	0.305	0.306	0.305	0.310	0.320	0.329	0.322	0.327	0.326	0.327
Continuous Corn	4	0.277	0.287	0.295	0.299	0.302	0.303	0.301	0.307	0.324	0.338	0.340	0.333	0.341
Photo Period Sorghum	1	0.304	0.275	0.243	0.236	0.283	0.302	0.304	0.316	0.315	0.328	0.321	0.335	0.333
Photo Period Sorghum	2	0.294	0.306	0.303	0.316	0.326	0.332	0.336	0.341	0.332	0.000	0.000	0.295	0.317
Photo Period Sorghum	3	0.295	0.306	0.307	0.304	0.299	0.301	0.303	0.309	0.316	0.321	0.323	0.313	0.338
Photo Period Sorghum	4	0.310	0.306	0.303	0.312	0.318	0.323	0.324	0.327	0.322	0.325	0.322	0.000	0.000
Miscanthus	1	0.304	0.302	0.300	0.310	0.335	0.334	0.337	0.346	0.334	0.249	0.292	0.293	0.305
Miscanthus	2	0.294	0.306	0.303	0.316	0.326	0.332	0.336	0.341	0.332	0.000	0.000	0.295	0.317
Miscanthus	3	0.295	0.287	0.304	0.306	0.318	0.338	0.338	0.329	0.336	0.281	0.297	0.293	0.296
Miscanthus	4	0.299	0.312	0.315	0.321	0.318	0.321	0.322	0.324	0.316	0.000	0.000	0.294	0.304
Switchgrass (Kanlow)	1	0.312	0.309	0.317	0.332	0.321	0.330	0.337	0.328	0.331	0.279	0.303	0.304	0.306
Switchgrass (Kanlow)	2	0.304	0.304	0.302	0.311	0.324	0.330	0.333	0.335	0.332	0.000	0.000	0.000	0.290
Switchgrass (Kanlow)	3	0.302	0.300	0.314	0.328	0.330	0.332	0.328	0.327	0.344	0.292	0.311	0.302	0.326
Switchgrass (Kanlow)	4	0.329	0.324	0.325	0.329	0.333	0.323	0.326	0.327	0.332	0.000	0.000	0.000	0.290
Big Bluestem	1	0.313	0.324	0.320	0.316	0.323	0.335	0.350	0.354	0.349	0.352	0.278	0.303	0.303
Big Bluestem	2	0.309	0.298	0.294	0.305	0.323	0.334	0.342	0.345	0.342	0.343	0.000	0.000	0.000
Big Bluestem	3	0.305	0.310	0.309	0.310	0.324	0.327	0.325	0.329	0.325	0.337	0.277	0.303	0.312
Big Bluestem	4	0.319	0.299	0.301	0.310	0.316	0.328	0.325	0.329	0.334	0.334	0.000	0.000	0.000

		Depth (cm)												
Treatment	**Rep**	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**	**150**	**170**	**180**	**200**
		6/13/2011												
		---VWC (m^3 m^{-3})---												
Continuous Corn	1	0.254	0.299	0.298	0.303	0.317	0.320	0.316	0.320	0.329	0.331	0.326	0.328	0.327
Continuous Corn	2	0.286	0.320	0.315	0.308	0.316	0.314	0.322	0.330	0.331	0.327	0.331	0.330	0.337
Continuous Corn	3	0.294	0.301	0.314	0.313	0.311	0.329	0.321	0.322	0.333	0.329	0.330	0.323	0.331
Continuous Corn	4	0.287	0.300	0.304	0.303	0.305	0.305	0.311	0.321	0.334	0.344	0.332	0.333	0.347
Photo Period Sorghum	1	0.255	0.275	0.243	0.236	0.283	0.302	0.304	0.316	0.315	0.328	0.321	0.335	0.333
Photo Period Sorghum	2	0.210	0.249	0.262	0.301	0.306	0.310	0.312	0.328	0.332	0.341	0.339	0.343	0.331
Photo Period Sorghum	3	0.228	0.306	0.307	0.304	0.299	0.301	0.303	0.309	0.316	0.321	0.323	0.313	0.338
Photo Period Sorghum	4	0.291	0.310	0.315	0.306	0.314	0.316	0.332	0.332	0.318	0.320	0.326	0.331	0.329
Miscanthus	1	0.255	0.274	0.293	0.294	0.307	0.319	0.331	0.334	0.340	0.337	0.344	0.345	0.339
Miscanthus	2	0.210	0.249	0.262	0.301	0.306	0.310	0.312	0.328	0.332	0.341	0.339	0.343	0.331
Miscanthus	3	0.228	0.275	0.281	0.303	0.302	0.298	0.302	0.321	0.324	0.330	0.335	0.330	0.331
Miscanthus	4	0.231	0.284	0.281	0.301	0.311	0.316	0.326	0.326	0.318	0.318	0.320	0.321	0.323
Switchgrass (Kanlow)	1	0.275	0.308	0.325	0.308	0.324	0.325	0.326	0.328	0.329	0.340	0.337	0.336	0.335
Switchgrass (Kanlow)	2	0.246	0.291	0.297	0.304	0.308	0.314	0.311	0.325	0.331	0.340	0.338	0.339	0.335
Switchgrass (Kanlow)	3	0.257	0.289	0.298	0.305	0.304	0.309	0.321	0.334	0.338	0.332	0.333	0.327	0.327
Switchgrass (Kanlow)	4	0.288	0.300	0.304	0.328	0.335	0.334	0.333	0.336	0.334	0.331	0.326	0.327	0.338
Big Bluestem	1	0.255	0.298	0.307	0.312	0.332	0.323	0.326	0.336	0.349	0.352	0.350	0.351	0.366
Big Bluestem	2	0.230	0.279	0.306	0.309	0.308	0.304	0.316	0.339	0.342	0.340	0.344	0.333	0.338
Big Bluestem	3	0.269	0.289	0.298	0.305	0.304	0.311	0.320	0.320	0.326	0.329	0.333	0.332	0.343
Big Bluestem	4	0.222	0.289	0.314	0.301	0.299	0.308	0.316	0.322	0.338	0.335	0.331	0.329	0.338

		Depth (cm)												
Treatment	**Rep**	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**	**150**	**170**	**180**	**200**
		6/28/2011												
		---VWC (m^3 m^{-3})---												
Continuous Corn	1	0.185	0.239	0.269	0.293	0.303	0.314	0.313	0.315	0.323	0.332	0.339	0.323	0.333
Continuous Corn	2	0.259	0.295	0.289	0.291	0.303	0.315	0.311	0.319	0.333	0.329	0.335	0.343	0.333
Continuous Corn	3	0.240	0.244	0.239	0.245	0.278	0.318	0.313	0.329	0.335	0.336	0.344	0.347	0.335
Continuous Corn	4	0.263	0.271	0.294	0.291	0.302	0.312	0.328	0.330	0.332	0.327	0.338	0.327	0.330
Photo Period Sorghum	1	0.166	0.275	0.243	0.236	0.283	0.302	0.304	0.316	0.315	0.328	0.321	0.335	0.333
Photo Period Sorghum	2	0.204	0.241	0.251	0.281	0.295	0.306	0.301	0.324	0.340	0.335	0.333	0.342	0.329
Photo Period Sorghum	3	0.281	0.306	0.307	0.304	0.299	0.301	0.303	0.309	0.316	0.321	0.323	0.313	0.338
Photo Period Sorghum	4	0.167	0.230	0.283	0.302	0.303	0.309	0.321	0.322	0.333	0.343	0.351	0.337	0.329
Miscanthus	1	0.166	0.182	0.250	0.272	0.293	0.302	0.309	0.323	0.337	0.335	0.339	0.342	0.335
Miscanthus	2	0.204	0.241	0.251	0.281	0.295	0.306	0.301	0.324	0.340	0.335	0.333	0.342	0.329
Miscanthus	3	0.281	0.319	0.307	0.317	0.314	0.310	0.315	0.315	0.327	0.336	0.339	0.334	0.333
Miscanthus	4	0.259	0.292	0.304	0.314	0.315	0.319	0.323	0.317	0.324	0.325	0.324	0.331	0.376
Switchgrass (Kanlow)	1	0.169	0.201	0.251	0.286	0.292	0.293	0.299	0.311	0.325	0.331	0.329	0.324	0.340
Switchgrass (Kanlow)	2	0.206	0.251	0.285	0.304	0.300	0.304	0.314	0.327	0.337	0.329	0.338	0.322	0.341
Switchgrass (Kanlow)	3	0.200	0.239	0.265	0.294	0.308	0.311	0.311	0.325	0.323	0.333	0.329	0.327	0.341
Switchgrass (Kanlow)	4	0.250	0.278	0.291	0.323	0.328	0.325	0.328	0.332	0.336	0.327	0.331	0.320	0.331
Big Bluestem	1	0.199	0.222	0.259	0.287	0.302	0.310	0.318	0.322	0.315	0.325	0.320	0.328	0.325
Big Bluestem	2	0.186	0.261	0.290	0.292	0.292	0.307	0.311	0.317	0.334	0.335	0.328	0.332	0.336
Big Bluestem	3	0.281	0.315	0.310	0.308	0.305	0.312	0.324	0.332	0.320	0.326	0.330	0.327	0.328
Big Bluestem	4	0.210	0.255	0.287	0.297	0.306	0.305	0.306	0.321	0.334	0.342	0.345	0.341	0.349

		Depth (cm)												
Treatment	**Rep**	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**	**150**	**170**	**180**	**200**
		7/13/2011												
		---VWC (m^3 m^{-3})---												
Continuous Corn	1	0.164	0.189	0.189	0.239	0.289	0.300	0.305	0.324	0.333	0.338	0.334	0.333	0.328
Continuous Corn	2	0.224	0.230	0.236	0.250	0.285	0.300	0.316	0.323	0.334	0.333	0.340	0.327	0.337
Continuous Corn	3	0.213	0.210	0.227	0.283	0.301	0.319	0.327	0.325	0.332	0.334	0.328	0.335	0.346
Continuous Corn	4	0.167	0.186	0.219	0.253	0.287	0.293	0.305	0.316	0.327	0.342	0.339	0.347	0.355
Photo Period Sorghum	1	0.228	0.275	0.243	0.236	0.283	0.302	0.304	0.316	0.315	0.328	0.321	0.335	0.333
Photo Period Sorghum	2	0.155	0.164	0.233	0.265	0.268	0.294	0.303	0.318	0.331	0.347	0.338	0.342	0.333
Photo Period Sorghum	3	0.164	0.306	0.307	0.304	0.299	0.301	0.303	0.309	0.316	0.321	0.323	0.313	0.338
Photo Period Sorghum	4	0.232	0.310	0.310	0.312	0.301	0.316	0.324	0.327	0.326	0.324	0.330	0.326	0.329
Miscanthus	1	0.228	0.233	0.233	0.221	0.240	0.292	0.318	0.333	0.339	0.335	0.342	0.345	0.344
Miscanthus	2	0.155	0.164	0.233	0.265	0.268	0.294	0.303	0.318	0.331	0.347	0.338	0.342	0.333
Miscanthus	3	0.164	0.176	0.231	0.277	0.292	0.290	0.298	0.310	0.320	0.333	0.335	0.325	0.331
Miscanthus	4	0.191	0.205	0.227	0.276	0.293	0.313	0.323	0.327	0.322	0.321	0.323	0.323	0.323
Switchgrass (Kanlow)	1	0.246	0.233	0.233	0.251	0.278	0.312	0.319	0.330	0.341	0.332	0.341	0.331	0.341
Switchgrass (Kanlow)	2	0.187	0.211	0.214	0.249	0.276	0.306	0.304	0.314	0.329	0.336	0.347	0.340	0.337
Switchgrass (Kanlow)	3	0.186	0.237	0.265	0.298	0.302	0.303	0.313	0.333	0.342	0.332	0.330	0.335	0.343
Switchgrass (Kanlow)	4	0.254	0.265	0.270	0.285	0.307	0.317	0.326	0.331	0.336	0.325	0.329	0.326	0.339
Big Bluestem	1	0.207	0.227	0.227	0.284	0.301	0.312	0.317	0.322	0.337	0.345	0.347	0.351	0.357
Big Bluestem	2	0.156	0.213	0.255	0.282	0.291	0.299	0.313	0.329	0.338	0.343	0.347	0.336	0.339
Big Bluestem	3	0.166	0.175	0.209	0.264	0.301	0.306	0.315	0.321	0.329	0.329	0.332	0.323	0.347
Big Bluestem	4	0.206	0.269	0.290	0.298	0.298	0.298	0.308	0.321	0.326	0.328	0.333	0.337	0.342

		Depth (cm)												
Treatment	**Rep**	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**	**150**	**170**	**180**	**200**
		7/27/2011												
		---VWC (m^3 m^{-3})---												
Continuous Corn	1	0.141	0.174	0.169	0.199	0.239	0.261	0.295	0.316	0.323	0.333	0.324	0.331	0.329
Continuous Corn	2	0.184	0.173	0.206	0.210	0.202	0.219	0.256	0.299	0.327	0.329	0.329	0.328	0.330
Continuous Corn	3	0.170	0.176	0.185	0.201	0.244	0.279	0.293	0.315	0.328	0.330	0.329	0.333	0.338
Continuous Corn	4	0.169	0.194	0.210	0.246	0.277	0.298	0.319	0.322	0.324	0.319	0.335	0.341	0.325
Photo Period Sorghum	1	0.224	0.275	0.243	0.236	0.283	0.302	0.304	0.316	0.315	0.328	0.321	0.335	0.333
Photo Period Sorghum	2	0.209	0.219	0.238	0.238	0.274	0.297	0.305	0.323	0.325	0.340	0.344	0.346	0.337
Photo Period Sorghum	3	0.206	0.306	0.307	0.304	0.299	0.301	0.303	0.309	0.316	0.321	0.323	0.313	0.338
Photo Period Sorghum	4	0.150	0.169	0.188	0.209	0.229	0.262	0.283	0.301	0.324	0.331	0.341	0.332	0.349
Miscanthus	1	0.224	0.229	0.209	0.215	0.213	0.233	0.287	0.319	0.328	0.324	0.343	0.338	0.339
Miscanthus	2	0.209	0.219	0.238	0.238	0.274	0.297	0.305	0.323	0.325	0.340	0.344	0.346	0.337
Miscanthus	3	0.206	0.202	0.214	0.256	0.269	0.275	0.285	0.296	0.306	0.325	0.331	0.327	0.334
Miscanthus	4	0.198	0.193	0.213	0.234	0.277	0.295	0.314	0.319	0.320	0.328	0.325	0.325	0.324
Switchgrass (Kanlow)	1	0.237	0.227	0.213	0.221	0.256	0.280	0.296	0.327	0.330	0.333	0.335	0.335	0.334
Switchgrass (Kanlow)	2	0.190	0.200	0.237	0.233	0.247	0.268	0.288	0.299	0.314	0.331	0.338	0.338	0.332
Switchgrass (Kanlow)	3	0.194	0.225	0.253	0.262	0.289	0.295	0.302	0.323	0.329	0.325	0.334	0.332	0.331
Switchgrass (Kanlow)	4	0.234	0.247	0.224	0.232	0.252	0.297	0.313	0.326	0.332	0.323	0.325	0.328	0.339
Big Bluestem	1	0.202	0.202	0.209	0.236	0.263	0.283	0.303	0.320	0.335	0.344	0.357	0.351	0.356
Big Bluestem	2	0.201	0.209	0.225	0.247	0.252	0.296	0.284	0.300	0.323	0.331	0.339	0.334	0.331
Big Bluestem	3	0.196	0.200	0.232	0.239	0.263	0.306	0.303	0.315	0.318	0.331	0.324	0.326	0.344
Big Bluestem	4	0.226	0.237	0.244	0.278	0.294	0.297	0.303	0.314	0.318	0.326	0.333	0.337	0.328

