

**Establishment of switchgrass in corn across a landscape gradient: Establishment, yield,  
and quality of biomass feedstock**

by

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## ABSTRACT

Biofuel production in the United States is expected to offset a significant portion of current fuel use through continued use of corn (*Zea mays* L.) grain and increasingly from alternative feedstocks. Switchgrass (*Panicum virgatum* L.) is one such species with potential to be used as an alternative feedstock, but establishment is slow and requires long term commitment of land to reach maximum productivity. Switchgrass can be established while producing a corn crop using 2-4-D and atrazine herbicide and seeding switchgrass prior to corn planting, reducing the risk of producing switchgrass as a crop. Relative performance of both corn and switchgrass in the landscape can vary and can influence productivity. An experiment was conducted which examined performance of corn during establishment of ‘Cave-in-Rock’ and ‘Kanlow’ switchgrass, stand frequency in the following year, subsequent yield, and composition of harvested switchgrass biomass across a toposequence of landscape positions. Seeding switchgrass reduced yields from 11.6 Mg·ha<sup>-1</sup> to 9.6 Mg·ha<sup>-1</sup> and from 10.8 Mg·ha<sup>-1</sup> to 8.3 Mg·ha<sup>-1</sup>, for grain and stover, respectively. Establishment stand frequencies were adequate in all landscape positions and frequencies ranging from 39 to 82 percent. Yield and cellulose concentration of subsequent year switchgrass biomass was greater for ‘Kanlow’. Nitrogen concentration was lower in ‘Kanlow’, but overall N removal was greater due to higher yield. Landscape position effect was demonstrated in the floodplain only, with floodplain position higher in total dry matter yield, ash content, N removal, and cellulose. Floodplain position biomass was lower in hemicellulose and total C. Switchgrass can be established in all landscape position when seeded prior to corn planting, subsequent composition of switchgrass varied by variety and landscape position. More years of data are needed to confirm these biomass quality differences between variety and landscape position.

## Chapter 1

### GENERAL INTRODUCTION

Bioenergy production is a complex economic, social, and biogeochemical phenomenon which has gained attention for a multitude of reasons. Pursuit of carbon-based renewable energy production and the continued and increasing need for food and fiber has created an ever more complex dynamic for world agricultural systems. Responsible bioenergy production can be an important part of the world energy portfolio creating systems which protect fresh water and soil resources while providing for food, feed, fiber, and fuel needs into the future.

#### **Present and Future Biofuel Production**

Bioenergy production in the United States has primarily been focused on development of liquid transportation fuels. At present, corn (*Zea mays* L.) grain-based ethanol is the major source of renewable transportation fuel. The Energy Independence and Security Act (EISA) of 2007 acknowledges the role of corn grain as a part of the future of bioenergy, though cellulose-based fuels are expected to make up the majority of future production expansion (Sissine, 2007). This includes feedstocks from a mixture of annual, perennial, herbaceous, and woody species.

Iowa currently has an important role in the production of biofuels. Iowa produces more corn and ethanol than any other U.S. state. The landscape is dominated by agricultural production, and infrastructure for ethanol production and marketing already exists. In 2009,

13.3 million acres of corn and 9.53 million acres of soybean were harvested in the state (NASS, 2010). Another 1.68 million acres of Conservation Reserve Program (CRP) are enrolled in 2011 (FSA, 2011). Conservation reserve program lands historically have been cropped and may eventually return to production. Many of these CRP acres are on land unsuitable for continuous grain production but may be well suited for harvest of a perennial biomass crop. Perennial biomass crops could be incorporated into Iowa crop production systems providing beneficial ecosystem services while concurrently producing a harvestable energy crop and a return to the landowner.

Corn is often the most productive and profitable crop for growers in Iowa. Infrastructure is in place to produce, market, and transport corn grain on a large scale. There has been a major expansion of corn ethanol refining in Iowa since the mid 1990's and currently 41 plants are producing approximately 3.57 billion gallons per year (Iowa RFA, 2010). Ethanol production and by products annually consume 36 percent of the total US corn crop (NCGA, 2011). Title II of the EISA of 2007 states that, beginning in 2016, all new increases in renewable liquid transportation fuels must be met with advanced biofuels, defined as fuels originating from feedstock other than corn starch. Nonetheless, projections expect that ethanol will be produced by using at least 36 percent of U.S. corn production annually through 2020 (USDA I. A., 2010).

### **Profitability**

Profitable biofuel production is viewed differently by feedstock producers and refinery operators. Both parties must have positive profitability in order to ensure viability of advanced biofuel production. High yielding, quality feedstock must be produced to ensure

adequate returns to the producer as well as feedstock prices that can enable profitable refining. For feedstock producers, compatibility with existing farming systems reduces the need to purchase new equipment and increases profitability of establishing alternative crops (Perrin et al., 2008). Establishment of perennial grasses is relatively slow as roots are establishing and, in future years, account for a significant proportion of total biomass accumulation (Frank et al., 2004). A method that allows establishment while concurrently producing a marketable crop would be a benefit to producers.

### **Crop Yield**

Corn and switchgrass are current and potential future sources of feedstock for bioenergy production. Corn grain is the dominant feedstock currently and corn stover represents the single greatest potentially harvestable feedstock in the U.S. ( U.S. Department of Energy, 2011). In 2009, corn grain yields averaged  $11.4 \text{ Mg}\cdot\text{ha}^{-1}$  (182 bu/ac) in Iowa, and  $11.5 \text{ Mg}\cdot\text{ha}^{-1}$  (184 bu/ac) in Boone County, IA (NASS, 2010; USDA N. A., 2010). These represent record average grain yields for the state at market moisture of 15 percent. Stover yields are thought to be slightly less than dry grain mass yield based on removal and yield studies (Linden et al., 2000; Wilhelm et al., 2004). A conservative estimate of total stover is equal to the total dry weight of corn grain harvested.

Switchgrass is a perennial C4 grass native to North America with potential to produce large quantities of harvestable biomass. Achieving maximum switchgrass yield requires multiple growing seasons. Achieving consistent, maximum yield usually requires two to three growing seasons following establishment (McLaughlin et al., 2005). In Iowa, quality stands have been grown, but the highest yield potential for switchgrass is in the mid-south

and southern United States (Wullschlegel et al., 2010; Heggenstaller, 2009). In Ames, IA, near our study site, yields of over 12 Mg·ha<sup>-1</sup> have been achieved with nitrogen (N) applications of 120 kg N·ha<sup>-1</sup> on established ‘Cave-in-Rock’ stands (Vogel et al., 2002). Field scale experiments in southern Iowa examined stands of ‘Cave-in-Rock’ finding two sites averaging 5.9 and 4.75 Mg·ha<sup>-1</sup>, respectively, when receiving 112 kg N·ha<sup>-1</sup> (Lemus et al., 2008). Within the same region of the state variety trials were conducted finding the cultivar ‘Kanlow’ had significantly greater yield potential than ‘Cave-in-Rock’, with average yields from small plots averaging 13.1 Mg·ha<sup>-1</sup> (Lemus et al., 2002). Switchgrass performs best on land suited for corn production, but maintains relatively high productivity on less productive sites (Varvel et al., 2008).

### **Environmental Impact of Biomass Feedstock Production**

Biomass energy production has many benefits compared to fossil fuels. Carbon (C) originating from biomass has been fixed from the atmosphere, reducing the net C addition to the atmosphere compared to fossil sources. Corn stover represents the largest pool of currently available biomass in the U.S., but environmental impacts of removal are of concern, including soil erosion (Lindstrom, 1986), soil organic matter reduction (Wilhelm et al., 2007), and decreases in future crop yield (Wilhelm et al., 2004). Areas with less slope are better suited for corn stover removal. Greenhouse gas emissions are less understood in terms of stover removal between systems but annual cropping systems with high N fertilizer input have potential to export nitrous oxide (N<sub>2</sub>O) gas as an important component of their GHG emissions. Reduction of excess applied N fertilizer and more efficient uptake by plants are means to reduce the warming potential of N<sub>2</sub>O.

Switchgrass has an extensive root system with the potential to sequester C in the soil (Frank et al., 2004). Perennial grasses also have the benefit of reduced maintenance after establishment compared to annual row crops. This reduces emissions from machinery associated with tillage and seeding. The deep root system of switchgrass gains access to water and nutrients deeper in the soil profile, and consequently, switchgrass generally has lower requirements of fertilizer and pesticides compared to corn. In addition, translocation of nutrients by switchgrass, specifically N, into belowground tissues during pre-dormancy reduces the need for supplemental fertilizer to match removal values, as low N removal occurs with fall harvest (Reynolds et al., 2000). The N cycle is dynamic and N can leave the field as surface runoff, leach to groundwater as nitrate ( $\text{NO}_3^-$ ), volatilize into the atmosphere as ammonia ( $\text{NH}_3$ ) or  $\text{N}_2\text{O}$ , or be taken up into tissues of soil microorganisms or target plants. The energy intensive process of N fertilizer production makes efficient use by crops important as the end goal of biomass production is a net energy gain. The combination of reduced input and extensive root systems reduce the potential of losses and improve N use efficiency of switchgrass compared to annual crops.

### **Need For Site Specific Data**

In order to meet the energy goals set forth by the ESIA of 2007, expanded production of biomass feedstocks are needed. Corn and switchgrass have potential to help meet these production goals in the midwestern USA. The focus of this research examines the potential to establish switchgrass into corn across management zones defined by landscape position. Evaluating the establishment success of productive stands and measuring the yield and quality of harvested material in subsequent years is the goal of this research. Understanding

the relative performance and impact of placement on the landscape in terms of feedstock yield and quality will better inform decision making about placement and establishment methods of switchgrass across an agricultural landscape.

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## Chapter 2

### ESTABLISHMENT SWITCHGRASS IN CORN ACROSS A LANDSCAPE GRADIENT: CORN YIELD AND SWITCHGRASS STAND FREQUENCIES

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#### Abstract

Corn (*Zea mays* L.) and switchgrass (*Panicum virgatum* L.) are C<sub>4</sub> species with potential to be used as biomass feedstocks. Switchgrass does not produce harvestable quantities of biomass during the seeding year, but can be established when seeded prior to corn using 2-4-D and atrazine herbicides. ‘Cave-in-Rock’ and ‘Kanlow’ switchgrass were seeded prior to corn planting in summit, shoulderslope, backslope, toeslope, and floodplain landscape positions. A control treatment with no switchgrass and using glyphosate herbicide was planted to corn only. Corn grain and stover yield was reduced when switchgrass was planted and herbicide treatment differed. Grain yields were reduced from 11.6 Mg·ha<sup>-1</sup> to 9.6 Mg·ha<sup>-1</sup>, and stover yield was reduced from 10.8 Mg·ha<sup>-1</sup> to 8.3 Mg·ha<sup>-1</sup> for control and switchgrass treatments, respectively. Landscape position grain and stover yield differed with the floodplain position having highest yields of both grain and stover. Switchgrass establishment was successful in all positions with both varieties. ‘Cave-in Rock’ had higher stand frequency in all positions except backslope. Seeding switchgrass prior to planting corn is an effective establishment method in all parts of the landscape. Grain and stover can be harvested to offset switchgrass establishment costs, though reductions in yield compared to sole cropped corn using glyphosate are likely.

## Introduction

Switchgrass (*Panicum virgatum* L.) has been identified as a potential biomass feedstock in the United States and has been the subject of a major research effort over the last several decades by the US Department of Energy (McLaughlin and Kszos, 2005).

Switchgrass has been grown in many regional trials, the high yield and adaptability of the species makes it a candidate as a potential bioenergy feedstock (Wullschleger et al., 2010).

The ability of switchgrass to be established from seed provides an advantage over other perennial grasses such as giant miscanthus (*Miscanthus x giganteus*) where most costs associated with miscanthus production are upfront establishment expenses (James et al., 2010). Though establishment is less costly for switchgrass, miscanthus does have greater yield potential in the upper midwest as demonstrated by Heaton et al. (2008). Slow establishment of perennial crops such as switchgrass and miscanthus is a concern for their adoption by producers. Switchgrass plantings do not yield high quantities of above ground biomass in the seeding year and do not reach maximum yield potential until the second or third growing season (Parrish and Fike, 2005). This establishment period represents a delay in the return to the producer or landowner, making establishment a less attractive option compared to annual crops.

Switchgrass has been successfully established using herbicides to control weeds. Broadleaf species are of less concern as many chemical formulations are available to eliminate broadleaf species post emergence. Successful weed control has been achieved with use of atrazine on pure seeded stands (Martin et al., 1982; McKenna et al., 1991).

Switchgrass has been successfully established if seeded preceding corn planting in the same season using atrazine, which provides weed control for both the corn and switchgrass (Hintz

et al., 1998). This strategy did not negatively affect corn-grain or silage yield. There were differences in grain and silage yield between maturity and population treatments, but not seeded versus non seeded treatments. The differences in warm-season grass establishment were more dependent on year and environmental conditions than corn management parameters of population and hybrid maturity. However, the effect of seeded switchgrass on corn-grain and stover yield in different landscape positions is not well understood. Also, management options such as glyphosate resistant crops provide weed control options that were not available at the time their research (Hintz et al., 1998) was conducted. Adoption of these technologies had increased dramatically over this time (ERS, 2009). Whether differences in yield occur between older herbicide formulations versus a full spectrum post-emergence herbicide are unknown. A recent establishment study was performed in the upper great lakes region by Withers (2010) comparing methods for direct seeding of switchgrass. All methodologies including no till, dual roller seeder, and a conventional grain drill were all able to achieve >40 percent coverage in three different seeding dates with exception of an early season date using a dual roller seeder in Michigan. This research also used atrazine and pre-plant glyphosate herbicide to ensure weed control after establishment. Many other studies have examined method of establishment using herbicides and seeding method, but differences in methodologies have shown no clear advantage to any one specific method (Parrish and Fike, 2005).

Corn is the most widely grown crop in Iowa and the U.S. (USDA, 2010). Average Iowa grain yield in 2009 was  $11.4 \text{ Mg}\cdot\text{ha}^{-1}$  (USDA, 2010) the highest average statewide yield on record. Markets for corn grain have been expanded to include starch-based ethanol

production, which consumed 94.2 million tons of corn in 2010 (NCGA, 2011). The Energy Independence and Security Act (EISA) of 2007 mandates increased domestic production of biofuels to 36 billion gallons by 2022 (Sissine, 2007). By 2016 all increases in production must be from advanced biofuels, defined as cellulosic ethanol and other biofuels derived from feedstocks other than corn starch. Advanced biofuel generation includes fuels derived from lignocellulose rich materials such as corn stover and switchgrass. These lignocellulosic materials could be collected from current or newly established resources to increase U.S. renewable fuel production (USDA I. A., 2010). Determining where and with what species these feedstocks will be produced needs greater site specific information.