								Depth (cm)						
Treatment	**Rep**	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**	**150**	**170**	**180**	**200**
								8/11/2011						
								---VWC (m^3 m^{-3})---						
Continuous Corn	1	0.143	0.173	0.175	0.202	0.240	0.256	0.289	0.305	0.318	0.329	0.327	0.320	0.326
Continuous Corn	2	0.186	0.203	0.200	0.195	0.203	0.221	0.252	0.265	0.318	0.319	0.334	0.328	0.327
Continuous Corn	3	0.163	0.165	0.181	0.194	0.227	0.243	0.250	0.299	0.324	0.324	0.327	0.329	0.349
Continuous Corn	4	0.155	0.169	0.186	0.208	0.225	0.250	0.282	0.291	0.313	0.330	0.326	0.336	0.339
Photo Period Sorghum	1	0.233	0.275	0.243	0.236	0.283	0.302	0.304	0.316	0.315	0.328	0.321	0.335	0.333
Photo Period Sorghum	2	0.204	0.208	0.217	0.252	0.249	0.276	0.298	0.308	0.319	0.326	0.341	0.333	0.331
Photo Period Sorghum	3	0.168	0.306	0.307	0.304	0.299	0.301	0.303	0.309	0.316	0.321	0.323	0.313	0.338
Photo Period Sorghum	4	0.197	0.242	0.246	0.266	0.290	0.298	0.315	0.325	0.320	0.322	0.323	0.324	0.320
Miscanthus	1	0.233	0.225	0.207	0.215	0.216	0.219	0.252	0.311	0.318	0.331	0.343	0.342	0.342
Miscanthus	2	0.204	0.208	0.217	0.252	0.249	0.276	0.298	0.308	0.319	0.326	0.341	0.333	0.331
Miscanthus	3	0.168	0.200	0.224	0.237	0.242	0.281	0.289	0.309	0.320	0.334	0.333	0.327	0.342
Miscanthus	4	0.204	0.238	0.247	0.272	0.290	0.306	0.308	0.324	0.312	0.322	0.328	0.333	0.342
Switchgrass (Kanlow)	1	0.238	0.214	0.205	0.213	0.249	0.266	0.282	0.311	0.325	0.327	0.333	0.333	0.332
Switchgrass (Kanlow)	2	0.200	0.187	0.196	0.226	0.253	0.261	0.283	0.293	0.307	0.323	0.330	0.337	0.335
Switchgrass (Kanlow)	3	0.189	0.211	0.233	0.239	0.252	0.281	0.300	0.294	0.320	0.324	0.330	0.330	0.342
Switchgrass (Kanlow)	4	0.225	0.243	0.252	0.276	0.300	0.314	0.306	0.309	0.317	0.329	0.325	0.326	0.348
Big Bluestem	1	0.190	0.197	0.203	0.222	0.252	0.273	0.306	0.327	0.327	0.329	0.348	0.347	0.348
Big Bluestem	2	0.204	0.209	0.231	0.251	0.256	0.265	0.299	0.316	0.322	0.330	0.333	0.324	0.325
Big Bluestem	3	0.163	0.198	0.208	0.233	0.247	0.289	0.304	0.313	0.313	0.327	0.322	0.329	0.349
Big Bluestem	4	0.239	0.259	0.264	0.278	0.292	0.293	0.304	0.315	0.324	0.323	0.333	0.339	0.335

		Depth (cm)												
Treatment	**Rep**	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**	**150**	**170**	**180**	**200**
		8/23/2011												
		---VWC (m^3 m^{-3})---												
Continuous Corn	1	0.141	0.176	0.172	0.199	0.245	0.256	0.290	0.303	0.319	0.328	0.326	0.329	0.332
Continuous Corn	2	0.163	0.170	0.191	0.195	0.195	0.205	0.224	0.264	0.308	0.324	0.332	0.335	0.326
Continuous Corn	3	0.148	0.166	0.178	0.200	0.227	0.239	0.264	0.295	0.308	0.328	0.327	0.331	0.341
Continuous Corn	4	0.156	0.175	0.183	0.212	0.229	0.251	0.279	0.297	0.309	0.331	0.331	0.333	0.356
Photo Period Sorghum	1	0.216	0.275	0.243	0.236	0.283	0.302	0.304	0.316	0.315	0.328	0.321	0.335	0.333
Photo Period Sorghum	2	0.204	0.200	0.209	0.244	0.253	0.269	0.276	0.304	0.317	0.323	0.327	0.335	0.340
Photo Period Sorghum	3	0.195	0.306	0.307	0.304	0.299	0.301	0.303	0.309	0.316	0.321	0.323	0.313	0.338
Photo Period Sorghum	4	0.155	0.194	0.218	0.234	0.288	0.297	0.310	0.319	0.316	0.318	0.333	0.329	0.326
Miscanthus	1	0.216	0.217	0.212	0.218	0.220	0.219	0.250	0.302	0.316	0.326	0.336	0.348	0.341
Miscanthus	2	0.204	0.200	0.209	0.244	0.253	0.269	0.276	0.304	0.317	0.323	0.327	0.335	0.340
Miscanthus	3	0.195	0.201	0.214	0.254	0.257	0.261	0.284	0.285	0.310	0.324	0.328	0.323	0.329
Miscanthus	4	0.201	0.243	0.257	0.283	0.296	0.297	0.305	0.318	0.324	0.326	0.332	0.335	0.350
Switchgrass (Kanlow)	1	0.219	0.212	0.209	0.215	0.248	0.268	0.285	0.296	0.317	0.331	0.341	0.338	0.338
Switchgrass (Kanlow)	2	0.204	0.184	0.193	0.232	0.249	0.258	0.266	0.298	0.305	0.314	0.323	0.332	0.340
Switchgrass (Kanlow)	3	0.187	0.197	0.213	0.246	0.252	0.257	0.278	0.293	0.306	0.326	0.331	0.328	0.338
Switchgrass (Kanlow)	4	0.184	0.231	0.242	0.278	0.288	0.292	0.304	0.313	0.321	0.325	0.330	0.320	0.339
Big Bluestem	1	0.212	0.206	0.205	0.218	0.249	0.262	0.289	0.299	0.318	0.330	0.342	0.339	0.344
Big Bluestem	2	0.187	0.190	0.204	0.236	0.241	0.249	0.271	0.291	0.307	0.318	0.326	0.330	0.335
Big Bluestem	3	0.192	0.205	0.221	0.256	0.262	0.285	0.292	0.300	0.313	0.321	0.335	0.335	0.331
Big Bluestem	4	0.188	0.247	0.254	0.276	0.292	0.286	0.307	0.314	0.323	0.331	0.331	0.332	0.335

								Depth (cm)						
Treatment	**Rep**	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**	**150**	**170**	**180**	**200**
								9/8/2011						
								---VWC (m^3 m^{-3})---						
Continuous Corn	1	0.130	0.173	0.174	0.203	0.239	0.256	0.296	0.306	0.326	0.327	0.330	0.328	0.332
Continuous Corn	2	0.166	0.164	0.210	0.197	0.192	0.201	0.221	0.268	0.311	0.327	0.329	0.339	0.331
Continuous Corn	3	0.131	0.165	0.176	0.189	0.216	0.238	0.253	0.283	0.313	0.328	0.327	0.329	0.338
Continuous Corn	4	0.138	0.189	0.240	0.245	0.253	0.275	0.284	0.302	0.310	0.329	0.327	0.326	0.325
Photo Period Sorghum	1	0.201	0.275	0.243	0.236	0.283	0.302	0.304	0.316	0.315	0.328	0.321	0.335	0.333
Photo Period Sorghum	2	0.200	0.197	0.212	0.241	0.248	0.247	0.262	0.292	0.307	0.317	0.320	0.334	0.340
Photo Period Sorghum	3	0.178	0.306	0.307	0.304	0.299	0.301	0.303	0.309	0.316	0.321	0.323	0.313	0.338
Photo Period Sorghum	4	0.145	0.168	0.193	0.211	0.223	0.265	0.284	0.296	0.316	0.325	0.329	0.332	0.359
Miscanthus	1	0.201	0.214	0.202	0.205	0.214	0.219	0.234	0.263	0.302	0.324	0.331	0.346	0.337
Miscanthus	2	0.200	0.197	0.212	0.241	0.248	0.247	0.262	0.292	0.307	0.317	0.320	0.334	0.340
Miscanthus	3	0.178	0.196	0.209	0.239	0.247	0.254	0.269	0.278	0.303	0.321	0.327	0.318	0.326
Miscanthus	4	0.205	0.231	0.248	0.274	0.331	0.282	0.283	0.302	0.309	0.322	0.329	0.335	0.344
Switchgrass (Kanlow)	1	0.208	0.204	0.201	0.209	0.240	0.265	0.261	0.280	0.310	0.328	0.333	0.330	0.331
Switchgrass (Kanlow)	2	0.197	0.196	0.205	0.231	0.240	0.253	0.272	0.291	0.304	0.315	0.329	0.338	0.346
Switchgrass (Kanlow)	3	0.166	0.195	0.216	0.236	0.244	0.249	0.285	0.295	0.323	0.319	0.325	0.326	0.335
Switchgrass (Kanlow)	4	0.205	0.232	0.235	0.280	0.283	0.289	0.295	0.300	0.319	0.330	0.324	0.328	0.334
Big Bluestem	1	0.203	0.200	0.203	0.209	0.244	0.261	0.266	0.270	0.299	0.321	0.327	0.335	0.339
Big Bluestem	2	0.183	0.201	0.214	0.231	0.236	0.253	0.269	0.284	0.300	0.311	0.322	0.327	0.331
Big Bluestem	3	0.183	0.201	0.226	0.248	0.260	0.275	0.290	0.295	0.311	0.317	0.330	0.342	0.335
Big Bluestem	4	0.187	0.238	0.242	0.267	0.282	0.291	0.308	0.316	0.313	0.324	0.330	0.326	0.334

		Depth (cm)												
Treatment	**Rep**	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**	**150**	**170**	**180**	**200**
		9/20/2011												
		---VWC (m^3 m^{-3})---												
Continuous Corn	1	0.180	0.174	0.169	0.195	0.240	0.270	0.298	0.296	0.317	0.330	0.319	0.329	0.327
Continuous Corn	2	0.236	0.204	0.194	0.192	0.191	0.208	0.222	0.277	0.308	0.322	0.328	0.322	0.332
Continuous Corn	3	0.200	0.156	0.179	0.189	0.188	0.194	0.203	0.271	0.301	0.316	0.323	0.339	0.354
Continuous Corn	4	0.115	0.197	0.279	0.265	0.276	0.304	0.329	0.316	0.308	0.307	0.317	0.343	0.313
Photo Period Sorghum	1	0.241	0.275	0.243	0.236	0.283	0.302	0.304	0.316	0.315	0.328	0.321	0.335	0.333
Photo Period Sorghum	2	0.236	0.238	0.211	0.207	0.203	0.217	0.247	0.280	0.297	0.322	0.312	0.327	0.339
Photo Period Sorghum	3	0.231	0.306	0.307	0.304	0.299	0.301	0.303	0.309	0.316	0.321	0.323	0.313	0.338
Photo Period Sorghum	4	0.151	0.142	0.205	0.204	0.221	0.277	0.273	0.292	0.300	0.321	0.340	0.339	0.346
Miscanthus	1	0.241	0.243	0.208	0.202	0.205	0.216	0.236	0.258	0.302	0.311	0.327	0.334	0.336
Miscanthus	2	0.236	0.238	0.211	0.207	0.203	0.217	0.247	0.280	0.297	0.322	0.312	0.327	0.339
Miscanthus	3	0.231	0.232	0.232	0.187	0.193	0.206	0.236	0.257	0.314	0.299	0.321	0.327	0.331
Miscanthus	4	0.220	0.202	0.211	0.204	0.219	0.238	0.227	0.255	0.330	0.312	0.347	0.327	0.333
Switchgrass (Kanlow)	1	0.248	0.221	0.199	0.208	0.236	0.260	0.258	0.277	0.306	0.322	0.333	0.323	0.335
Switchgrass (Kanlow)	2	0.240	0.223	0.207	0.229	0.246	0.256	0.266	0.284	0.304	0.320	0.330	0.327	0.335
Switchgrass (Kanlow)	3	0.235	0.242	0.223	0.223	0.228	0.241	0.275	0.307	0.321	0.315	0.302	0.329	0.328
Switchgrass (Kanlow)	4	0.224	0.233	0.224	0.240	0.237	0.282	0.302	0.310	0.306	0.332	0.329	0.336	0.311
Big Bluestem	1	0.243	0.217	0.201	0.208	0.240	0.255	0.263	0.268	0.296	0.315	0.326	0.328	0.343
Big Bluestem	2	0.226	0.229	0.216	0.229	0.242	0.255	0.264	0.278	0.300	0.316	0.323	0.316	0.320
Big Bluestem	3	0.272	0.259	0.242	0.248	0.256	0.297	0.280	0.317	0.307	0.317	0.318	0.356	0.321
Big Bluestem	4	0.203	0.241	0.229	0.214	0.240	0.287	0.330	0.348	0.297	0.322	0.347	0.343	0.327

								Depth (cm)						
Treatment	**Rep**	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**	**150**	**170**	**180**	**200**
								10/12/2011						
								---VWC (m^3 m^{-3})---						
Continuous Corn	1	0.269	0.285	0.228	0.199	0.243	0.285	0.297	0.307	0.315	0.328	0.329	0.325	0.324
Continuous Corn	2	0.270	0.285	0.229	0.196	0.194	0.223	0.221	0.288	0.307	0.319	0.338	0.318	0.329
Continuous Corn	3	0.279	0.275	0.233	0.196	0.217	0.247	0.250	0.294	0.308	0.321	0.331	0.329	0.337
Continuous Corn	4	0.264	0.285	0.230	0.233	0.236	0.271	0.275	0.307	0.307	0.312	0.332	0.328	0.320
Photo Period Sorghum	1	0.251	0.275	0.243	0.236	0.283	0.302	0.304	0.316	0.315	0.328	0.321	0.335	0.333
Photo Period Sorghum	2	0.246	0.261	0.222	0.214	0.214	0.214	0.239	0.306	0.307	0.341	0.324	0.344	0.341
Photo Period Sorghum	3	0.240	0.306	0.307	0.304	0.299	0.301	0.303	0.309	0.316	0.321	0.323	0.313	0.338
Photo Period Sorghum	4	0.278	0.235	0.194	0.208	0.236	0.275	0.275	0.294	0.303	0.321	0.330	0.324	0.336
Miscanthus	1	0.251	0.265	0.219	0.210	0.216	0.214	0.228	0.283	0.312	0.330	0.339	0.350	0.339
Miscanthus	2	0.246	0.261	0.222	0.214	0.214	0.214	0.239	0.306	0.307	0.341	0.324	0.344	0.341
Miscanthus	3	0.240	0.246	0.224	0.198	0.203	0.210	0.233	0.267	0.312	0.312	0.329	0.337	0.334
Miscanthus	4	0.232	0.228	0.215	0.208	0.215	0.226	0.234	0.277	0.317	0.324	0.334	0.333	0.337
Switchgrass (Kanlow)	1	0.248	0.221	0.199	0.208	0.236	0.260	0.258	0.277	0.306	0.322	0.333	0.323	0.335
Switchgrass (Kanlow)	2	0.240	0.223	0.207	0.229	0.246	0.256	0.266	0.284	0.304	0.320	0.330	0.327	0.335
Switchgrass (Kanlow)	3	0.241	0.231	0.211	0.215	0.232	0.250	0.267	0.292	0.314	0.318	0.317	0.326	0.332
Switchgrass (Kanlow)	4	0.232	0.228	0.216	0.234	0.242	0.269	0.284	0.297	0.305	0.326	0.329	0.331	0.323
Big Bluestem	1	0.243	0.217	0.201	0.208	0.240	0.255	0.263	0.268	0.296	0.315	0.326	0.328	0.343
Big Bluestem	2	0.226	0.229	0.216	0.229	0.242	0.255	0.264	0.278	0.300	0.316	0.323	0.316	0.320
Big Bluestem	3	0.258	0.238	0.221	0.228	0.248	0.276	0.271	0.292	0.301	0.316	0.322	0.342	0.332
Big Bluestem	4	0.215	0.235	0.222	0.221	0.241	0.271	0.297	0.313	0.299	0.319	0.335	0.330	0.323