Location specific concerns of negative consequences of harvesting corn stover include increased erosion (Gilley et al., 1986; Mann et al., 2002; Lindstrom, 1986), reduced future crop productivity (Linden, 2000; Wilhelm W. J., 1986), and reductions in soil organic matter (Wilhelm et al., 2007). The extent to which these risks are realized will depend greatly on the quantity and location of stover collection (Newman et al., 2010) (Blanco-Canqui et al., 2006) (Wilhelm et al., 2004). Corn yield varies both regionally (Williams et al., 2008) and in finer landscape and field levels (Kaspar et al., 2004; Thelemann et al., 2010; Mamani-Pati et al., 2010). Understanding relative performance of corn in different parts of a field is important when determining placement of a perennial alternative crop such as switchgrass. A system that can generate a marketable crop while establishing switchgrass as a perennial feedstock for advanced biofuel production would be advantageous in minimizing establishment risk to producers interested in producing perennial lignocellulosic biofuel feedstocks. Establishment of a perennial would also provide stover harvest in the first year and help establish a perennial in place for the following season. An experiment was

conducted to determine if differences in corn grain and stover yield would occur between corn seeded with switchgrass and corn only. This comparison was conducted across a toposequence including five different landscape positions (summit, shoulderslope, backslope, toeslope, floodplain; from highest to lowest elevation, respectively) to test for site specific impacts on corn grain and stover yield and success of switchgrass establishment.

## **Materials and Methods**

The experiment was conducted at the Committee for Agricultural Development Uthe Farm (41.928, -93.762) in Boone County, IA, in 2009. Plots evaluated are part of a long-term cropping systems comparison of five potential biomass cropping systems across a landscape gradient. Continuous corn and switchgrass established with corn are two of five treatments in this cropping systems comparison. The experiment is a randomized complete block design with five treatments (cropping systems) and three blocks spanning each of five landscape positions. Landscape positions are designated in this experiment solely on relative position in the landscape as defined by elevation along a contour. The site contains two terraces and is adjacent to Big Creek, a tributary of the Des Moines River.

### **Site Establishment**

Preceding this experiment, the site had been a commercial corn and soybean field for more than thirty years. Specific management history is unclear beyond more than a few years prior to onset of the experiment. In 2008, the field was planted to corn and the area to be established as test plots was cut for silage in September. In addition to the historically cropped field, a portion of an area not currently under cultivation between the cropped field and the stream was prepared for plot establishment. This area was sprayed with Round UpWeatherMAX® (Monsanto Company, St.Louis, MO) herbicide at a rate of 2.045 l·ha<sup>-1</sup> a.i. on the same day as silage harvest. Two weeks after spraying, the area was tilled to an approximate depth of 45 cm with a moldboard plow and disked twice before plots were marked. This tilled area comprises only the floodplain landscape position, which was taken out of the Conservation Reserve Program (CRP) for the purpose of this study. Plot

placement is shown in Figs. 1 and 2. Plots are shown overlaid on soil type (Fig. 1) and along an elevation gradient (Fig. 2). Landscape positions are the series of plots that follow a similar contour and generally have a common soil type.

Whole plots were 18.3 m by 24.4 m for corn, and whole plots planted to switchgrass are split into two 18.3 m by 12.2 m subplots for comparison of two switchgrass varieties, 'Kanlow' and 'Cave-in-Rock'. Variety was randomly assigned to the subplot. Seeding of switchgrass preceded corn planting with a no-till grain drill in 20 cm row spacing at a depth of 2.5 cm. Switchgrass was seeded at a rate of  $6.72 \text{ kg}\cdot\text{ha}^{-1}$ . All plots were planted to a glyphosate resistant corn hybrid, 'Pioneer 34A20'. Planting rate into both treatments was done at a rate of  $83,980 \text{ seeds}\cdot\text{ha}^{-1}$  at a depth of 3.81cm on 19 May 2009 using a Kinze 300 (Kinze Manufacturing Inc. Ladora, IA) four row pull type no-till planter with 76 cm row spacing.

All plots received  $150 \text{ kg N}\cdot\text{ha}^{-1}$  surface applied as urea at time of corn planting. Herbicide formulation differed between treatments. The corn only treatment was sprayed with Round-Up WeatherMAX® mixed for  $1.75 \text{ l product}\cdot\text{ha}^{-1}$ , and switchgrass seeded treatments were sprayed with a mixture of Atrazine (2-chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine) using AAtrex Nine-O® (Syngenta Crop Protection, Greensboro, NC) at  $2.24 \text{ kg a.i.}\cdot\text{ha}^{-1}$  and  $1.75 \text{ l}\cdot\text{ha}^{-1}$  2,4-D (2,4-Dichlorophenoxyacetic acid) in amine form. Herbicide application was done at 206.7 Kpa delivering  $129.9 \text{ l}\cdot\text{ha}^{-1}$  of herbicide mixture.

## **Harvest Methodology**

Corn harvest followed maturity as indicated by black layer formation. Wet October weather delayed corn harvest until 27 October. Two samples were taken per plot, each sample consisted of two, 1.52m sections hand harvested randomly within rows four and ten, and rows twenty-three and twenty-nine for sample one and two, respectively. Switchgrass varieties were associated with one of these two samples in each plot. For control plots, the mean of the two samples was used for analysis. Ears were counted, weighed, and dried for grain yield determination. Non-ear plant portions (stover) in the sample area were cut at ~20 cm height, weighed, and a subsample of three plants was bagged and dried for moisture estimates. All ear samples and stover subsamples were dried in a forced air dryer for 72 h at 60 °C and weighed again to estimate moisture content. Ears were shelled using a hand operated grain thresher and both cob weight, grain weight, and grain moisture was recorded for yield estimates. Grain and cob mass was weighed using a K-tron model KS-1 scale (K-Tron process group, Pittman, NJ) and a Farmex MT-16 handheld grain moisture tester (Agritronix Inc., Streetsboro, OH) calibrated for corn grain was used to determine moisture content after threshing. Plots were cleared following sampling using field scale harvesting equipment.

## **Switchgrass Stand Frequency**

Switchgrass stand frequency counts were taken on 28 May 2010 before canopy closure of switchgrass. Switchgrass plants had begun vegetative growth at this time, but elongation of tiller internodes had not yet begun. A frequency grid measuring 1 x 1 m was

subdivided into twenty-five equal squares (20 cm x 20 cm) using the method described by Vogel and Masters (2001). The quadrat was placed randomly in the plot four times for each variety and the number of squares with at least one actively growing switchgrass plant present was recorded. The total of the four observations was divided by 100 to provide an estimate of establishment coverage in the spring after seeding prior to corn. Minimum stand thresholds of 40 percent would imply successful switchgrass establishment for subsequent biomass harvest (Schmer, 2006).

### **Data Analysis**

Yield data were analyzed using SAS (SAS Institute, Cary, NC) GLM procedure. Stover and grain yields were analyzed as a split-block with landscape position and treatment (switchgrass variety or control). Stand frequency for the two switchgrass varieties was analyzed using landscape by variety interaction and least square means were used to compare interactions. Significance was determined at the  $P \leq 0.05$  level between treatments and  $P \leq 0.1$  for landscape positions. Different alpha levels were used as landscape position variability between plots in a single position. Comparisons between treatment and landscape position effects were done using Fisher's least significant differences (LSD) test using the same alpha levels. Stand frequency landscape position by switchgrass variety interaction was analyzed as ten unique treatments to allow comparison between any variety in any landscape position to all other combinations. LSD comparison was performed with alpha level 0.10. Landscape position and treatment were considered fixed factors, and replication was random.

## Results

### Weather

The 2009 growing season was characterized by below-average temperatures and above-average precipitation (Fig. 3). During July and August combined, 102 fewer growing degree days base 10 °C (GDD) than average for these months were accumulated. The month of October also accumulated 112 fewer GDD than average. Above-average precipitation occurred in April, which along with precipitation in May, delayed corn planting until 19 May. Cool temperatures and high October precipitation delayed harvest until 27 October.

### Treatment

Switchgrass and control treatments differed in terms of grain and stover yield (Table 2). Overall yield reduction from  $11.6 \pm 1.97 \text{ Mg}\cdot\text{ha}^{-1}$  of corn grain for the control and  $9.7 \pm 2.6$  and  $9.6 \pm 2.3 \text{ Mg}\cdot\text{ha}^{-1}$  for 'Cave-in-Rock' and 'Kanlow', respectively. Corn seeded to either switchgrass variety did not differ from one another, but corn seeded to either variety differed from the control. Stover yield was  $10.8 \pm 1.9 \text{ Mg}\cdot\text{ha}^{-1}$  for the control and differed from the corn seeded to switchgrass which yielded  $8.2 \pm 1.9$  and  $8.3 \pm 1.8 \text{ Mg}\cdot\text{ha}^{-1}$  for 'Cave-in-Rock' and 'Kanlow', respectively. No difference between grain or stover harvest moistures were observed between any of the treatments.

Establishment was successful in all landscape positions with stand frequencies ranging from 39 to 82 percent. The two varieties did not differ within any given landscape position as differences between varieties were not greater than the LSD of 24 percent. (Table

3). 'Kanlow' had greater establishment frequency only in the backslope as 'Cave-in-Rock' had greater, but not significantly different, stand frequencies in all other positions.

### **Landscape Position**

F tests (Table 1) in the analysis of variance were calculated using the landscape position by replication interaction as the error resulted in low F values as there was high mean squared values for the error term. Moisture values had much smaller mean squared error values. While moisture was the same within landscape positions there was much variation in the yield values of grain and stover indicated by high mean square values for the landscape position by replication interaction. Though the overall means square was high for the interaction, landscape position means were homogeneous ( $P>0.01$ ) as indicated by Bartlett's test of homogeneity (data not shown). This variability is probable given the inherent spatial separation of the plots in this experiment. Also the small number of experimental units enables the deviations to be sensitive to outliers in the data. The effect of landscape position was found to have differences in means for all parameters measured using Fisher's LSD tests with  $\alpha=0.1$  (Table 2).

Highest grain and stover yields were observed in the floodplain. The lowest grain yields were observed on the backslope position which was different from the floodplain. Lowest stover yields were observed in the toeslope position. Toeslope, backslope, and shoulderslope stover yields were all different than the floodplain. The floodplain position had significantly higher stover moisture content than all other positions, though grain moisture was the same in all positions except the summit which was lower. Switchgrass establishment between landscape positions differed by variety (Table 3). 'Cave-in-Rock' had

the highest stand frequency in the summit position but the summit was only different from the backslope position according to the LSD test. The backslope position had the lowest stand frequency for 'Cave-in-Rock' and was different than the summit, shoulderslope, and toeslope. 'Kanlow' switchgrass also had highest stand frequency in the summit position, but the summit and floodplain were the only positions separated by the LSD.

## Discussion

Seeding of switchgrass prior to planting corn in the same year is an effective strategy for establishment. Yield of both corn grain and stover were reduced when switchgrass was seeded with corn and glyphosate was not used for weed control. Grain yield was reduced approximately  $1.9 \text{ Mg}\cdot\text{ha}^{-1}$ , a substantial reduction. Although compared to sowing switchgrass alone in early spring, this method would still provide a marketable grain crop during establishment. Landscape position effect on corn grain yield had differences of  $3.2 \text{ Mg}\cdot\text{ha}^{-1}$  between floodplain and backslope positions, a substantial difference. The somewhat high alpha level of  $\alpha = 0.1$  level is set so because the study is done in a field setting, and variability is expected to occur within landscape positions. This probability of a type I error (conclusion of different means when actually the same) is adequate for examining mean differences in this case. To better understand the effect of landscape position on corn yield, more years, corn hybrids, switchgrass varieties, preceding crops, stover management, and weed control methods could be explored to determine if both switchgrass establishment and corn yield could be improved. Possibilities exist to improve this system to achieve adequate stand frequencies of switchgrass in all landscape positions and maximize grain yields concurrently.

It is not well understood how the value of corn stover could affect management decisions if switchgrass is being established. Stover removal and no tillage was a speculative management practice based on a presumption of an available use for stover and an economic benefit of removal. Other factors regarding stover management include N immobilization and reduction in spring soil temperatures by stover. It is unknown how leaving stover

residue on switchgrass following establishment would affect seedling survival and subsequent year yield. Though stover was removed in this case other management strategies could be used to manage stover residues with potentially different effects on survival and subsequent growth.

These findings are different than those of Hintz et al. (1998), which found no difference in yield between switchgrass seeded and treatments without seeding. However, a difference in our control treatment, use of broad-spectrum post emergence herbicide was not available at the time their experiment was conducted. Our results also included a difference in stover yield which was different than Hintz et al. (1998) which found no difference in silage yield among similar management practices of population, maturity, and harvest timing. Landscape position differences for stover and grain yield are consistent with Thelemann et al. (2010) which also found differences between corn and other biomass crops. Our average of  $9.75 \text{ Mg}\cdot\text{ha}^{-1}$  of corn grain for switchgrass seeded corn is less than, but comparable when contrasted to the 2009 Boone county average of  $11.5 \text{ Mg}\cdot\text{ha}^{-1}$  (NASS, 2010). Although the LSD comparison was not protected by the F-test the means did pass Bartlett's homogeneity of variances test even with the overall mean square for replication by landscape interaction was high. An interaction of landscape position and treatment was not observed which is unexpected given the differences in means for both landscape position and treatment, respectively. It is likely that an interaction was not observed due to the large amount of variation captured in the overall error term. The mean square of the error term could be reduced if more observations were made in each position increasing the power of all error terms which could potentially show more accurately the effects of landscape position, treatment, and their interaction.

Although the establishment is a critical part of switchgrass management for biomass, switchgrass establishment measurements are much less common than yield measurements on established stands. A threshold value of 40 percent coverage by Schmer et al. (2006) was used by Withers (2010) in determining the relative differences of tillage, planting date, and seeding method. Our results were similar Withers (2010) with most treatments achieving >40 percent coverage in the seeding year. Similar herbicide formulations to our experiment were used, however, the seeding rate was higher at 9 kg·ha<sup>-1</sup>, different environmental conditions were present, and no corn crop was grown during establishment, making good comparisons difficult. Future measurements on this stand will be used to determine if stand frequencies and yields in non-establishment years are comparable with prior year values for establishment and benchmark yield values found in the literature.