		Depth (cm)												
Treatment	**Rep**	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**	**150**	**170**	**180**	**200**
		10/27/2011												
		---VWC (m^3 m^{-3})---												
Continuous Corn	1	0.236	0.278	0.234	0.203	0.249	0.289	0.304	0.298	0.319	0.319	0.329	0.327	0.321
Continuous Corn	2	0.268	0.244	0.204	0.195	0.189	0.204	0.241	0.284	0.306	0.313	0.332	0.331	0.329
Continuous Corn	3	0.212	0.234	0.252	0.236	0.237	0.256	0.302	0.294	0.310	0.297	0.327	0.344	0.316
Continuous Corn	4	0.206	0.199	0.222	0.230	0.227	0.233	0.316	0.299	0.305	0.299	0.322	0.356	0.320
Photo Period Sorghum	1	0.247	0.275	0.243	0.236	0.283	0.302	0.304	0.316	0.315	0.328	0.321	0.335	0.333
Photo Period Sorghum	2	0.242	0.252	0.218	0.211	0.210	0.215	0.242	0.296	0.304	0.334	0.320	0.338	0.340
Photo Period Sorghum	3	0.242	0.306	0.307	0.304	0.299	0.301	0.303	0.309	0.316	0.321	0.323	0.313	0.338
Photo Period Sorghum	4	0.278	0.235	0.194	0.208	0.236	0.275	0.275	0.294	0.303	0.321	0.330	0.324	0.336
Miscanthus	1	0.247	0.257	0.215	0.207	0.212	0.215	0.231	0.274	0.308	0.323	0.335	0.344	0.338
Miscanthus	2	0.242	0.252	0.218	0.211	0.210	0.215	0.242	0.296	0.304	0.334	0.320	0.338	0.340
Miscanthus	3	0.242	0.251	0.227	0.199	0.206	0.209	0.231	0.274	0.314	0.317	0.332	0.341	0.335
Miscanthus	4	0.234	0.234	0.218	0.210	0.218	0.226	0.232	0.284	0.320	0.329	0.337	0.337	0.337
Switchgrass (Kanlow)	1	0.264	0.243	0.204	0.204	0.238	0.247	0.269	0.301	0.310	0.322	0.331	0.328	0.332
Switchgrass (Kanlow)	2	0.240	0.223	0.207	0.229	0.246	0.256	0.266	0.284	0.304	0.320	0.330	0.327	0.335
Switchgrass (Kanlow)	3	0.241	0.231	0.211	0.215	0.232	0.250	0.267	0.292	0.314	0.318	0.317	0.326	0.332
Switchgrass (Kanlow)	4	0.232	0.228	0.216	0.234	0.242	0.269	0.284	0.297	0.305	0.326	0.329	0.331	0.323
Big Bluestem	1	0.243	0.217	0.201	0.208	0.240	0.255	0.263	0.268	0.296	0.315	0.326	0.328	0.343
Big Bluestem	2	0.226	0.229	0.216	0.229	0.242	0.255	0.264	0.278	0.300	0.316	0.323	0.316	0.320
Big Bluestem	3	0.258	0.238	0.221	0.228	0.248	0.276	0.271	0.292	0.301	0.316	0.322	0.342	0.332
Big Bluestem	4	0.215	0.235	0.222	0.221	0.241	0.271	0.297	0.313	0.299	0.319	0.335	0.330	0.323

								Depth (cm)						
Treatment	**Rep**	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**	**150**	**170**	**180**	**200**
								11/15/2012						
								---VWC (m^3 m^{-3})---						
Continuous Corn	1	0.271	0.298	0.290	0.293	0.296	0.296	0.305	0.306	0.316	0.320	0.325	0.326	0.317
Continuous Corn	2	0.259	0.285	0.289	0.279	0.295	0.297	0.312	0.325	0.318	0.312	0.330	0.334	0.330
Continuous Corn	3	0.245	0.286	0.288	0.295	0.300	0.299	0.304	0.306	0.308	0.316	0.321	0.331	0.339
Continuous Corn	4	0.248	0.283	0.289	0.293	0.298	0.291	0.313	0.309	0.317	0.324	0.321	0.337	0.327
Photo Period Sorghum	1	0.292	0.275	0.243	0.236	0.283	0.302	0.304	0.316	0.315	0.328	0.321	0.335	0.333
Photo Period Sorghum	2	0.287	0.261	0.223	0.214	0.240	0.274	0.311	0.308	0.304	0.321	0.317	0.329	0.335
Photo Period Sorghum	3	0.287	0.306	0.307	0.304	0.299	0.301	0.303	0.309	0.316	0.321	0.323	0.313	0.338
Photo Period Sorghum	4	0.273	0.277	0.292	0.271	0.274	0.248	0.257	0.289	0.297	0.315	0.326	0.332	0.332
Miscanthus	1	0.292	0.291	0.296	0.262	0.212	0.206	0.210	0.262	0.309	0.324	0.328	0.337	0.334
Miscanthus	2	0.287	0.261	0.223	0.214	0.240	0.274	0.311	0.308	0.304	0.321	0.317	0.329	0.335
Miscanthus	3	0.287	0.304	0.300	0.253	0.245	0.252	0.291	0.302	0.318	0.328	0.331	0.338	0.329
Miscanthus	4	0.290	0.283	0.302	0.288	0.255	0.244	0.292	0.311	0.317	0.324	0.331	0.330	0.335
Switchgrass (Kanlow)	1	0.289	0.257	0.223	0.212	0.237	0.268	0.306	0.303	0.321	0.317	0.328	0.334	0.330
Switchgrass (Kanlow)	2	0.287	0.267	0.214	0.224	0.248	0.263	0.286	0.298	0.313	0.321	0.325	0.330	0.337
Switchgrass (Kanlow)	3	0.283	0.265	0.227	0.214	0.238	0.257	0.283	0.296	0.315	0.321	0.328	0.330	0.336
Switchgrass (Kanlow)	4	0.273	0.258	0.240	0.231	0.241	0.278	0.287	0.301	0.314	0.326	0.322	0.328	0.330
Big Bluestem	1	0.292	0.304	0.298	0.247	0.240	0.246	0.291	0.307	0.316	0.311	0.327	0.331	0.329
Big Bluestem	2	0.285	0.288	0.300	0.249	0.247	0.271	0.278	0.290	0.308	0.324	0.326	0.331	0.326
Big Bluestem	3	0.300	0.281	0.291	0.280	0.254	0.243	0.269	0.295	0.308	0.318	0.323	0.333	0.335
Big Bluestem	4	0.291	0.292	0.287	0.253	0.248	0.270	0.293	0.309	0.318	0.317	0.328	0.332	0.335

Table A.32 Neutron probe volumetric water content (VWC), data at Manhattan in 2012.

		Depth (cm)												
Treatment	**Rep**	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**	**150**	**170**	**180**	**200**
								4/9/2012						
								---VWC (m^3 m^{-3})---						
Continuous Corn	1	0.274	0.298	0.288	0.289	0.305	0.313	0.309	0.313	0.322	0.332	0.331	0.324	0.325
Continuous Corn	2	0.259	0.291	0.304	0.301	0.306	0.306	0.313	0.315	0.324	0.332	0.332	0.327	0.333
Continuous Corn	3	0.288	0.310	0.300	0.298	0.295	0.306	0.310	0.311	0.318	0.317	0.326	0.330	0.332
Continuous Corn	4	0.291	0.303	0.294	0.287	0.299	0.306	0.312	0.318	0.313	0.323	0.326	0.326	0.332
Photo Period Sorghum	1	0.297	0.275	0.243	0.236	0.283	0.302	0.304	0.316	0.315	0.328	0.321	0.335	0.333
Photo Period Sorghum	2	0.295	0.306	0.308	0.304	0.306	0.295	0.303	0.314	0.332	0.334	0.337	0.336	0.338
Photo Period Sorghum	3	0.294	0.306	0.307	0.304	0.299	0.301	0.303	0.309	0.316	0.321	0.323	0.313	0.338
Photo Period Sorghum	4	0.282	0.312	0.310	0.296	0.300	0.303	0.316	0.323	0.322	0.328	0.328	0.335	0.337
Miscanthus	1	0.297	0.301	0.317	0.309	0.305	0.304	0.315	0.320	0.332	0.331	0.334	0.345	0.333
Miscanthus	2	0.295	0.306	0.308	0.304	0.306	0.295	0.303	0.314	0.332	0.334	0.337	0.336	0.338
Miscanthus	3	0.294	0.308	0.302	0.301	0.299	0.291	0.303	0.307	0.318	0.331	0.326	0.335	0.338
Miscanthus	4	0.291	0.303	0.294	0.287	0.299	0.306	0.312	0.318	0.313	0.331	0.330	0.332	0.331
Switchgrass (Kanlow)	1	0.282	0.314	0.324	0.309	0.307	0.313	0.320	0.328	0.327	0.335	0.331	0.333	0.332
Switchgrass (Kanlow)	2	0.295	0.305	0.303	0.309	0.305	0.302	0.304	0.319	0.316	0.323	0.326	0.329	0.333
Switchgrass (Kanlow)	3	0.299	0.314	0.303	0.303	0.300	0.300	0.313	0.319	0.324	0.331	0.332	0.331	0.338
Switchgrass (Kanlow)	4	0.289	0.309	0.306	0.310	0.310	0.319	0.320	0.327	0.331	0.333	0.330	0.327	0.332
Big Bluestem	1	0.302	0.311	0.312	0.315	0.318	0.313	0.319	0.320	0.332	0.335	0.336	0.342	0.355
Big Bluestem	2	0.297	0.310	0.309	0.311	0.308	0.318	0.323	0.327	0.329	0.332	0.336	0.340	0.336
Big Bluestem	3	0.295	0.312	0.299	0.308	0.310	0.306	0.313	0.314	0.323	0.324	0.332	0.332	0.331
Big Bluestem	4	0.298	0.303	0.307	0.310	0.311	0.310	0.319	0.321	0.331	0.332	0.328	0.330	0.333

								Depth (cm)						
Treatment	**Rep**	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**	**150**	**170**	**180**	**200**
								4/23/2012						
								---VWC (m^3 m^{-3})---						
Continuous Corn	1	0.244	0.286	0.289	0.296	0.300	0.296	0.313	0.315	0.319	0.332	0.335	0.329	0.333
Continuous Corn	2	0.264	0.302	0.297	0.295	0.299	0.306	0.303	0.317	0.322	0.321	0.329	0.335	0.332
Continuous Corn	3	0.264	0.286	0.293	0.305	0.303	0.305	0.315	0.309	0.326	0.333	0.335	0.333	0.339
Continuous Corn	4	0.244	0.270	0.282	0.295	0.293	0.299	0.307	0.315	0.323	0.333	0.334	0.332	0.341
Photo Period Sorghum	1	0.256	0.275	0.243	0.236	0.283	0.302	0.304	0.316	0.315	0.328	0.321	0.335	0.333
Photo Period Sorghum	2	0.259	0.284	0.290	0.297	0.293	0.303	0.304	0.313	0.326	0.335	0.332	0.293	0.338
Photo Period Sorghum	3	0.275	0.306	0.307	0.304	0.299	0.301	0.303	0.309	0.316	0.321	0.323	0.313	0.338
Photo Period Sorghum	4	0.273	0.296	0.309	0.306	0.309	0.316	0.323	0.320	0.329	0.333	0.329	0.335	0.332
Miscanthus	1	0.256	0.273	0.291	0.299	0.306	0.301	0.308	0.313	0.321	0.329	0.334	0.332	0.334
Miscanthus	2	0.259	0.284	0.290	0.297	0.293	0.303	0.304	0.313	0.326	0.335	0.332	0.293	0.338
Miscanthus	3	0.275	0.294	0.297	0.300	0.296	0.293	0.297	0.302	0.322	0.338	0.332	0.334	0.332
Miscanthus	4	0.273	0.286	0.290	0.289	0.296	0.305	0.312	0.306	0.328	0.333	0.335	0.329	0.333
Switchgrass (Kanlow)	1	0.277	0.291	0.287	0.296	0.301	0.298	0.305	0.309	0.329	0.332	0.327	0.336	0.333
Switchgrass (Kanlow)	2	0.287	0.298	0.299	0.293	0.296	0.303	0.303	0.312	0.321	0.336	0.339	0.333	0.337
Switchgrass (Kanlow)	3	0.289	0.299	0.300	0.303	0.293	0.298	0.306	0.329	0.323	0.329	0.330	0.338	0.340
Switchgrass (Kanlow)	4	0.269	0.290	0.284	0.298	0.301	0.307	0.313	0.310	0.325	0.333	0.334	0.329	0.332
Big Bluestem	1	0.276	0.303	0.301	0.307	0.318	0.313	0.318	0.319	0.329	0.339	0.343	0.342	0.351
Big Bluestem	2	0.259	0.286	0.296	0.294	0.298	0.301	0.306	0.312	0.324	0.332	0.327	0.336	0.332
Big Bluestem	3	0.285	0.294	0.293	0.301	0.297	0.302	0.307	0.321	0.317	0.328	0.334	0.330	0.338
Big Bluestem	4	0.253	0.294	0.295	0.295	0.295	0.299	0.302	0.316	0.328	0.334	0.332	0.329	0.334

		Depth (cm)												
Treatment	**Rep**	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**	**150**	**170**	**180**	**200**
		5/7/2012												
		---VWC (m^3 m^{-3})---												
Continuous Corn	1	0.185	0.239	0.269	0.293	0.303	0.314	0.313	0.315	0.323	0.332	0.339	0.323	0.333
Continuous Corn	2	0.240	0.244	0.239	0.245	0.278	0.318	0.313	0.329	0.335	0.336	0.344	0.347	0.335
Continuous Corn	3	0.212	0.274	0.273	0.284	0.300	0.304	0.307	0.310	0.320	0.329	0.331	0.328	0.334
Continuous Corn	4	0.263	0.271	0.294	0.291	0.302	0.312	0.328	0.330	0.332	0.327	0.338	0.327	0.330
Photo Period Sorghum	1	0.301	0.308	0.316	0.321	0.333	0.328	0.335	0.333	0.000	0.000	0.000	0.000	0.000
Photo Period Sorghum	2	0.245	0.266	0.290	0.300	0.310	0.309	0.317	0.378	0.330	0.326	0.335	0.329	0.337
Photo Period Sorghum	3	0.238	0.285	0.282	0.296	0.295	0.296	0.295	0.312	0.313	0.325	0.333	0.334	0.332
Photo Period Sorghum	4	0.167	0.230	0.283	0.302	0.303	0.309	0.321	0.322	0.333	0.343	0.351	0.337	0.329
Miscanthus	1	0.298	0.304	0.308	0.313	0.319	0.333	0.326	0.335	0.334	0.000	0.000	0.000	0.000
Miscanthus	2	0.281	0.319	0.307	0.317	0.314	0.310	0.315	0.315	0.327	0.336	0.339	0.334	0.333
Miscanthus	3	0.197	0.237	0.260	0.290	0.296	0.300	0.299	0.321	0.329	0.332	0.335	0.332	0.331
Miscanthus	4	0.259	0.292	0.304	0.314	0.315	0.319	0.323	0.317	0.324	0.325	0.324	0.331	0.376
Switchgrass (Kanlow)	1	0.266	0.287	0.294	0.297	0.303	0.314	0.322	0.329	0.332	0.334	0.332	0.000	0.000
Switchgrass (Kanlow)	2	0.200	0.239	0.265	0.294	0.308	0.311	0.311	0.325	0.323	0.333	0.329	0.327	0.341
Switchgrass (Kanlow)	3	0.217	0.266	0.283	0.291	0.297	0.290	0.299	0.300	0.316	0.328	0.331	0.329	0.335
Switchgrass (Kanlow)	4	0.250	0.278	0.291	0.323	0.328	0.325	0.328	0.332	0.336	0.327	0.331	0.320	0.331
Big Bluestem	1	0.282	0.285	0.300	0.296	0.300	0.307	0.323	0.329	0.331	0.329	0.337	0.000	0.000
Big Bluestem	2	0.281	0.315	0.310	0.308	0.305	0.312	0.324	0.332	0.320	0.326	0.330	0.327	0.328
Big Bluestem	3	0.233	0.275	0.291	0.303	0.308	0.308	0.311	0.314	0.324	0.326	0.332	0.326	0.334
Big Bluestem	4	0.210	0.255	0.287	0.297	0.306	0.305	0.306	0.321	0.334	0.342	0.345	0.341	0.349