Comparing our results to Iowa State University Extension recommendations for switchgrass establishment, which include tillage, mowing, and/or herbicide in some combination preceding and throughout establishment for weed control (Teel et al., 2003; Gibson and Barnhart, 2007), this strategy may reduce the need for seedbed preparation while providing a cash crop during the establishment year. Switchgrass stand frequency was adequate for both varieties used in this experiment. In all landscape positions at least one variety had greater than 50 percent stand frequency. Stand frequency was different between landscape positions and it is uncertain why, but higher seeding rates, if economical, could alleviate this problem. Switchgrass establishment is done for a variety of reasons, so placement within the landscape will vary depending on landowner goals. Though as shown in our results, the position and variety will influence the frequency of stands. The lowest stand frequency observed in the floodplain position could have been a result of different cropping

history, high weed pressures remaining from CRP, soil properties, or other factors not measured. Though stand frequency was reduced in the floodplain, mean grain and stover yields were greatest here for both seeded and control treatments. The relative greater performance of corn could have reduced light, nutrient, or water availability for switchgrass seedlings following germination. Though it is not certain what led to the reduction in stand frequency, the modest reduction in grain yield is promising as compared to producing no marketable crop during the establishment year. Our results demonstrate the potential of this establishment method to reduce economic risk associated with establishing switchgrass in central Iowa.

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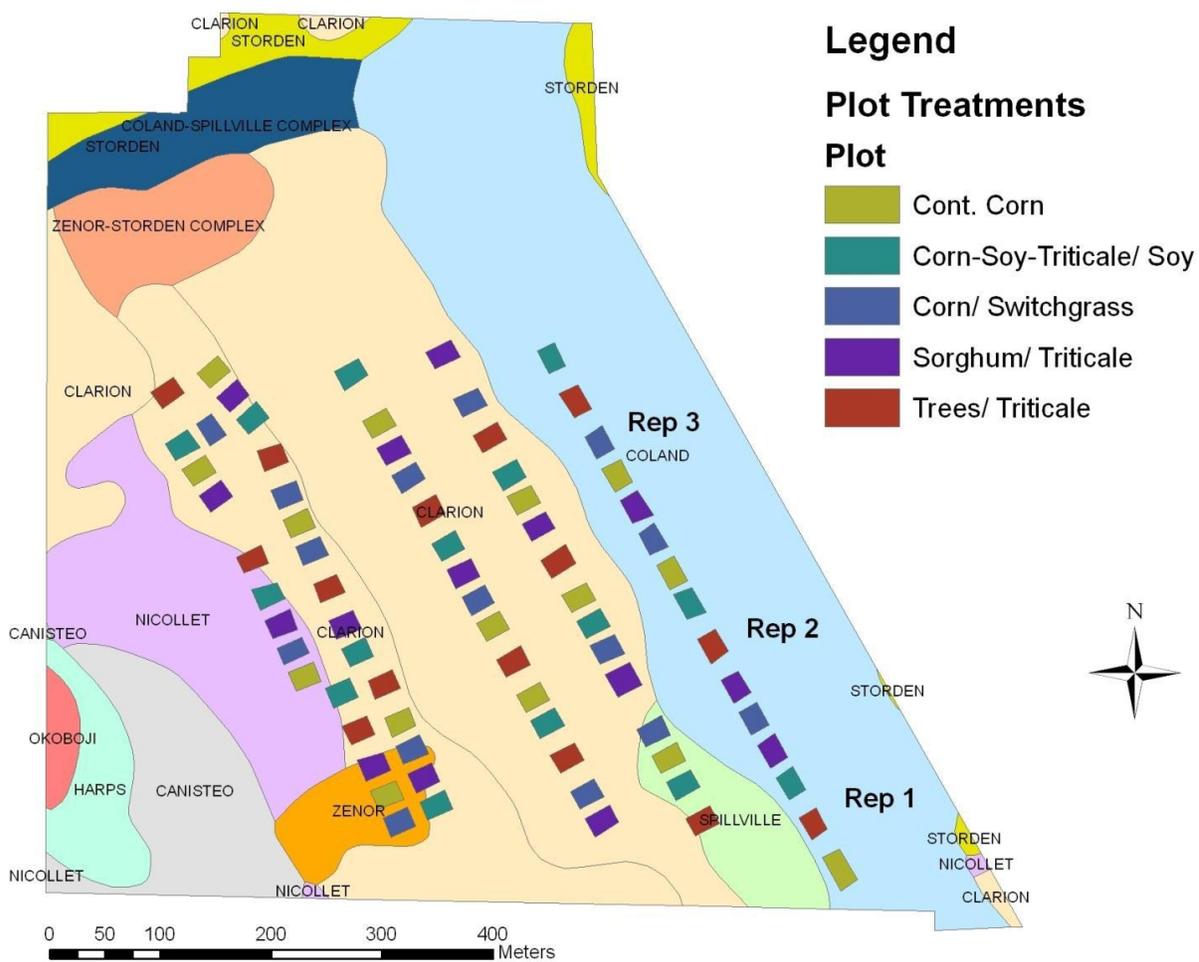


Fig. 1. Plot layout and soil type of Uthe farm at Luther, IA in Boone County (41.928, 93.762)

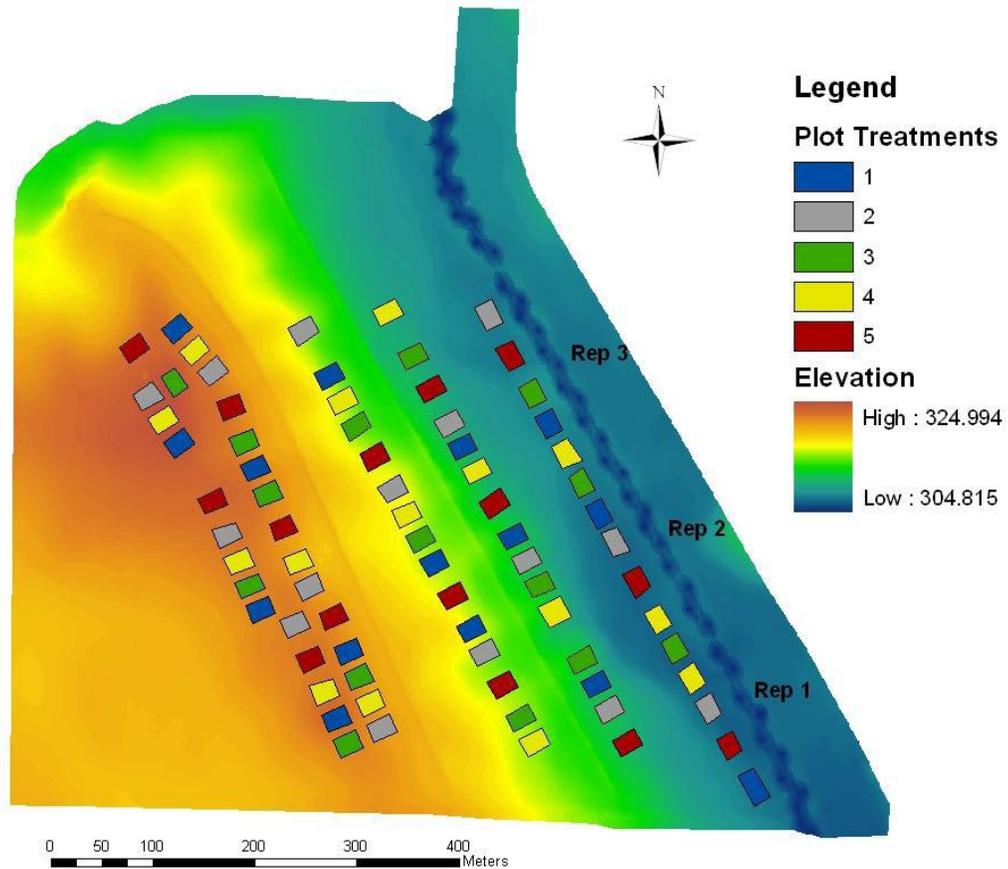


Fig. 2. Plot layout and elevation of landscape positions at Uthe farm at Luther, IA in Boone county (41.928, -93.762). Treatments 1 and 3 represent corn only (control) and corn seeded with switchgrass, respectively.

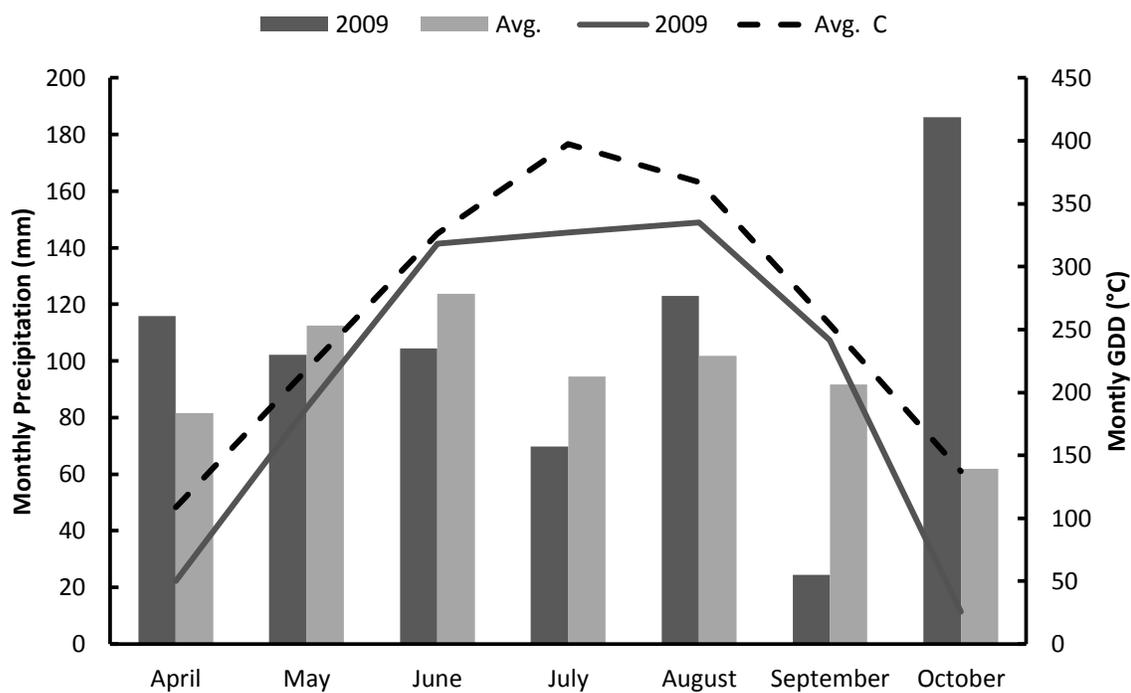


Fig. 3. Weather for 2009 growing season and site average. Lines refer to monthly growing degree days (GDD), and bars are monthly precipitation. Weather information obtained from Iowa environmental mesonet.

Table 1. Grain yield, grain moisture, stover yield, and stover moisture F-Values and significance in response to landscape position and seeding treatment

<u>Source</u>	<u>Grain Yield</u>	<u>Grain Moisture</u>	<u>Stover Yield</u>	<u>Stover Moisture</u>
LP	1.29	5.64*	2.20	6.39*
Trt	13.61*	3.07	275.7**	0.86
LP*Trt	0.49	0.43	0.99	0.35

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LP-Landscape Position Effect ,Trt-Treatment Effect \*\* Denotes significant at  $P < 0.05$

Table 2. Summary of corn grain and stover yields and harvest moistures in 2009 at Uthe Farm, Boone County, IA. Yields are adjusted for grain and stover to 15 and 0 percent moisture,

Treatment	<u>Grain</u>		<u>Stover</u>	
	<u>Yield</u>	<u>Moisture</u>	<u>Yield</u>	<u>Moisture</u>
	(Mg·ha <sup>-1</sup> )	(%)	(Mg·ha <sup>-1</sup> )	(%)
Control	11.6 a	31.6 a	10.8 a	51.9 a
‘Kanlow’	9.6 b	30.7 a	8.3 b	48.4 a
‘Cave in Rock’	9.7 b	32.1 a	8.2 b	50.0 a
Landscape position <sup>y</sup>				
Summit	10.3 ab <sup>x</sup>	27.2 b	9.1 ab	34.4 a
Shoulderslope	10.4 ab	31.1 a	8.4 b	49.3 b
Backslope	9.1 b	32.5 a	8.6 b	52.2 ab
Toeslope	9.5 ab	33.5 a	8.2 b	54.4 ab
Floodplain	12.3 a	32.9 a	11.1 a	60.4 c

<sup>x</sup>Means within subheadings of landscape position followed by the same letter are not different at  $\alpha = 0.10$  according to Fisher’s least significant difference (LSD) test.

<sup>y</sup> Mean comparison of stover and grain are unprotected by F test (Table 1).

Table 3. Mean stand frequency by landscape position of ‘Cave in Rock’ and ‘Kanlow’ switchgrass varieties in May 2010 (year after establishment).

<u>Landscape position</u>	<u>‘Cave in Rock’</u> (%)	<u>‘Kanlow’</u> (%)
Summit	82.6 a <sup>z</sup>	71.3 abc
Shoulderslope	72.6 ab	60.0 abcd
Backslope	48.3 cd	57.6 bcd
Toeslope	78.0 ab	55.0 bcd
Floodplain	60.6 abcd	39.0 d

<sup>z</sup> Means followed by the same letter are not different at  $\alpha = 0.10$  according to Fisher’s least significant difference (LSD) test.

### Chapter 3

## YIELD AND QUALITY OF NEWLY ESTABLISHED SWITCHGRASS IN RESPONSE TO VARIETY AND LANDSCAPE POSITION

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\*This chapter will be combined with 2011 switchgrass yield and quality data for submission to Agronomy Journal

### Abstract

Switchgrass (*Panicum virgatum* L.) has potential to be used as a bioenergy feedstock in the midwestern United States. Performance and quality of newly established switchgrass of multiple cultivars within different portions of the landscape has not been examined. ‘Cave-in-Rock’ and ‘Kanlow’ switchgrass were established in corn using 2-4-D and atrazine. The following year the plots received no nitrogen (N) fertilizer and were harvested following senescence. There were differences between the varieties in measures of yield, neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), N concentration, and cellulose concentration. Differences in landscape position were observed for ADF, carbon concentration, total ash, cellulose concentration, hemicellulose concentration, and total N removal. Interactions of variety and landscape position were observed for yield, NDF, total ash, and cellulose concentration. These differences were observed in a single year, multiple years of data are needed to determine whether these differences continue to be observed as the stands mature.