								Depth (cm)						
Treatment	**Rep**	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**	**150**	**170**	**180**	**200**
								5/21/2012						
								---VWC (m^3 m^{-3})---						
Continuous Corn	1	0.164	0.189	0.189	0.239	0.289	0.300	0.305	0.324	0.333	0.338	0.334	0.333	0.328
Continuous Corn	2	0.213	0.210	0.227	0.283	0.301	0.319	0.327	0.325	0.332	0.334	0.328	0.335	0.346
Continuous Corn	3	0.200	0.268	0.260	0.276	0.298	0.307	0.301	0.314	0.326	0.335	0.331	0.331	0.336
Continuous Corn	4	0.167	0.186	0.219	0.253	0.287	0.293	0.305	0.316	0.327	0.342	0.339	0.347	0.355
Photo Period Sorghum	1	0.318	0.322	0.331	0.334	0.330	0.327	0.334	0.335	0.000	0.000	0.000	0.000	0.000
Photo Period Sorghum	2	0.212	0.280	0.278	0.301	0.309	0.305	0.313	0.319	0.329	0.335	0.330	0.335	0.329
Photo Period Sorghum	3	0.244	0.279	0.274	0.243	0.298	0.305	0.313	0.315	0.326	0.335	0.329	0.336	0.332
Photo Period Sorghum	4	0.232	0.310	0.310	0.312	0.301	0.316	0.324	0.327	0.326	0.324	0.330	0.326	0.329
Miscanthus	1	0.303	0.307	0.314	0.322	0.327	0.331	0.334	0.332	0.329	0.000	0.000	0.000	0.000
Miscanthus	2	0.164	0.176	0.231	0.277	0.292	0.290	0.298	0.310	0.320	0.333	0.335	0.325	0.331
Miscanthus	3	0.234	0.233	0.241	0.246	0.274	0.298	0.305	0.318	0.331	0.326	0.334	0.341	0.340
Miscanthus	4	0.191	0.205	0.227	0.276	0.293	0.313	0.323	0.327	0.322	0.321	0.323	0.323	0.323
Switchgrass (Kanlow)	1	0.238	0.264	0.279	0.290	0.302	0.308	0.331	0.333	0.338	0.343	0.338	0.000	0.000
Switchgrass (Kanlow)	2	0.186	0.237	0.265	0.298	0.302	0.303	0.313	0.333	0.342	0.332	0.330	0.335	0.343
Switchgrass (Kanlow)	3	0.244	0.283	0.296	0.291	0.292	0.314	0.318	0.321	0.335	0.329	0.339	0.344	0.345
Switchgrass (Kanlow)	4	0.254	0.265	0.270	0.285	0.307	0.317	0.326	0.331	0.336	0.325	0.329	0.326	0.339
Big Bluestem	1	0.244	0.263	0.287	0.294	0.312	0.323	0.335	0.337	0.335	0.344	0.343	0.000	0.000
Big Bluestem	2	0.166	0.175	0.209	0.264	0.301	0.306	0.315	0.321	0.329	0.329	0.332	0.323	0.347
Big Bluestem	3	0.244	0.270	0.286	0.296	0.300	0.308	0.310	0.318	0.331	0.333	0.331	0.337	0.333
Big Bluestem	4	0.206	0.269	0.290	0.298	0.298	0.298	0.308	0.321	0.326	0.328	0.333	0.337	0.342

							Depth (cm)						
Treatment	**Rep**	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**	**150**	**170**	**180**	**200**
								6/4/2012					
								---VWC (m^3 m^{-3})---					
Continuous Corn	1	0.141	0.174	0.169	0.199	0.239	0.261	0.295	0.316	0.323	0.333	0.324	0.331	0.329
Continuous Corn	2	0.170	0.176	0.185	0.201	0.244	0.279	0.293	0.315	0.328	0.330	0.329	0.333	0.338
Continuous Corn	3	0.233	0.265	0.271	0.282	0.293	0.311	0.311	0.313	0.326	0.324	0.323	0.331	0.327
Continuous Corn	4	0.169	0.194	0.210	0.246	0.277	0.298	0.319	0.322	0.324	0.319	0.335	0.341	0.325
Photo Period Sorghum	1	0.306	0.308	0.313	0.332	0.324	0.329	0.333	0.328	0.000	0.000	0.000	0.000	0.000
Photo Period Sorghum	2	0.156	0.189	0.194	0.228	0.236	0.298	0.301	0.318	0.318	0.328	0.332	0.323	0.331
Photo Period Sorghum	3	0.259	0.292	0.278	0.284	0.306	0.305	0.297	0.304	0.323	0.329	0.323	0.328	0.330
Photo Period Sorghum	4	0.150	0.169	0.188	0.209	0.229	0.262	0.283	0.301	0.324	0.331	0.341	0.332	0.349
Miscanthus	1	0.296	0.297	0.302	0.311	0.324	0.325	0.331	0.326	0.332	0.000	0.000	0.000	0.000
Miscanthus	2	0.206	0.202	0.214	0.256	0.269	0.275	0.285	0.296	0.306	0.325	0.331	0.327	0.334
Miscanthus	3	0.227	0.231	0.225	0.232	0.256	0.285	0.306	0.320	0.327	0.334	0.335	0.343	0.335
Miscanthus	4	0.198	0.193	0.213	0.234	0.277	0.295	0.314	0.319	0.320	0.328	0.325	0.325	0.324
Switchgrass (Kanlow)	1	0.215	0.265	0.273	0.289	0.297	0.306	0.324	0.331	0.327	0.324	0.332	0.000	0.000
Switchgrass (Kanlow)	2	0.194	0.225	0.253	0.262	0.289	0.295	0.302	0.323	0.329	0.325	0.334	0.332	0.331
Switchgrass (Kanlow)	3	0.276	0.272	0.277	0.268	0.285	0.304	0.310	0.317	0.326	0.323	0.331	0.338	0.331
Switchgrass (Kanlow)	4	0.234	0.247	0.224	0.232	0.252	0.297	0.313	0.326	0.332	0.323	0.325	0.328	0.339
Big Bluestem	1	0.217	0.253	0.271	0.288	0.291	0.296	0.324	0.331	0.323	0.328	0.327	0.000	0.000
Big Bluestem	2	0.196	0.200	0.232	0.239	0.263	0.306	0.303	0.315	0.318	0.331	0.324	0.326	0.344
Big Bluestem	3	0.241	0.256	0.264	0.293	0.303	0.299	0.309	0.318	0.324	0.327	0.333	0.328	0.332
Big Bluestem	4	0.226	0.237	0.244	0.278	0.294	0.297	0.303	0.314	0.318	0.326	0.333	0.337	0.328

Table A.33 Wind erodible fraction (%< 0.84 mm), mean geometric mean diameter (GMD) and geometric standard deviation (GSD) for the Colby site in Spring 2011.

Treatment	Rep	%<0.84	GMD (mm)	GSD
Switchgrass (Blackwell)	1	9.33	17.42	8.98
Switchgrass (Blackwell)	2	33.70	3.94	13.19
Switchgrass (Blackwell)	3	21.35	5.55	10.00
Miscanthus	1	7.04	19.34	7.80
Miscanthus	2	31.68	3.58	12.91
Miscanthus	3	24.40	5.53	11.28
Grain Sorghum	1	19.63	4.52	6.31
Grain Sorghum	2	31.37	3.18	7.55
Grain Sorghum	3	24.57	3.32	7.89
Sweet Sorghum	1	26.49	4.54	10.29
Sweet Sorghum	2	16.42	10.09	9.51
Sweet Sorghum	3	44.12	1.60	14.32
W-S-F 0% residue removal	1	15.96	10.18	8.81
W-S-F 0% residue removal	2	39.19	3.25	12.11
W-S-F 0% residue removal	3	26.30	3.42	8.54
W-S-F 100% residue removal	1	14.97	8.37	7.87
W-S-F 100% residue removal	2	13.33	8.25	7.73
W-S-F 100% residue removal	3	25.86	5.55	9.83

Table A.34 Wind erodible fraction (%< 0.84 mm), mean geometric mean diameter (GMD) and geometric standard deviation (GSD) for the Colby site in Fall 2011.

Treatment	Rep	%<0.84	GMD (mm)	GSD
Switchgrass (Blackwell)	1	32.71	1.99	15.57
Switchgrass (Blackwell)	2	15.81	7.70	13.73
Switchgrass (Blackwell)	3	39.18	1.33	12.74
Miscanthus	1	25.08	2.75	11.12
Miscanthus	2	6.21	21.28	8.29
Miscanthus	3	20.56	6.76	9.93
Grain Sorghum	1	32.40	3.04	21.99
Grain Sorghum	2	37.64	1.46	9.97
Grain Sorghum	3	20.33	5.21	13.28
Sweet Sorghum	1	23.72	2.68	9.75
Sweet Sorghum	2	31.16	1.72	14.36
Sweet Sorghum	3	24.08	3.58	13.79
W-S-F 0% residue removal	1	16.21	5.32	10.83
W-S-F 0% residue removal	2	21.38	7.26	16.48

W-S-F 0% residue removal	3	25.92	4.12	17.30
W-S-F 100% residue removal	1	37.84	1.31	13.72
W-S-F 100% residue removal	2	22.37	3.56	12.32
W-S-F 100% residue removal	3	11.47	7.97	9.90

Table A.35 Wind erodible fraction (%< 0.84 mm), mean geometric mean diameter (GMD) and geometric standard deviation (GSD) for the Colby site in Spring 2012.

Treatment	Rep	%<0.84	GMD (mm)	GSD
Switchgrass (Blackwell)	1	26.35	2.45	10.10
Switchgrass (Blackwell)	2	38.28	1.81	14.23
Switchgrass (Blackwell)	3	27.58	2.25	8.81
Miscanthus	1	62.27	0.51	12.17
Miscanthus	2	57.51	0.48	7.99
Miscanthus	3	50.98	0.69	10.23
Grain Sorghum	1	60.21	0.55	7.37
Grain Sorghum	2	65.42	0.35	10.41
Grain Sorghum	3	38.40	1.78	12.40
Sweet Sorghum	1	39.68	1.58	13.12
Sweet Sorghum	2	76.63	0.20	8.00
Sweet Sorghum	3	53.39	0.70	9.59
W-S-F 0% residue removal	1	64.40	0.43	7.40
W-S-F 0% residue removal	2	37.13	1.54	11.89
W-S-F 0% residue removal	3	52.79	0.78	9.42
W-S-F 100% residue removal	1	35.52	1.36	10.17
W-S-F 100% residue removal	2	34.36	3.55	16.72
W-S-F 100% residue removal	3	32.75	1.80	12.18

Table A.36 Wind erodible fraction (%< 0.84 mm), mean geometric mean diameter (GMD) and geometric standard deviation (GSD) for the Hays site in Spring 2011.

Treatment	Rep	%<0.84	GMD (mm)	GSD
Switchgrass (Blackwell)	1	69.06	0.43	9.69
Switchgrass (Blackwell)	2	40.44	1.45	11.12
Switchgrass (Blackwell)	3	62.68	0.53	9.69
Miscanthus	1	77.40	0.24	8.42
Miscanthus	2	56.43	0.99	14.42
Miscanthus	3	67.37	0.44	12.15
Grain Sorghum	1	45.51	1.35	17.02
Grain Sorghum	2	56.68	0.73	11.85
Grain Sorghum	3	73.78	0.26	8.62
Sweet Sorghum	1	53.67	0.75	13.46
Sweet Sorghum	2	36.21	2.11	14.37
Sweet Sorghum	3	60.10	0.64	11.61
W-S-F 0% residue removal	1	65.03	0.39	10.02
W-S-F 0% residue removal	2	65.27	0.51	9.10
W-S-F 0% residue removal	3	45.95	1.11	14.65
W-S-F 100% residue removal	1	74.38	0.32	8.82
W-S-F 100% residue removal	2	74.58	0.36	7.99
W-S-F 100% residue removal	3	50.49	0.80	9.43

Table A.37 Wind erodible fraction (%< 0.84 mm), mean geometric mean diameter (GMD) and geometric standard deviation (GSD) for the Hays site in Fall 2011.

Treatment	Rep	%<0.84	GMD (mm)	GSD
Switchgrass (Blackwell)	1	14.31	5.15	6.60
Switchgrass (Blackwell)	2	23.70	5.05	11.14
Switchgrass (Blackwell)	3	39.66	2.02	12.22
Miscanthus	1	47.33	1.06	11.16
Miscanthus	2	50.65	1.09	7.38
Miscanthus	3	26.90	0.76	10.25
Grain Sorghum	1	40.84	0.98	11.01
Grain Sorghum	2	15.71	2.87	10.37
Grain Sorghum	3	53.15	0.77	11.46
Sweet Sorghum	1	37.58	1.35	8.74
Sweet Sorghum	2	39.60	1.12	10.80
Sweet Sorghum	3	58.64	0.59	10.90
W-S-F 0% residue removal	1	46.55	0.77	9.06
W-S-F 0% residue removal	2	18.71	1.46	9.23

W-S-F 0% residue removal	3	48.80	0.95	8.13
W-S-F 100% residue removal	1	59.10	0.65	8.30
W-S-F 100% residue removal	2	64.62	0.68	14.35
W-S-F 100% residue removal	3	53.55	0.78	7.58

Table A.38 Wind erodible fraction (%< 0.84 mm), mean geometric mean diameter (GMD) and geometric standard deviation (GSD) for the Hays site in Spring 2012.

Treatment	Rep	%<0.84	GMD (mm)	GSD
Switchgrass (Blackwell)	1	40.33	2.43	13.57
Switchgrass (Blackwell)	2	41.14	2.18	14.00
Switchgrass (Blackwell)	3	45.25	1.63	12.02
Miscanthus	1	59.15	0.93	11.10
Miscanthus	2	46.67	1.63	11.73
Miscanthus	3	61.88	0.79	10.13
Grain Sorghum	1	71.57	0.32	7.81
Grain Sorghum	2	63.91	0.53	8.77
Grain Sorghum	3	68.02	0.42	8.30
Sweet Sorghum	1	81.85	0.19	8.11
Sweet Sorghum	2	73.00	0.35	7.06
Sweet Sorghum	3	49.23	1.16	9.85
W-S-F 0% residue removal	1	69.49	0.41	7.05
W-S-F 0% residue removal	2	63.34	0.61	8.18
W-S-F 0% residue removal	3	59.94	0.67	9.70
W-S-F 100% residue removal	1	67.81	0.49	9.04
W-S-F 100% residue removal	2	69.83	0.48	6.91
W-S-F 100% residue removal	3	67.11	0.42	8.32

Table A.39 Wind erodible fraction (%< 0.84 mm), mean geometric mean diameter (GMD) and geometric standard deviation (GSD) for the Manhattan site in Spring 2011.