## **Introduction**

Switchgrass (*Panicum virgatum* L.) has been identified as a potential biomass feedstock for the United States. It is widely adapted across the humid regions of the US making it an attractive species for biofuel feedstock production. Establishment of long lived stands that achieve maximum yield are essential to producing a viable biofuel feedstock. There are two major ecotypes of switchgrass, upland and lowland, which have been found to have different yield potential on average (Wulschleger et al., 2010). Wulschleger et al. (2010) also concluded determinants of yield include N fertilization, temperature, and precipitation. Establishment has been studied from multiple perspectives including depth, seeding rate, soil conditions, planting date, seeding strategy, seed dormancy, water availability, and weed control methods (Parrish and Fike, 2005). All of these may contribute to the success of a seeding depending on the location of the stand, though for practical reasons it is not possible or necessary to actively manage for all of these variables. Switchgrass is typically targeted to land that is marginal for row crop production and will likely be planted on rolling landscapes. This chapter will examine performance and quality characteristics of young switchgrass across a landscape gradient to inform impacts of placement on a landscape level.

## **Landscape Position**

Soil properties, including physical, chemical, and biological vary depending on landscape position. Productivity of crops also often varies among these different locations in a landscape but determining absolute causality is difficult. When these soil properties are

examined in aggregate, corn grain yield variation within a single site or field can be described (Thelemann et al., 2010; Kaspar et al., 2004; Mamani-Pati et al., 2010).

Thelemann et al. (2010) specifically examined performance of herbaceous and woody biomass crops in various landscape positions within a single site, and found differences in performance of 'Sunburst' switchgrass across landscape positions, among other crop species, in the first two years of growth. Many factors may affect the establishment and yield of switchgrass, though the variables of influence are not likely to be all found at a single site, at all locations within the site, nor practical to manage for at a field scale.

### **Establishment**

Switchgrass establishment studies are much less common than studies which measure yield. A farm scale establishment study by Schmer et al. (2006) determined a threshold value following the establishment year of 40 percent or greater for establishment to not be limiting of future biomass harvests in the Great Plains. Withers (2010) studied application method and planting date in Michigan finding that highest rate of establishment and subsequent year yield with late spring planting using tillage. However, tillage was not necessary to achieve >40% establishment. Results were in agreement with the summary of establishment studies by Parrish and Fike (2005) demonstrating that establishment was possible through no-till methods. While both methods are possible, no convincing case can be made for adhering to one method over the other in all cases.

Economic return to the producer is a major hurdle to the adoption of bioenergy feedstock production. Perrin et al. (2008) found that producers who obtained harvestable yield in the initial year had both higher yields in future years and lower cost of production per Mg of biomass over a five-year period. This demonstrates the long term economic risk

associated with establishment of switchgrass for biomass and the need for strategies that both mitigate risk and ensure establishment of adequate stands for future harvest. One such strategy studied by Hintz et al. (1998) used a establishment strategy in which switchgrass was seeded prior to corn planting and compatible herbicides of 2,4-D (2,4-Dichlorophenoxyacetic acid) amine form and atrazine (2-chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine) were applied to provide weed control for both crops. This strategy was successful in establishing adequate plant populations and did not significantly reduce corn grain or silage yield. Seeding switchgrass prior to corn harvested for grain and stover could presumably achieve the same results.

Though yield across landscape position (Thelemann et al.,2010), ecotype (Wullschleger et al., 2010), and establishment method (Hintz et al., 1998; Withers, 2010) have been examined, a combination of ecotype, landscape position, and a seeding with corn establishment method has not been examined in the literature for establishment and subsequent yield. The importance of the summative effects of these factors is apparent.

Placement of switchgrass is important as the species needs multiple years to achieve maximum productivity (Parrish and Fike, 2005). Between only 33-66 percent of maximum yield are obtained in the first two growing seasons (McLaughlin and Kszos, 2005), though management and subsequent yield on established stands vary in the literature. Stand age after establishment has not been found to be a determinant of yield, with productive stands being possible for many years (Fike et al., 2006; Wullschleger et al., 2010).

## Harvest

Following successful establishment, feedstock quality is an important consideration. Conversion methods are largely determined by the inherent characteristics of the species and management practices used in production. N fertilization (Vogel et al., 2002; Wullschleger et al., 2010), timing of harvest (Vogel et al., 2002; Adler et al., 2005), and number of harvests (Vogel et al., 2002; Reynolds et al., 2000) are well studied management practices which influence switchgrass quantity and quality. Quantity varies depending on the number and timing of harvests. One late season harvest after senescence results in a feedstock with lower N and ash concentrations, influencing quality (Reynolds et al., 2000; Waramit et al., 2011). Waramit et al. (2011) found that different N rates had no effect on N concentration in harvested material for warm season grasses, including 'Cave-in-Rock' switchgrass, following senescence. However, this study only examined a single upland switchgrass cultivar. In southern Iowa, studies of feedstock quality across cultivars (Lemus et al., 2002) and of management by location interactions (Lemus et al., 2008) examined feedstock quality. Lemus et al. (2002) found that cellulose content did not vary among any of the 20 varieties tested. For the two varieties of interest in this experiment, 'Cave-in-Rock' and 'Kanlow', none of the parameters were different beyond the 5% LSD with the exception of ADL for which 'Cave-in-Rock' had greater concentrations than 'Kanlow'. In the management by location experiment using long term stands of 'Cave-in-Rock', Lemus et al. (2008) found a location by year interaction for hemicellulose, N concentration, and ash concentration. A N by year interaction for cellulose was observed, but no interactions of quality measures were consistent over years and location. Sanderson and Wolf (1995) found that ash concentrations of 'Alamo' and 'Cave-in-Rock' were not different at two locations in Texas and Virginia.

Lignocellulose concentrations were different between locations for 'Alamo' but all other parameters were consistent and followed a pattern defined as a function of cumulative degree day (base 10° C) accumulation. Overall, results of switchgrass quality measures are mixed and seem to be confounded by management practices, years, varieties, and locations. It is not clear whether any location, variety, or year interactions would be present between different landscape positions at a single location along a landscape toposequence with management zones defined on the basis of elevation defining various landscape positions. The goal of our experiment was to examine the quantity and quality of harvested biomass from two newly established switchgrass varieties collected from different locations across a landscape gradient at a single location in central Iowa.

## **Materials and Methods**

### **Experimental Design**

Two switchgrass cultivars ‘Cave-in-Rock’ and ‘Kanlow’, representing upland and lowland cultivars, respectively, were established with corn during 2009. Whole plots were 18.3 m by 24.4 m, and are split into two 18.3 m by 12.2 m plots in which variety was assigned randomly. In 2010 and 2011, switchgrass stand counts were taken using a 1 m<sup>2</sup> grid with 25 equal square cells and the grid frequency method as described by Vogel and Masters (2001). In 2010, the plots received no N fertilizer.

### **Harvest Methodology**

Plots were trimmed approximately 1.5 m into the plot following a killing frost using a John Deere 972 flail type forage chopper to eliminate edge effect. Plot harvest followed on 8 November 2010 using a John Deere 5730 self-propelled forage harvester equipped with three 227 kg load cells and Kemper 3000 all cut head. Effective harvest width was 300 cm and length of swath was measured to nearest 15 cm. Due to slight differences in passes for edging, swath length was approximately 15 m and measured lengths varied no more than 1 m between all samples. Chopped material was subsampled, weighed, and placed into a forced air dryer for a minimum of 48 hours at 60°C and weighed again until reaching a constant mass.