Treatment	Rep	%<0.84	GMD (mm)	GSD
Continuous Corn	1	20.03	8.26	15.91
Continuous Corn	2	11.23	11.08	9.41
Continuous Corn	3	18.88	7.36	16.06
Continuous Corn	4	16.82	9.66	15.46
Photo Period Sorghum	1	14.96	8.28	10.54
Photo Period Sorghum	2	22.95	4.34	12.54
Photo Period Sorghum	3	7.30	26.01	12.24
Photo Period Sorghum	4	29.26	2.28	14.01
Sweet Sorghum	1	25.46	3.70	14.09
Sweet Sorghum	2	17.37	6.78	11.98
Sweet Sorghum	3	11.93	17.27	13.66
Sweet Sorghum	4	21.19	4.47	11.65
Grain Sorghum	1	24.48	3.01	12.52
Grain Sorghum	2	12.19	12.27	14.27
Grain Sorghum	3	21.33	6.02	17.20
Grain Sorghum	4	17.77	5.76	12.07
Miscanthus	1	5.96	16.57	12.44
Miscanthus	2	7.86	30.06	12.11
Miscanthus	3	10.36	15.22	11.39
Miscanthus	4	3.40	52.38	7.56
Switchgrass (Kanlow)	1	6.32	39.03	9.75
Switchgrass (Kanlow)	2	10.17	24.63	12.91
Switchgrass (Kanlow)	3	9.65	14.84	10.16
Switchgrass (Kanlow)	4	5.59	48.48	9.38
Big Bluestem	1	12.98	10.64	13.74
Big Bluestem	2	5.61	38.70	10.21
Big Bluestem	3	20.55	5.70	15.26
Big Bluestem	4	22.62	4.83	15.26

Table A.40 Wind erodible fraction (%< 0.84 mm), mean geometric mean diameter (GMD) and geometric standard deviation (GSD) for the Manhattan site in Fall 2011.

Treatment	Rep	%<0.84	GMD (mm)	GSD
Continuous Corn	1	20.87	3.66	11.68
Continuous Corn	2	11.47	7.97	9.90
Continuous Corn	3	37.84	1.31	13.72
Continuous Corn	4	32.40	3.04	21.99
Photo Period Sorghum	1	20.33	5.21	13.28
Photo Period Sorghum	2	24.08	3.58	13.79
Photo Period Sorghum	3	22.37	3.56	12.32
Photo Period Sorghum	4	32.71	1.99	15.57
Sweet Sorghum	1	23.72	2.68	9.75
Sweet Sorghum	2	16.21	5.32	10.83
Sweet Sorghum	3	25.92	4.12	17.30
Sweet Sorghum	4	39.18	1.33	12.74
Grain Sorghum	1	25.08	2.75	11.12
Grain Sorghum	2	15.81	7.70	13.73
Grain Sorghum	3	31.16	1.72	14.36
Grain Sorghum	4	21.38	7.26	16.48
Miscanthus	1	3.89	25.48	6.39
Miscanthus	2	19.50	5.79	16.67
Miscanthus	3	21.98	4.10	14.04
Miscanthus	4	7.42	34.15	12.99
Switchgrass (Kanlow)	1	2.95	76.26	7.12
Switchgrass (Kanlow)	2	4.94	29.30	7.98
Switchgrass (Kanlow)	3	15.01	7.42	12.16
Switchgrass (Kanlow)	4	3.61	38.34	7.66
Big Bluestem	1	10.49	11.15	10.83
Big Bluestem	2	8.06	19.31	10.95
Big Bluestem	3	7.20	12.64	7.34
Big Bluestem	4	17.69	4.29	10.16

Table A.41 Wind erodible fraction (%< 0.84 mm), mean geometric mean diameter (GMD) and geometric standard deviation (GSD) for the Manhattan site in Fall 2011.

Treatment	Rep	%<0.84	GMD (mm)	GSD
Continuous Corn	1	52.73	0.71	18.80
Continuous Corn	2	41.69	1.54	15.61
Continuous Corn	3	35.83	1.72	16.56
Continuous Corn	4	42.33	0.99	16.35
Photo Period Sorghum	1	28.23	3.53	14.98
Photo Period Sorghum	2	30.90	2.78	17.05
Photo Period Sorghum	3	35.49	1.72	17.15
Photo Period Sorghum	4	44.44	1.11	20.15
Sweet Sorghum	1	40.11	1.52	26.74
Sweet Sorghum	2	22.59	3.98	13.94
Sweet Sorghum	3	31.27	2.15	16.11
Sweet Sorghum	4	32.98	2.68	17.50
Grain Sorghum	1	30.81	2.51	17.80
Grain Sorghum	2	51.46	0.56	16.02
Grain Sorghum	3	25.58	4.60	19.43
Grain Sorghum	4	27.83	2.78	15.14
Miscanthus	1	10.92	5.00	6.51
Miscanthus	2	16.24	6.96	13.29
Miscanthus	3	6.92	21.29	9.47
Miscanthus	4	20.16	4.03	10.38
Switchgrass (Kanlow)	1	13.70	8.66	10.43
Switchgrass (Kanlow)	2	18.30	5.74	13.19
Switchgrass (Kanlow)	3	21.09	4.79	12.91
Switchgrass (Kanlow)	4	14.80	7.35	9.30
Big Bluestem	1	16.24	4.67	9.41
Big Bluestem	2	16.01	6.51	12.72
Big Bluestem	3	20.00	4.43	12.16
Big Bluestem	4	14.70	7.68	10.73

Table A.42 Surface roughness values at Colby.

		Standard Deviation		
Treatment	**Rep**	**Spring 2011**	**Fall 2011**	**Spring 2012**
Switchgrass (Blackwell)	1	5.07	4.54	5.16
Switchgrass (Blackwell)	2	4.56	5.22	5.18
Switchgrass (Blackwell)	3	5.31	---	7.95
Miscanthus	1	4.63	3.72	4.29
Miscanthus	2	4.05	3.29	2.19
Miscanthus	3	3.93	5.75	6.56
Grain Sorghum	1	5.67	4.45	5.62
Grain Sorghum	2	7.15	4.40	4.36
Grain Sorghum	3	4.28	3.28	4.24
Sweet Sorghum	1	4.82	5.04	0.85
Sweet Sorghum	2	6.02	4.48	2.53
Sweet Sorghum	3	4.88	3.01	5.74
W-S-F 0% residue removal	1	4.69	4.75	2.74
W-S-F 0% residue removal	2	6.26	5.28	7.00
W-S-F 0% residue removal	3	4.41	4.84	3.75
W-S-F 100% residue removal	1	5.10	3.88	4.66
W-S-F 100% residue removal	2	6.22	4.61	3.23
W-S-F 100% residue removal	3	4.79	2.76	5.30

Table A.43 Surface roughness values at Hays.

		Standard Deviation		
Treatment	**Rep**	**Spring 2011**	**Fall 2011**	**Spring 2012**
Switchgrass (Blackwell)	1	3.60	5.97	4.99
Switchgrass (Blackwell)	2	4.48	8.85	5.85
Switchgrass (Blackwell)	3	8.69	7.86	7.97
Miscanthus	1	6.00	5.52	4.69
Miscanthus	2	5.20	4.41	3.18
Miscanthus	3	3.69	4.40	5.65
Grain Sorghum	1	4.19	7.10	1.89
Grain Sorghum	2	0.92	0.99	2.04
Grain Sorghum	3	7.28	2.43	2.84
Sweet Sorghum	1	3.47	2.18	2.11
Sweet Sorghum	2	3.93	1.94	2.99
Sweet Sorghum	3	7.13	3.51	3.21
W-S-F 0% residue removal	1	3.73	2.63	5.53
W-S-F 0% residue removal	2	3.14	1.94	3.23
W-S-F 0% residue removal	3	6.30	2.55	3.55
W-S-F 100% residue removal	1	4.84	3.50	2.58
W-S-F 100% residue removal	2	3.43	1.65	5.10
W-S-F 100% residue removal	3	5.00	2.77	2.42

Table A.44 Surface roughness values at Manhattan.

		Standard Deviation		
Treatment	**Rep**	**Spring 2011**	**Fall 2011**	**Spring 2012**
Continuous Corn	1	6.68	4.96	3.96
Continuous Corn	2	4.84	2.67	2.82
Continuous Corn	3	3.32	3.48	---
Continuous Corn	4	3.08	2.08	2.49
Photo Period Sorghum	1	2.92	1.48	3.38
Photo Period Sorghum	2	2.06	2.80	2.33
Photo Period Sorghum	3	3.46	4.03	2.53
Photo Period Sorghum	4	3.47	2.73	2.33
Sweet Sorghum	1	5.03	3.24	---
Sweet Sorghum	2	3.19	3.13	3.72
Sweet Sorghum	3	4.81	2.53	2.63
Sweet Sorghum	4	2.85	3.19	4.15
Grain Sorghum	1	8.05	5.96	2.69
Grain Sorghum	2	1.79	3.67	2.64
Grain Sorghum	3	3.28	2.65	4.26
Grain Sorghum	4	1.98	2.55	2.50
Miscanthus	1	6.69	5.96	3.54
Miscanthus	2	4.33	0.88	6.54
Miscanthus	3	3.21	2.89	5.11
Miscanthus	4	4.62	2.93	6.06
Switchgrass (Kanlow)	1	4.52	2.37	3.52
Switchgrass (Kanlow)	2	4.11	4.16	3.43
Switchgrass (Kanlow)	3	3.87	2.29	3.97
Switchgrass (Kanlow)	4	5.30	5.56	6.93
Big Bluestem	1	8.33	3.09	4.27
Big Bluestem	2	4.88	1.19	3.33
Big Bluestem	3	2.32	5.14	3.26
Big Bluestem	4	4.57	3.50	5.38

Table A.45 Aggregate Stability values at Colby.

		ln J/kg		
Treatment	**Rep**	**Spring 2011**	**Fall 2011**	**Spring 2012**
Switchgrass (Blackwell)	1	2.96	3.27	3.91
Switchgrass (Blackwell)	2	2.86	3.89	3.16
Switchgrass (Blackwell)	3	4.12	3.54	3.36
Miscanthus	1	3.31	4.00	3.54
Miscanthus	2	3.16	4.71	3.32
Miscanthus	3	3.60	3.74	3.79
Grain Sorghum	1	4.39	3.70	3.10
Grain Sorghum	2	4.45	4.59	3.25
Grain Sorghum	3	3.59	3.16	3.37
Sweet Sorghum	1	3.67	5.11	3.67
Sweet Sorghum	2	3.43	4.78	3.26
Sweet Sorghum	3	4.42	4.61	3.08
W-S-F 0% residue removal	1	4.06	4.54	3.26
W-S-F 0% residue removal	2	4.14	3.41	3.01
W-S-F 0% residue removal	3	3.85	3.28	3.27
W-S-F 100% residue removal	1	3.63	3.23	3.77
W-S-F 100% residue removal	2	3.94	4.07	3.64
W-S-F 100% residue removal	3	3.93	3.89	2.67

Table A.46 Aggregate Stability values at Hays.

		ln J/kg		
Treatment	**Rep**	**Spring 2011**	**Fall 2011**	**Spring 2012**
Switchgrass (Blackwell)	1	3.01	4.44	3.96
Switchgrass (Blackwell)	2	3.00	3.51	3.40
Switchgrass (Blackwell)	3	2.79	3.12	3.82
Miscanthus	1	2.48	3.95	3.23
Miscanthus	2	3.13	3.34	3.29
Miscanthus	3	3.38	3.93	3.45
Grain Sorghum	1	3.53	4.15	3.57
Grain Sorghum	2	3.57	3.42	3.57
Grain Sorghum	3	2.83	3.80	3.62
Sweet Sorghum	1	2.79	4.44	3.32
Sweet Sorghum	2	3.75	3.86	3.51
Sweet Sorghum	3	2.73	3.51	4.10
W-S-F 0% residue removal	1	3.76	3.60	3.64
W-S-F 0% residue removal	2	3.70	3.60	3.33
W-S-F 0% residue removal	3	3.97	3.32	2.94
W-S-F 100% residue removal	1	2.71	3.52	3.37
W-S-F 100% residue removal	2	2.45	3.99	3.05
W-S-F 100% residue removal	3	3.42	4.21	3.52

Table A.47 Aggregate Stability values at Manhattan.

		ln J/kg		
Treatment	**Rep**	**Spring 2011**	**Fall 2011**	**Spring 2012**
Continuous Corn	1	3.26	3.74	3.39
Continuous Corn	2	3.45	4.38	3.24
Continuous Corn	3	2.90	4.59	---
Continuous Corn	4	3.16	4.00	2.94
Photo Period Sorghum	1	3.20	4.88	3.32
Photo Period Sorghum	2	2.90	3.74	2.94
Photo Period Sorghum	3	3.86	5.39	3.51
Photo Period Sorghum	4	3.15	4.17	3.15
Sweet Sorghum	1	2.86	3.34	3.16
Sweet Sorghum	2	2.78	4.63	3.31
Sweet Sorghum	3	3.22	4.32	3.19
Sweet Sorghum	4	3.39	3.53	3.10
Grain Sorghum	1	3.33	3.29	2.95
Grain Sorghum	2	3.55	4.58	3.21
Grain Sorghum	3	3.35	3.20	2.98
Grain Sorghum	4	2.81	4.62	3.17
Miscanthus	1	4.14	4.69	4.03
Miscanthus	2	4.10	4.66	3.74
Miscanthus	3	4.47	4.87	4.87
Miscanthus	4	3.75	3.97	3.69
Switchgrass (Kanlow)	1	3.93	4.70	3.32
Switchgrass (Kanlow)	2	3.57	4.67	3.23
Switchgrass (Kanlow)	3	3.68	4.42	3.38
Switchgrass (Kanlow)	4	3.42	5.35	3.11
Big Bluestem	1	3.78	5.23	4.13
Big Bluestem	2	3.94	4.59	3.65
Big Bluestem	3	3.42	4.43	3.79
Big Bluestem	4	3.26	4.59	3.89

Appendix B - Raw Data; Biomass Yield and Forage Quality

Table B.1 Biomass yields at Colby.

Treatment	Rep	2010	2011
		---Yield (Mg ha^{-1})---	
Switchgrass (Blackwell)	1	3.59	4.00
Switch Grass (Blackwell)	2	2.15	2.91
Switch Grass (Blackwell)	3	2.38	2.71
Miscanthus	1	1.30	1.95
Miscanthus	2	1.13	1.27
Miscanthus	3	0.97	1.71
Grain Sorghum	1	4.32	3.48
Grain Sorghum	2	4.36	3.50
Grain Sorghum	3	4.92	2.96
Sweet Sorghum	1	7.97	8.98
Sweet Sorghum	2	7.49	7.19
Sweet Sorghum	3	6.77	7.10

Table B.2 Biomass yield at Hays in 2010.

Treatment	Rep	Yield ($Mg\ ha^{-1}$)
Switchgrass (Blackwell)	1	2.17
Switchgrass (Blackwell)	2	1.62
Switchgrass (Blackwell)	3	3.92
Switchgrass (Pathfinder)	1	4.14
Switchgrass (Pathfinder)	2	4.73
Switchgrass (Pathfinder)	3	2.40
Miscanthus	1	2.48
Miscanthus	2	1.89
Miscanthus	3	1.45
Big Bluestem (Kaw)	1	3.14
Big Bluestem (Kaw)	2	1.72
Big Bluestem (Kaw)	3	2.42
Sand Bluestem	1	1.49
Sand Bluestem	2	3.08
Sand Bluestem	3	1.02
Mixed Grass	1	0.97
Mixed Grass	2	2.94
Mixed Grass	3	3.73
Indian Grass (Cheyenne)	1	3.75
Indian Grass (Cheyenne)	2	4.47
Indian Grass (Cheyenne)	3	3.47
Eastern Gamagrass	1	1.71
Eastern Gamagrass	2	1.29
Eastern Gamagrass	3	1.44
Grain Sorghum	1	5.27
Grain Sorghum	2	5.20
Grain Sorghum	3	6.18
Sweet Sorghum	1	5.76
Sweet Sorghum	2	7.61
Sweet Sorghum	3	7.28

Table B.3 Biomass yield at Manhattan in 2010.

Treatment	Rep	Yield (Mg ha^{-1})	Treatment	Rep	Yield (Mg ha^{-1})
Continuous Corn	1	6.64	Miscanthus	1	9.44
Continuous Corn	2	3.59	Miscanthus	2	8.99
Continuous Corn	3	10.46	Miscanthus	3	11.29
Continuous Corn	4	8.34	Miscanthus	4	9.03
Rotated Corn	1	12.0	Switchgrass (Kanlow)	1	5.12
Rotated Corn	2	11.1	Switchgrass (Kanlow)	2	11.12
Rotated Corn	3	12.1	Switchgrass (Kanlow)	3	9.16
Rotated Corn	4	15.2	Switchgrass (Kanlow)	4	6.21
Photo Period Sorghum	1	17.48	Big Bluestem	1	3.87
Photo Period Sorghum	2	20.56	Big Bluestem	2	4.45
Photo Period Sorghum	3	20.45	Big Bluestem	3	4.06
Photo Period Sorghum	4	24.57	Big Bluestem	4	2.79
Sweet Sorghum	1	20.20	Indiangrass Mix	1	1.17
Sweet Sorghum	2	22.47	Indiangrass Mix	2	---
Sweet Sorghum	3	24.39	Indiangrass Mix	3	3.14
Sweet Sorghum	4	25.71	Indiangrass Mix	4	3.10
Grain Sorghum	1	16.81	Switchgrass Mix	1	2.85
Grain Sorghum	2	10.84	Switchgrass Mix	2	---
Grain Sorghum	3	14.39	Switchgrass Mix	3	3.00
Grain Sorghum	4	13.20	Switchgrass Mix	4	2.69

Table B.4 Biomass yield at Manhattan in 2011.

Treatment	Rep	Yield ($Mg\ ha^{-1}$)	Treatment	Rep	Yield ($Mg\ ha^{-1}$)
Continuous Corn	1	7.16	Miscanthus	1	5.43
Continuous Corn	2	8.92	Miscanthus	2	15.49
Continuous Corn	3	8.48	Miscanthus	3	15.21
Continuous Corn	4	9.34	Miscanthus	4	18.99
Rotated Corn	1	9.19	Switchgrass (Kanlow)	1	6.05
Rotated Corn	2	11.54	Switchgrass (Kanlow)	2	9.96
Rotated Corn	3	10.75	Switchgrass (Kanlow)	3	12.26
Rotated Corn	4	12.66	Switchgrass (Kanlow)	4	15.31
Photo Period Sorghum	1	20.79	Big Bluestem	1	8.75
Photo Period Sorghum	2	20.05	Big Bluestem	2	13.12
Photo Period Sorghum	3	19.77	Big Bluestem	3	16.41
Photo Period Sorghum	4	22.45	Big Bluestem	4	5.45
Sweet Sorghum	1	16.05	Indiangrass Mix	1	6.52
Sweet Sorghum	2	17.05	Indiangrass Mix	2	---
Sweet Sorghum	3	19.64	Indiangrass Mix	3	7.84
Sweet Sorghum	4	25.02	Indiangrass Mix	4	17.77
Grain Sorghum	1	9.16	Switchgrass Mix	1	---
Grain Sorghum	2	10.68	Switchgrass Mix	2	---
Grain Sorghum	3	11.99	Switchgrass Mix	3	6.32
Grain Sorghum	4	14.45	Switchgrass Mix	4	15.56

Table B.5 Biomass yield for forage study, biofuel cut system, at Hays in 2011.

Treatment	System	Harvest Height (m)	Rep	Yield (Mg ha^{-1})	Harvest Height (m)	Rep	Yield (Mg ha^{-1})
Big Bluestem	Biofuel	0.1	1	5.34	0.2	1	3.49
Big Bluestem	Biofuel	0.1	2	1.13	0.2	2	0.33
Big Bluestem	Biofuel	0.1	3	5.95	0.2	3	1.77
Eastern Gamagrass	Biofuel	0.1	1	4.44	0.2	1	1.11
Eastern Gamagrass	Biofuel	0.1	2	1.07	0.2	2	0.16
Eastern Gamagrass	Biofuel	0.1	3	2.05	0.2	3	0.39
Indiangrass	Biofuel	0.1	1	1.90	0.2	1	0.58
Indiangrass	Biofuel	0.1	2	3.24	0.2	2	0.63
Indiangrass	Biofuel	0.1	3	3.04	0.2	3	1.15
Miscanthus	Biofuel	0.1	1	4.43	0.2	1	1.60
Miscanthus	Biofuel	0.1	2	1.53	0.2	2	0.02
Miscanthus	Biofuel	0.1	3	3.22	0.2	3	0.85
Mixedgrass	Biofuel	0.1	1	3.84	0.2	1	1.89
Mixedgrass	Biofuel	0.1	2	2.43	0.2	2	0.76
Mixedgrass	Biofuel	0.1	3	1.45	0.2	3	0.32
Sand Bluestem	Biofuel	0.1	1	0.96	0.2	1	0.16
Sand Bluestem	Biofuel	0.1	2	2.74	0.2	2	0.56
Sand Bluestem	Biofuel	0.1	3	4.47	0.2	3	2.11
Switchgrass (Blackwell)	Biofuel	0.1	1	1.48	0.2	1	0.24
Switchgrass (Blackwell)	Biofuel	0.1	2	5.80	0.2	2	3.65
Switchgrass (Blackwell)	Biofuel	0.1	3	1.95	0.2	3	1.05
Switchgrass (Pathfinder)	Biofuel	0.1	1	3.70	0.2	1	1.39
Switchgrass (Pathfinder)	Biofuel	0.1	2	4.36	0.2	2	1.58
Switchgrass (Pathfinder)	Biofuel	0.1	3	4.30	0.2	3	1.35

Table B.6 Biomass yield for forage study, haycut system, at Hays in 2011.

Treatment	System	Harvest Height (m)	Rep	Yield (Mg ha^{-1})		
				1st Cut	2nd Cut	Total
Big Bluestem	Hay	0.1	1	2.00	1.48	3.49
Big Bluestem	Hay	0.1	2	0.95	0.99	1.94
Big Bluestem	Hay	0.1	3	1.36	0.46	1.82
Eastern Gamagrass	Hay	0.1	1	1.50	1.60	3.11
Eastern Gamagrass	Hay	0.1	2	1.15	0.62	1.77
Eastern Gamagrass	Hay	0.1	3	1.04	0.45	1.48
Indiangrass	Hay	0.1	1	1.07	0.70	1.76
Indiangrass	Hay	0.1	2	1.91	0.33	2.24
Indiangrass	Hay	0.1	3	1.92	1.38	3.30
Miscanthus	Hay	0.1	1	1.48	0.52	1.99
Miscanthus	Hay	0.1	2	0.70	0.69	1.39
Miscanthus	Hay	0.1	3	1.71	0.56	2.27
Mixedgrass	Hay	0.1	1	2.72	1.70	4.42
Mixedgrass	Hay	0.1	2	0.50	2.66	3.16
Mixedgrass	Hay	0.1	3	0.85	3.93	4.79
Sand Bluestem	Hay	0.1	1	0.47	0.88	1.34
Sand Bluestem	Hay	0.1	2	1.33	0.46	1.79
Sand Bluestem	Hay	0.1	3	1.59	0.75	2.34
Switchgrass (Blackwell)	Hay	0.1	1	0.92	1.71	2.63
Switchgrass (Blackwell)	Hay	0.1	2	1.99	3.45	5.43
Switchgrass (Blackwell)	Hay	0.1	3	1.19	3.13	4.32
Switchgrass (Pathfinder)	Hay	0.1	1	1.61	2.64	4.25
Switchgrass (Pathfinder)	Hay	0.1	2	1.77	2.33	4.10
Switchgrass (Pathfinder)	Hay	0.1	3	0.64	1.34	1.99
Big Bluestem	Hay	0.2	1	0.93	1.00	1.93
Big Bluestem	Hay	0.2	2	0.29	0.41	0.70
Big Bluestem	Hay	0.2	3	0.40	0.30	0.70
Eastern Gamagrass	Hay	0.2	1	0.97	1.41	2.38
Eastern Gamagrass	Hay	0.2	2	0.15	0.51	0.66
Eastern Gamagrass	Hay	0.2	3	0.46	0.45	0.91
Indiangrass	Hay	0.2	1	0.33	0.22	0.55
Indiangrass	Hay	0.2	2	1.63	0.10	1.73
Indiangrass	Hay	0.2	3	0.45	0.38	0.83
Miscanthus	Hay	0.2	1	0.16	0.25	0.42
Miscanthus	Hay	0.2	2	0.88	0.12	1.00

Miscanthus	Hay	0.2	3	0.23	0.38	0.61
Mixedgrass	Hay	0.2	1	0.95	0.29	1.25
Mixedgrass	Hay	0.2	2	1.25	0.55	1.80
Mixedgrass	Hay	0.2	3	0.55	1.29	1.84
Sand Bluestem	Hay	0.2	1	0.89	0.25	1.14
Sand Bluestem	Hay	0.2	2	0.32	0.28	0.60
Sand Bluestem	Hay	0.2	3	0.48	0.14	0.63
Switchgrass (Blackwell)	Hay	0.2	1	0.16	0.10	0.26
Switchgrass (Blackwell)	Hay	0.2	2	0.71	2.02	2.72
Switchgrass (Blackwell)	Hay	0.2	3	1.03	0.71	1.74
Switchgrass (Pathfinder)	Hay	0.2	1	0.65	1.63	2.28
Switchgrass (Pathfinder)	Hay	0.2	2	0.56	0.62	1.18
Switchgrass (Pathfinder)	Hay	0.2	3	1.48	0.39	1.87

Table B.7 Biomas yield for forage study at Manhattan in 2011.

Treatment	System	Harvest Height (m)	Rep	Yield (Mg ha^{-1})		
				1st Cut	2nd Cut	Total
Switchgrass (Kanlow)	Biofuel	0.1	1	---	7.30	7.30
Switchgrass (Kanlow)	Biofuel	0.1	2	---	7.82	7.82
Switchgrass (Kanlow)	Biofuel	0.1	3	---	5.82	5.82
Switchgrass (Kanlow)	Biofuel	0.2	1	---	7.01	7.01
Switchgrass (Kanlow)	Biofuel	0.2	2	---	6.82	6.82
Switchgrass (Kanlow)	Biofuel	0.2	3	---	6.22	6.22
Switchgrass (Kanlow)	Hay	0.1	1	2.39	5.72	8.11
Switchgrass (Kanlow)	Hay	0.1	2	2.46	6.43	8.89
Switchgrass (Kanlow)	Hay	0.1	3	1.68	5.35	7.03
Switchgrass (Kanlow)	Hay	0.2	1	1.39	5.38	6.77
Switchgrass (Kanlow)	Hay	0.2	2	1.37	5.84	7.21
Switchgrass (Kanlow)	Hay	0.2	3	1.20	5.31	6.50

Table B.8 CP, NDF, NDFD, and Ash for forage study, biofuel cut system, at Hays in 2011.

Treatment	System	Harvest Height (m)	Rep	Crude Protein (g kg^{-1})	NDF (g kg^{-1})	NDF proportion of NDF (g kg^{-1})	Ash (g kg^{-1})
Big Bluestem	Biofuel	0.1	1	57	767	460	144
Big Bluestem	Biofuel	0.1	2	59	775	560	157
Big Bluestem	Biofuel	0.1	3	54	750	480	95
Eastern Gamagrass	Biofuel	0.1	1	43	775	490	141
Eastern Gamagrass	Biofuel	0.1	2	55	764	490	150
Eastern Gamagrass	Biofuel	0.1	3	54	736	470	131
Indiangrass	Biofuel	0.1	1	59	736	510	129
Indiangrass	Biofuel	0.1	2	52	739	530	150
Indiangrass	Biofuel	0.1	3	52	748	520	138
Miscanthus	Biofuel	0.1	1	40	797	480	147
Miscanthus	Biofuel	0.1	2	43	758	500	119
Miscanthus	Biofuel	0.1	3	49	748	480	110
Mixedgrass	Biofuel	0.1	1	55	735	460	155
Mixedgrass	Biofuel	0.1	2	63	793	510	202
Mixedgrass	Biofuel	0.1	3	59	739	400	108
Sand Bluestem	Biofuel	0.1	1	48	798	490	123
Sand Bluestem	Biofuel	0.1	2	47	795	490	110
Sand Bluestem	Biofuel	0.1	3	44	799	450	92
Switchgrass (Blackwell)	Biofuel	0.1	1	44	757	450	121
Switchgrass (Blackwell)	Biofuel	0.1	2	32	788	460	137
Switchgrass (Blackwell)	Biofuel	0.1	3	41	746	440	100
Switchgrass (Pathfinder)	Biofuel	0.1	1	38	756	480	120
Switchgrass (Pathfinder)	Biofuel	0.1	2	41	770	420	125
Switchgrass (Pathfinder)	Biofuel	0.1	3	47	746	470	110

Big Bluestem	Biofuel	0.2	1	48	777	460	159
Big Bluestem	Biofuel	0.2	2	55	747	530	109
Big Bluestem	Biofuel	0.2	3	70	708	340	93
Eastern Gamagrass	Biofuel	0.2	1	39	773	490	158
Eastern Gamagrass	Biofuel	0.2	2	59	730	480	118
Eastern Gamagrass	Biofuel	0.2	3	52	733	470	147
Indiangrass	Biofuel	0.2	1	57	741	500	116
Indiangrass	Biofuel	0.2	2	50	738	490	117
Indiangrass	Biofuel	0.2	3	54	734	540	122
Miscanthus	Biofuel	0.2	1	38	776	490	142
Miscanthus	Biofuel	0.2	2	44	762	480	112
Miscanthus	Biofuel	0.2	3	50	736	500	102
Mixedgrass	Biofuel	0.2	1	54	757	420	107
Mixedgrass	Biofuel	0.2	2	72	731	490	116
Mixedgrass	Biofuel	0.2	3	60	728	390	98
Sand Bluestem	Biofuel	0.2	1	52	783	460	117
Sand Bluestem	Biofuel	0.2	2	47	760	450	93
Sand Bluestem	Biofuel	0.2	3	45	741	410	69
Switchgrass (Blackwell)	Biofuel	0.2	1	51	740	420	89
Switchgrass (Blackwell)	Biofuel	0.2	2	35	763	430	97
Switchgrass (Blackwell)	Biofuel	0.2	3	37	743	430	97
Switchgrass (Pathfinder)	Biofuel	0.2	1	36	757	450	128
Switchgrass (Pathfinder)	Biofuel	0.2	2	43	725	480	104

Table B.9 TDN, Ca, P, and K data for forage study, biofuel cut system, at Hays in 2011.

Treatment	System	Harvest Height (m)	Rep	TDN (g kg^{-1})	Ca (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})
Big Bluestem	Biofuel	0.1	1	512	4.10	0.50	6.40
Big Bluestem	Biofuel	0.1	2	542	4.10	0.40	6.60
Big Bluestem	Biofuel	0.1	3	502	4.10	0.60	7.00
Eastern Gamagrass	Biofuel	0.1	1	547	3.90	0.50	11.90
Eastern Gamagrass	Biofuel	0.1	2	536	3.80	0.50	10.70
Eastern Gamagrass	Biofuel	0.1	3	502	3.60	0.60	9.60
Indiangrass	Biofuel	0.1	1	536	3.90	0.60	8.50
Indiangrass	Biofuel	0.1	2	516	3.90	0.40	8.20
Indiangrass	Biofuel	0.1	3	510	3.60	0.40	7.70
Miscanthus	Biofuel	0.1	1	555	3.50	0.40	6.80
Miscanthus	Biofuel	0.1	2	519	4.00	0.60	7.30
Miscanthus	Biofuel	0.1	3	507	3.20	0.70	4.30
Mixedgrass	Biofuel	0.1	1	529	5.80	0.60	13.50
Mixedgrass	Biofuel	0.1	2	524	3.20	0.30	9.60
Mixedgrass	Biofuel	0.1	3	465	4.10	0.70	8.60
Sand Bluestem	Biofuel	0.1	1	550	3.40	0.40	5.70
Sand Bluestem	Biofuel	0.1	2	526	2.90	0.50	5.00
Sand Bluestem	Biofuel	0.1	3	501	3.00	0.70	8.50
Switchgrass (Blackwell)	Biofuel	0.1	1	552	3.90	0.70	5.90
Switchgrass (Blackwell)	Biofuel	0.1	2	566	3.50	0.50	6.00
Switchgrass (Blackwell)	Biofuel	0.1	3	510	3.80	0.80	6.20
Switchgrass (Pathfinder)	Biofuel	0.1	1	566	4.10	0.70	6.20
Switchgrass (Pathfinder)	Biofuel	0.1	2	547	3.50	0.70	7.50
Switchgrass (Pathfinder)	Biofuel	0.1	3	531	3.90	0.70	4.70
Big Bluestem	Biofuel	0.2	1	505	4.10	0.30	8.80

Big Bluestem	Biofuel	0.2	2	511	4.30	0.60	3.90
Big Bluestem	Biofuel	0.2	3	468	7.00	0.80	10.10
Eastern Gamagrass	Biofuel	0.2	1	528	3.90	0.40	12.80
Eastern Gamagrass	Biofuel	0.2	2	527	4.40	0.70	8.10
Eastern Gamagrass	Biofuel	0.2	3	512	3.90	0.50	9.30
Indiangrass	Biofuel	0.2	1	506	3.40	0.60	7.80
Indiangrass	Biofuel	0.2	2	513	4.10	0.60	7.80
Indiangrass	Biofuel	0.2	3	514	3.80	0.50	7.70
Miscanthus	Biofuel	0.2	1	559	3.70	0.30	5.40
Miscanthus	Biofuel	0.2	2	524	3.80	0.60	6.20
Miscanthus	Biofuel	0.2	3	534	3.40	0.80	5.60
Mixedgrass	Biofuel	0.2	1	471	3.40	0.70	9.60
Mixedgrass	Biofuel	0.2	2	544	3.30	1.00	10.80
Mixedgrass	Biofuel	0.2	3	477	5.50	0.70	11.70
Sand Bluestem	Biofuel	0.2	1	528	3.50	0.50	8.80
Sand Bluestem	Biofuel	0.2	2	509	3.50	0.60	5.40
Sand Bluestem	Biofuel	0.2	3	500	4.80	0.70	7.80
Switchgrass (Blackwell)	Biofuel	0.2	1	549	3.90	0.90	5.90
Switchgrass (Blackwell)	Biofuel	0.2	2	541	4.00	0.70	5.70
Switchgrass (Blackwell)	Biofuel	0.2	3	523	3.70	0.80	4.70
Switchgrass (Pathfinder)	Biofuel	0.2	1	549	3.80	0.60	5.40
Switchgrass (Pathfinder)	Biofuel	0.2	2	563	4.40	0.80	4.50
Switchgrass (Pathfinder)	Biofuel	0.2	3	540	3.70	0.70	4.60

Table B.10 CP, NDF, NDFD, and Ash for forage study, hay cut system, at Hays in 2011.

Treatment	System	Harvest Height (m)	Rep	Crude Protein (g kg^{-1})	NDF (g kg^{-1})	NDF proportion of NDF (g kg^{-1})	Ash (g kg^{-1})
Big Bluestem	Hay	0.1	1	78	659	485	101
Big Bluestem	Hay	0.1	2	78	679	530	112
Big Bluestem	Hay	0.1	3	75	699	493	103
Eastern Gamagrass	Hay	0.1	1	83	661	499	112
Eastern Gamagrass	Hay	0.1	2	77	686	481	120
Eastern Gamagrass	Hay	0.1	3	71	691	495	122
Indiangrass	Hay	0.1	1	64	684	532	117
Indiangrass	Hay	0.1	2	60	722	525	144
Indiangrass	Hay	0.1	3	80	687	558	134
Miscanthus	Hay	0.1	1	67	688	515	111
Miscanthus	Hay	0.1	2	71	675	530	119
Miscanthus	Hay	0.1	3	88	640	547	104
Mixedgrass	Hay	0.1	1	66	721	478	119
Mixedgrass	Hay	0.1	2	76	700	515	132
Mixedgrass	Hay	0.1	3	75	686	397	107
Sand Bluestem	Hay	0.1	1	76	672	486	93
Sand Bluestem	Hay	0.1	2	63	743	481	105
Sand Bluestem	Hay	0.1	3	64	723	499	98
Switchgrass (Blackwell)	Hay	0.1	1	74	654	502	86
Switchgrass (Blackwell)	Hay	0.1	2	75	667	501	101
Switchgrass (Blackwell)	Hay	0.1	3	87	643	520	97
Switchgrass (Pathfinder)	Hay	0.1	1	75	646	520	98
Switchgrass (Pathfinder)	Hay	0.1	2	70	673	500	119
Switchgrass (Pathfinder)	Hay	0.1	3	77	655	498	97

Big Bluestem	Hay	0.2	1	77	673	510	98
Big Bluestem	Hay	0.2	2	81	645	542	99
Big Bluestem	Hay	0.2	3	73	682	494	105
Eastern Gamagrass	Hay	0.2	1	86	664	484	106
Eastern Gamagrass	Hay	0.2	2	105	617	540	106
Eastern Gamagrass	Hay	0.2	3	79	670	490	98
Indiangrass	Hay	0.2	1	71	714	544	133
Indiangrass	Hay	0.2	2	54	737	478	116
Indiangrass	Hay	0.2	3	71	679	546	122
Miscanthus	Hay	0.2	1	54	722	463	110
Miscanthus	Hay	0.2	2	63	683	501	118
Miscanthus	Hay	0.2	3	81	642	542	93
Mixedgrass	Hay	0.2	1	75	666	467	94
Mixedgrass	Hay	0.2	2	69	712	402	113
Mixedgrass	Hay	0.2	3	81	650	480	96
Sand Bluestem	Hay	0.2	1	57	769	439	119
Sand Bluestem	Hay	0.2	2	71	705	497	88
Sand Bluestem	Hay	0.2	3	60	706	448	87
Switchgrass (Blackwell)	Hay	0.2	1	72	692	425	88
Switchgrass (Blackwell)	Hay	0.2	2	90	632	543	100
Switchgrass (Blackwell)	Hay	0.2	3	59	672	467	93
Switchgrass (Pathfinder)	Hay	0.2	1	80	647	514	89
Switchgrass (Pathfinder)	Hay	0.2	2	69	661	488	94
Switchgrass (Pathfinder)	Hay	0.2	3	62	694	473	103

Table B.11 TDN, Ca, P, and K for forage study, hay cut system, at Hays in 2011.

Treatment	System	Harvest Height (m)	Rep	TDN ($g\ kg^{-1}$)	Ca ($g\ kg^{-1}$)	P ($g\ kg^{-1}$)	K ($g\ kg^{-1}$)
Big Bluestem	Hay	0.1	1	532	5.42	1.12	12.43
Big Bluestem	Hay	0.1	2	553	4.21	1.11	10.32
Big Bluestem	Hay	0.1	3	529	4.65	0.95	9.53
Eastern Gamagrass	Hay	0.1	1	545	4.40	1.32	15.97
Eastern Gamagrass	Hay	0.1	2	551	4.23	1.12	13.33
Eastern Gamagrass	Hay	0.1	3	535	4.27	1.08	11.30
Indiangrass	Hay	0.1	1	521	4.31	1.00	11.32
Indiangrass	Hay	0.1	2	509	3.75	0.59	8.98
Indiangrass	Hay	0.1	3	539	4.31	0.94	13.27
Miscanthus	Hay	0.1	1	541	3.90	1.06	9.55
Miscanthus	Hay	0.1	2	545	4.10	1.25	12.96
Miscanthus	Hay	0.1	3	571	4.37	1.58	14.55
Mixedgrass	Hay	0.1	1	498	3.90	0.94	11.33
Mixedgrass	Hay	0.1	2	542	3.70	1.29	15.31
Mixedgrass	Hay	0.1	3	513	6.34	1.10	14.24
Sand Bluestem	Hay	0.1	1	537	4.10	1.36	13.46
Sand Bluestem	Hay	0.1	2	523	3.48	0.83	9.12
Sand Bluestem	Hay	0.1	3	535	3.96	0.95	10.36
Switchgrass (Blackwell)	Hay	0.1	1	568	4.28	1.45	11.65
Switchgrass (Blackwell)	Hay	0.1	2	565	4.06	1.45	13.69
Switchgrass (Blackwell)	Hay	0.1	3	581	4.67	1.60	14.99
Switchgrass (Pathfinder)	Hay	0.1	1	560	4.65	1.38	11.18
Switchgrass (Pathfinder)	Hay	0.1	2	574	3.94	1.30	11.95
Switchgrass (Pathfinder)	Hay	0.1	3	567	4.09	1.44	11.95
Big Bluestem	Hay	0.2	1	535	4.78	1.17	13.12

Big Bluestem	Hay	0.2	2	555	4.95	1.28	11.87
Big Bluestem	Hay	0.2	3	529	4.10	1.10	10.99
Eastern Gamagrass	Hay	0.2	1	543	4.70	1.37	16.90
Eastern Gamagrass	Hay	0.2	2	582	5.15	1.70	16.93
Eastern Gamagrass	Hay	0.2	3	559	4.25	1.29	12.10
Indiangrass	Hay	0.2	1	544	4.12	0.86	13.32
Indiangrass	Hay	0.2	2	494	4.14	0.57	8.75
Indiangrass	Hay	0.2	3	535	4.02	1.05	14.11
Miscanthus	Hay	0.2	1	519	3.78	0.77	9.62
Miscanthus	Hay	0.2	2	527	5.23	1.04	11.65
Miscanthus	Hay	0.2	3	575	4.16	1.47	13.27
Mixedgrass	Hay	0.2	1	525	4.05	1.36	14.37
Mixedgrass	Hay	0.2	2	484	5.21	0.93	11.63
Mixedgrass	Hay	0.2	3	552	4.69	1.65	18.58
Sand Bluestem	Hay	0.2	1	481	3.32	0.69	11.76
Sand Bluestem	Hay	0.2	2	559	3.85	1.16	12.57
Sand Bluestem	Hay	0.2	3	502	3.72	1.01	10.01
Switchgrass (Blackwell)	Hay	0.2	1	539	4.57	1.16	10.08
Switchgrass (Blackwell)	Hay	0.2	2	591	4.46	1.72	16.05
Switchgrass (Blackwell)	Hay	0.2	3	542	4.09	1.27	9.94
Switchgrass (Pathfinder)	Hay	0.2	1	572	4.31	1.53	13.43
Switchgrass (Pathfinder)	Hay	0.2	2	567	4.47	1.33	9.61
Switchgrass (Pathfinder)	Hay	0.2	3	554	4.43	0.97	7.18

Table B.12 Forage quality data, for forage study at Manhattan in 2011.

Treatment	System	Harvest Height (m)	Rep	Crude Protein	NDF (g kg^{-1})	NDF proportion of NDF (g kg^{-1})	Ash (g kg^{-1})	TDN (g kg^{-1})	Ca (g kg^{-1})	p (g kg^{-1})	K (g kg^{-1})
Switchgrass (Kanlow)	Biofuel	0.1	1	32	760	340	69	477	3.00	0.90	6.00
Switchgrass (Kanlow)	Biofuel	0.1	2	31	751	370	77	494	3.20	0.80	5.60
Switchgrass (Kanlow)	Biofuel	0.1	3	38	738	370	90	511	4.10	0.80	5.70
Switchgrass (Kanlow)	Biofuel	0.2	1	33	770	340	67	489	2.80	0.80	6.20
Switchgrass (Kanlow)	Biofuel	0.2	2	32	752	350	65	488	3.10	0.90	5.30
Switchgrass (Kanlow)	Biofuel	0.2	3	33	742	390	136	518	3.80	0.60	6.00
Switchgrass (Kanlow)	Hay	0.1	1	75	662	454	83	559	3.95	1.62	12.89
Switchgrass (Kanlow)	Hay	0.1	2	75	653	474	92	559	3.62	1.66	13.26
Switchgrass (Kanlow)	Hay	0.1	3	71	640	464	85	578	3.73	1.48	11.74
Switchgrass (Kanlow)	Hay	0.2	1	75	641	473	69	581	3.53	1.80	11.91
Switchgrass (Kanlow)	Hay	0.2	2	78	661	466	83	561	3.62	1.59	13.47
Switchgrass (Kanlow)	Hay	0.2	3	76	639	464	65	580	3.66	1.69	12.13

Appendix C - Figures

Figure C.1 Mariotte bottle

Figure C.2 Spring 2011 measured infiltration.

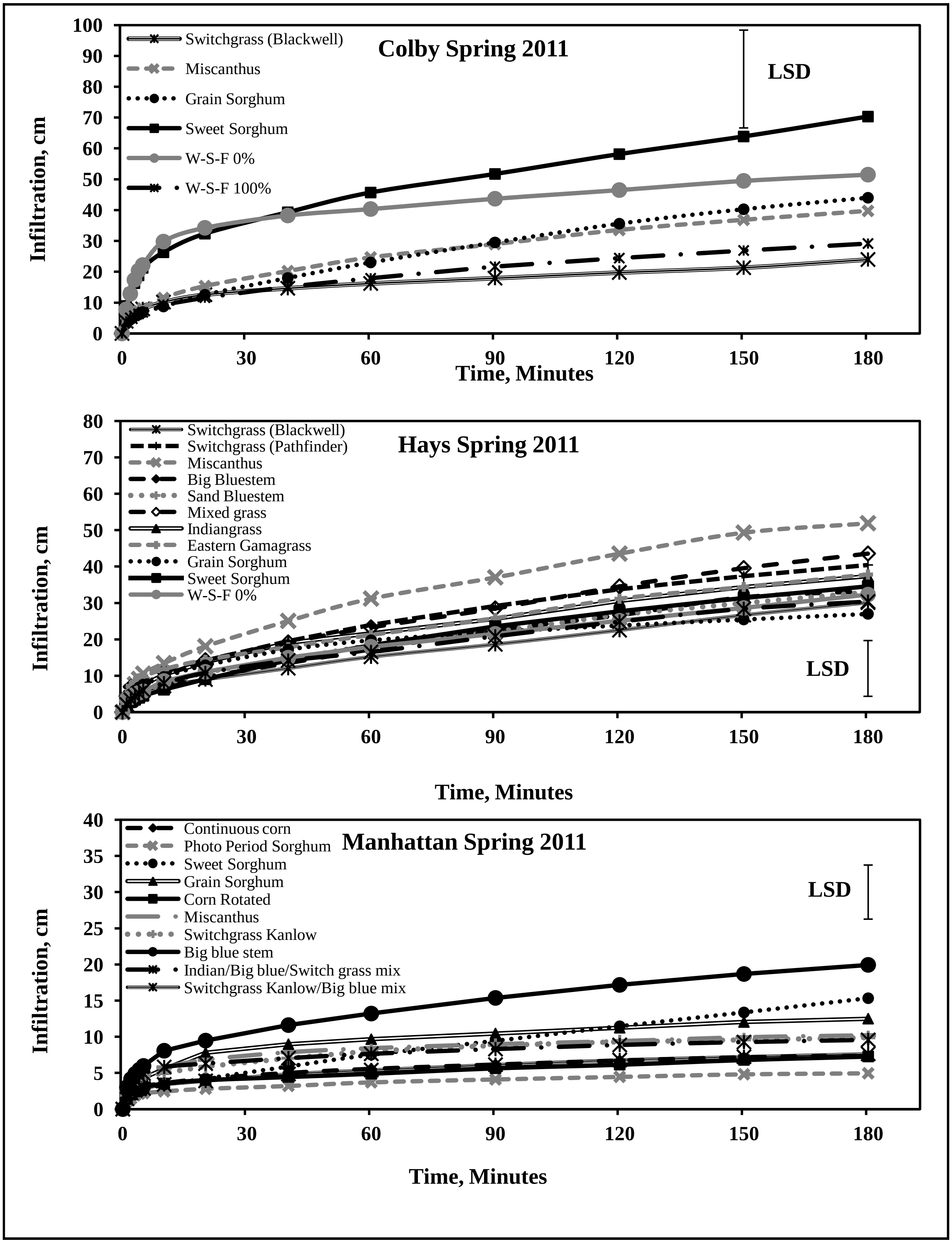


Figure C.3 Water retention curves at Colby, KS

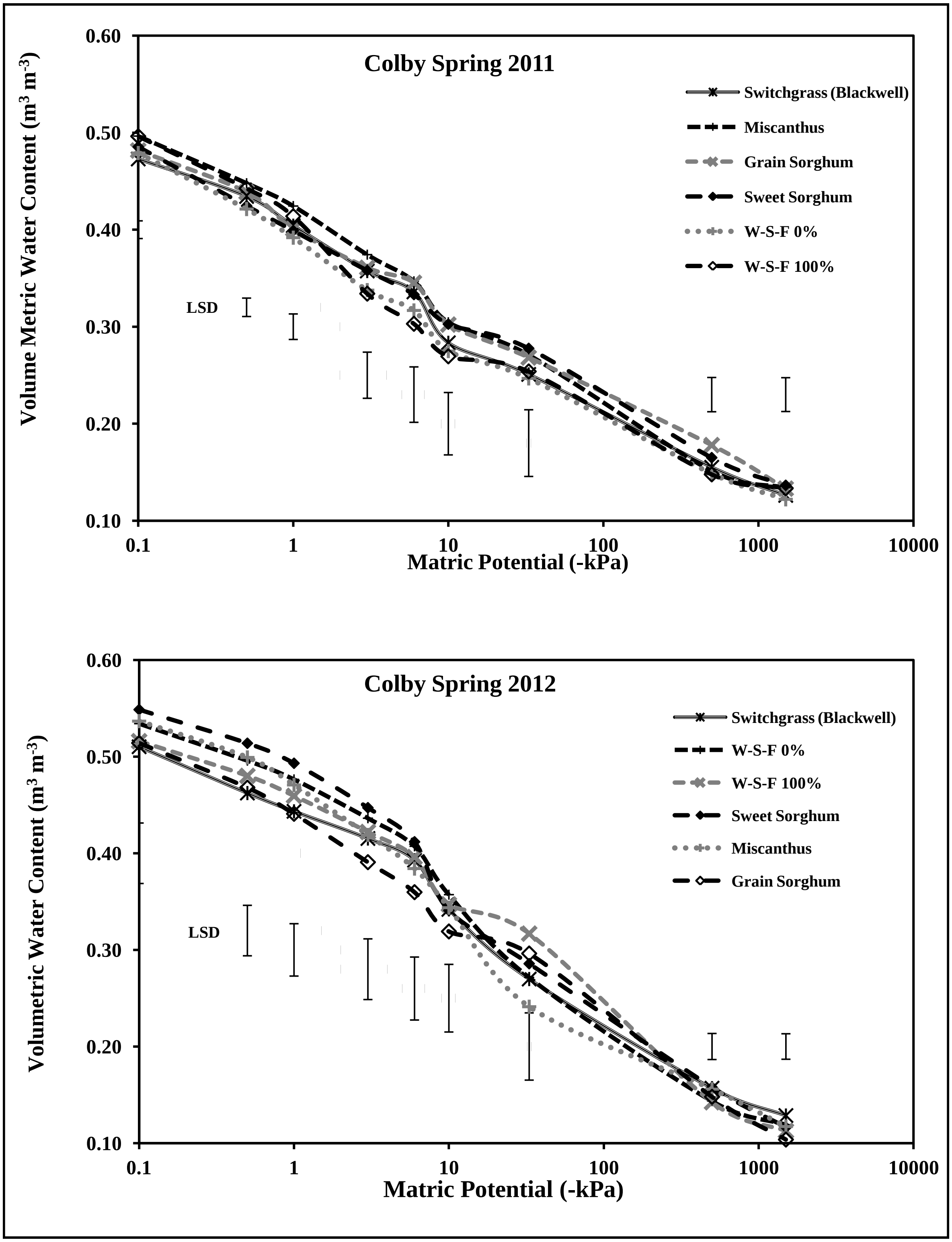


Figure C.4 Water retention curves at Hays, KS

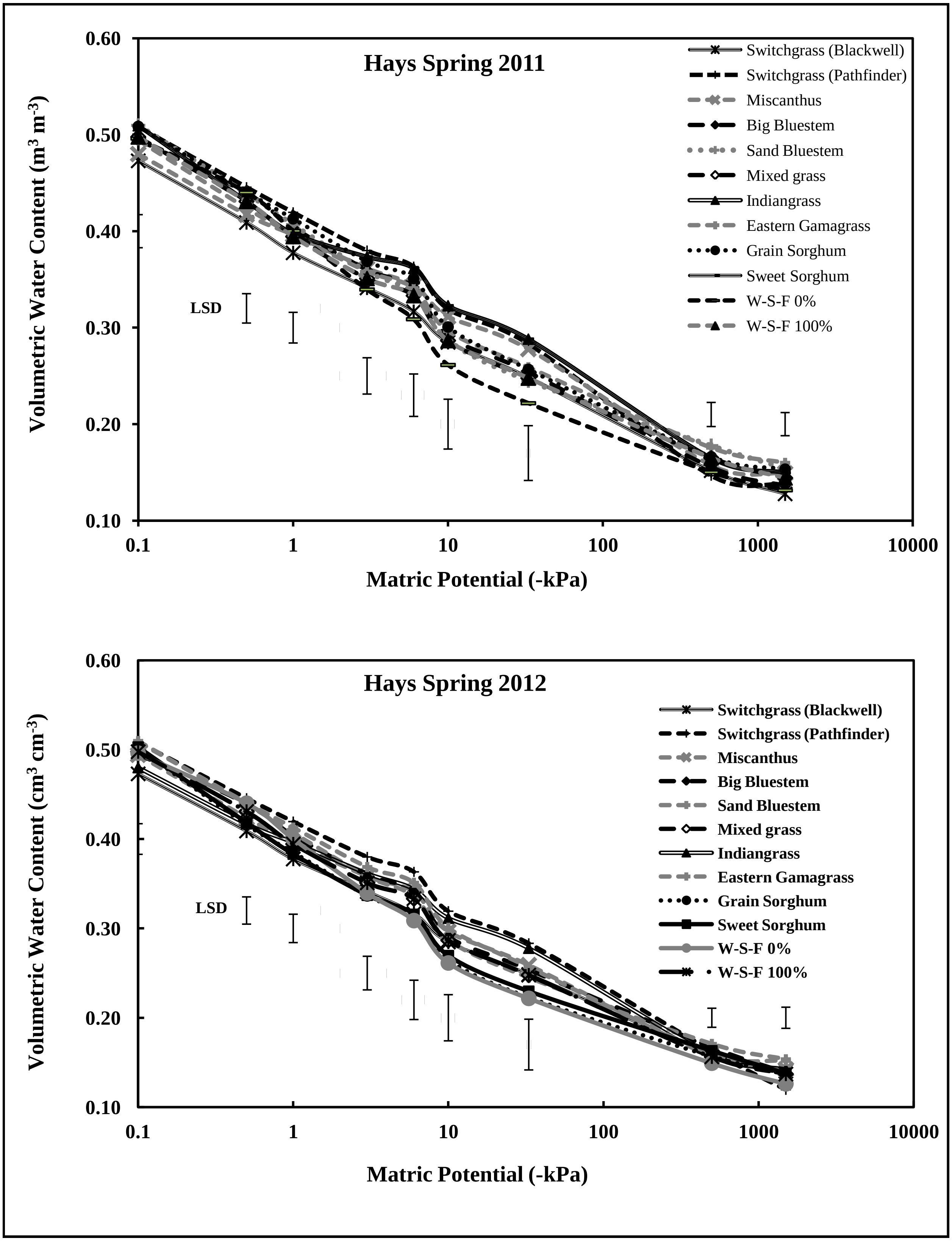
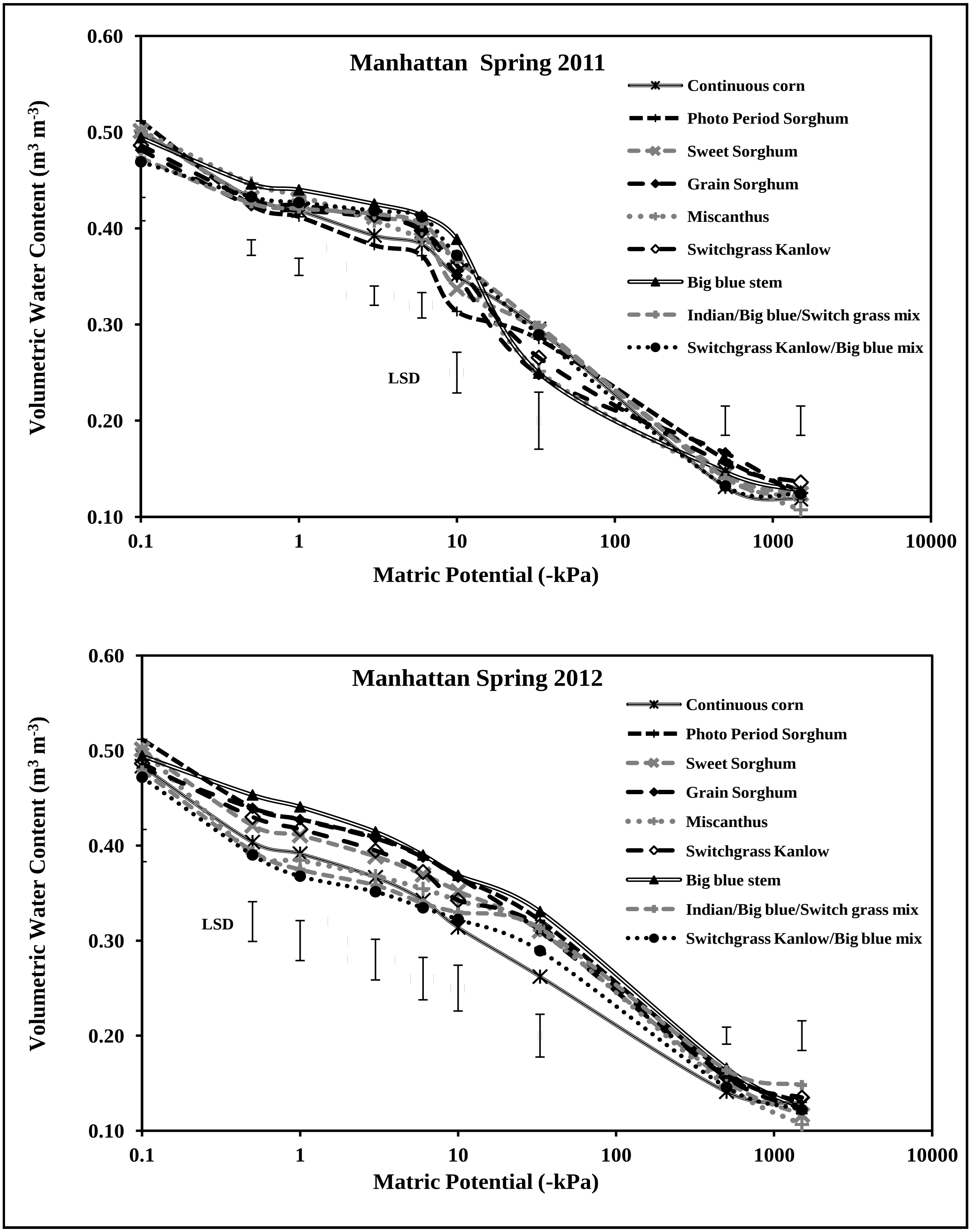


Figure C.5 Water retention curves at Manhattan, KS



Appendix D - SAS Codes

Wet Aggregate Stability and Water retention

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

```
dm 'log;clear;out;clear';
options nocenter;
data ColbyF10WSA;
input Trt Rep     A B C D E F;
datalines;
;
proc sort data=ColbyF10WSA;
by trt;
proc univariate data = ColbyS10WSA normal plot;
   var A;
   by trt;
proc mixed data=ColbyS10WSA;
class trt rep;
model A=trt;
random rep;
lsmeans trt /diff;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'c:\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
proc univariate data = ColbyS10WSA normal plot;
   var B;
   by trt;
proc mixed data=ColbyS10WSA;
class trt rep;
model B=trt;
random rep;
lsmeans trt /diff;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'c:\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
 proc univariate data = ColbyS10WSA normal plot;
   var C;
   by trt;
proc mixed data=ColbyS10WSA;
class trt rep;
model C=trt;
random rep;
lsmeans trt /diff;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
```

```
run;
%include 'c:\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
proc univariate data = ColbyS10WSA normal plot;
   var D;
   by trt;
proc mixed data=ColbyS10WSA;
class trt rep;
model D=trt;
random rep;
lsmeans trt /diff;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'c:\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
proc univariate data = ColbyS10WSA normal plot;
   var E;
   by trt;
proc mixed data=ColbyS10WSA;
class trt rep;
model E=trt;
random rep;
lsmeans trt /diff;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'c:\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
proc univariate data = ColbyS10WSA normal plot;
   var F;
   by trt;
proc mixed data=ColbyS10WSA; 172
class trt rep;
model F=trt;
random rep;
lsmeans trt /diff;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'c:\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
```

MWD, GMD, %<.84mm, Bulk Density, AWC, VWC

```
dm 'log;clear;out;clear';
```

```
options nocenter;
data ColbyS11GMD;
input Trt Rep  GMD;
datalines;
;
proc sort data=ColbyS11GMD;
by trt;
proc univariate data = Colby1BD normal plot;
   var GMD;
   by trt;
proc mixed data=ColbyS11GMD;
class trt rep;
model GMD=trt;
random rep;
lsmeans trt /diff;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'c:\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
```

Total Carbon and Nitrogen

```
dm 'log;clear;out;clear';
options nocenter;
data ColbyF10;
input Trt Rep  TN TC;
datalines; 173
;
proc sort data=ColbyF10;
by trt;
proc univariate data = ColbyF10 normal plot;
   var TN;
   by trt;
proc mixed data=ColbyF10;
class trt rep;
model TN=trt;
random rep;
lsmeans trt /diff;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'c:\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
proc univariate data = ColbyF10 normal plot;
   var TC;
   by trt;
```

```
proc mixed data=ColbyF10;
class trt rep;
model TC=trt;
random rep;
lsmeans trt /diff;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'c:\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
```

Forage quality ;

```
dm 'log;clear;out;clear';
options nocenter;
data Forage Quality;
input species$ system$ height rep yield cp ndf tdn ca p k ndfd ash;
datalines;
;
proc mixed data=Forage Quality;
class rep species system height;
model yield= species system system*species height height*species height*system
height*species*system;
random rep rep*species;
lsmeans height species system*height*species/pdiff;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'c:\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
proc mixed data=Forage Quality;
class rep species system height;
model cp= species system system*species height height*species height*system
height*species*system;
random rep rep*species;
lsmeans system species system*species/pdiff;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'c:\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
proc mixed data=Forage Quality;
class rep species system height;
model ndf= species system system*species height height*species height*system
height*species*system;
random rep rep*species;
lsmeans species system/pdiff;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'c:\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
proc mixed data=Forage Quality;
class rep species system height;
model tdn= species system system*species height height*species height*system
height*species*system;
random rep rep*species;
lsmeans species system/pdiff;
```

```
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'c:\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
proc mixed data=Forage Quality;
class rep species system height;
model ca= species system system*species height height*species height*system
height*species*system;
random rep rep*species;
lsmeans species system/pdiff;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'c:\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
proc mixed data=Forage Quality;
class rep species system height;
model p= species system system*species height height*species height*system
height*species*system;
random rep rep*species;
lsmeans species system/pdiff;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'c:\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
proc mixed data=Forage Quality;
class rep species system height;
model k= species system system*species height height*species height*system
height*species*system;
random rep rep*species;
lsmeans species system/pdiff;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'c:\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
proc mixed data=Forage Quality;
class rep species system height;
model ndfd= species system system*species height height*species height*system
height*species*system;
random rep rep*species;
lsmeans species system/pdiff;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
```

```
run;
%include 'c:\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
proc mixed data=Forage Quality;
class rep species system height;
model ash= species system system*species height height*species height*system
height*species*system;
random rep rep*species;
lsmeans species system/pdiff;
ods output diffs=ppp lsmeans=mmm;
ods listing exclude diffs lsmeans;
run;
%include 'c:\pdmix800.sas';
%pdmix800(ppp,mmm,alpha=.05,sort=yes);
```