### **Laboratory Analysis**

Subsamples were then ground in a Thomas-Wiley mill (Thomas Scientific, Swedesboro, NJ) to pass through a 1 mm sieve for storage and subsequent analysis.

All quality analyses of the biomass were determined on an oven dry matter basis. Dry matter was determined using weighed samples placed in an oven set at 105°C for four hours. The approximate moisture of each sample was estimated from measuring the difference in weights of the fresh minus oven dried sample. These oven dry samples were used determine the ash content by placing oven dry samples overnight into a muffle furnace at 600°C. The ash content was determined by measuring the remainder of sample left after ignition within the furnace.

Structural carbohydrates of each sample was calculated using the fiber analysis procedure described in Vogel et al. (1999). Neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) concentrations were estimated sequentially using an ANKOM 200/220 fiber analyzer (ANKOM Technologies, Macedon, NY). The concentration of hemicelluloses was estimated from subtraction of the ADF from the NDF, while as the concentration of cellulose of each sample was estimated by subtracting the ADL from the ADF. Lignin was estimated by subtracting ash content measured following combustion of the remaining sample in a muffle furnace following ADL extraction. All lignin values reported are on the ash-free basis. Total C and N concentration for each sample were estimated by the Iowa State University Plant and Soil Analysis Laboratory (Ames, IA) using a LECO analyzer (Model CHN-2000, LECO Co., St. Joseph, MI). Weather data was obtained from the Iowa Environmental Mesonet (Mesonet, 2001-2011) AgNet weather monitoring station A130209 (42.0212,-93.7745) at the Agronomy/Ag Engineering farm near Boone, IA, approximately 6 miles from the research site.

Yield and quality data were analyzed using the SAS (SAS Institute, 2009) GLM procedure. All variables were analyzed as a split-block design with landscape position and

variety as main effects. Switchgrass varieties were analyzed using replication by variety interaction and least square means were used to compare interactions. Significance was determined at  $\alpha = 0.05$  level. Comparisons between treatment effects were done using Fisher's least significant differences (LSD) test. Landscape position and switchgrass variety were considered fixed factors, and replication was considered random. F values reported for landscape position (L) and variety (V) are tested by their respective interaction with replication (R) (Table 1).

## Results

### Weather

Summary of weather for the 2010 growing season is shown in Figs. 1 and 2. This growing season can be characterized by average temperature and above average precipitation. The season began with above average accumulation of 267 GDD (growing degree days, base 50°F) in April compared with 188 GDD average. In May, this reversed with a below average 356 GDD compared to 484 GDD average. Early season precipitation was near average with the accumulated total of 248 mm through May compared to an average of 241mm. Beginning in June, a trend of well above average precipitation began with 282 mm, 129 mm, and 336 mm of precipitation compared to averages of 124 mm, 94 mm, and 102 mm for June, July, and August, respectively. This was nearly double the average rainfall for this three month period. Accumulated GDD for this same period were also above average with a total of 143 GDD more than average. September precipitation of 135 mm was greater than the average of 82 mm though GDD were 26 GDD lower than average. October was dry with only 9 mm of precipitation and 53 GDD more than average. Overall this season was not moisture or GDD limiting, however, excessive precipitation limited access to plots making N fertilizer application impossible until well past optimal timing. Over 200 mm of rainfall in the month of August occurred in a four-day time period under already saturated conditions leading to flooding at the site. As a result, much of the floodplain position was under flowing water for approximately 48 hours. Areas impacted by the flooding were lodged by flowing water but plants did not suffer prolonged saturated conditions leading to anaerobic conditions in the root zone. Both varieties were entirely

senesced at time of harvest. A noticeable outbreak of rust on 'Cave-in-Rock' occurred, but 'Kanlow' was not noticeably affected.

### **Variety**

Variety had a significant effect on total yield, NDF, ADF, ADL, lignin, N concentration, and cellulose concentration (Table 2). Means of all measures found to be significant by the analysis of variance for variety are summarized in Table 3. As shown in Fig.3, 'Kanlow' had higher average yields than 'Cave-in-Rock' in all positions though the largest differences were found in the summit and shoulderslope (Fig. 3). NDF concentrations were different by nearly the same quantity in the summit, shoulderslope, and toeslope positions. NDF was not different between varieties in the floodplain position (Fig. 4). 'Kanlow' ADF concentrations were greater than 'Cave-in-Rock' by an average of 26 g·kg<sup>-1</sup> (Fig. 5). Concentrations of ADL were consistently lower in 'Kanlow' than 'Cave-in-Rock' except in the floodplain where values were nearly equal (Fig. 6). This difference in ADL was also reflected in calculated lignin values which demonstrated the same trend once recalcitrant ADL ash was subtracted (Fig. 7). Mean cellulose content was 31 g·kg<sup>-1</sup> greater in 'Kanlow;' than 'Cave-in-Rock'. This difference was smaller in the backslope and floodplain positions and greater in summit, shoulder, and toeslope positions (Fig. 8). Hemicellulose concentration was greater in four landscape positions but this difference was not significant (Fig. 9). N concentration of biomass was different between varieties with Cave-in-Rock having higher concentrations (Fig. 10). Although concentration of N was greater in 'Cave-in-Rock', because yield was lower the total kg N·ha<sup>-1</sup> removal was greater for 'Kanlow' (Fig. 13), though this difference is not significant. Total ash and carbon concentrations were not different between varieties (Table 2).

## Landscape Position

Landscape position had a significant effect on ADF, total carbon, total ash, cellulose, hemicellulose, and N removal (Table 2). All other measures did not have differences detected (Table 2). Means of all measures found to be significant by the analysis of variance for landscape position are summarized in Table 4. The sources of variation are summarized in Table 2. ADF was found to be different across landscape positions. Fig. 5 shows this trend which is most pronounced in the floodplain position. Total carbon concentration decreased dramatically in the floodplain position (Fig. 11) and both varieties experienced the same trend. A landscape position by variety interaction was also observed. Ash concentrations of 'Kanlow' were lower than 'Cave-in-Rock' in the summit and shoulderslope but this was reversed in the backslope, toeslope, and floodplain position. Landscape position effect on cellulose concentration had a difference ( $P < 0.10$ ) of but a stronger effect ( $P < 0.05$ ) of landscape position by variety was observed. 'Cave-in-Rock' had consistently lower cellulose concentrations, but this difference was not as great in the floodplain position in which cellulose concentrations were nearly equal (Fig. 8). Hemicellulose concentration was different between landscape positions with a major decrease in the floodplain position. The same trend was observed for both varieties and there was no interaction (Fig. 9). N concentration of the samples did not differ by landscape position but total removal was significantly different. There was an increase in the floodplain position of approximately  $10 \text{ kg N}\cdot\text{ha}^{-1}$  more N removed (Fig. 13). No variety by landscape position interaction was observed as total removal increased for both varieties in the floodplain.

## Discussion

Overall yields were low for switchgrass compared to literature values for these varieties (Wullschleger et al., 2010) though with no N fertilization in the first season after establishment, lower yields are not unexpected. The relative difference of cellulose content between the two varieties is consistent with Lemus et al. (2002). Higher cellulose content of 'Kanlow' would be advantageous to a feedstock intended for cellulosic ethanol production. Lower relative lignin concentration, while not significantly different, would also be an advantage for 'Kanlow' for use as a cellulosic ethanol feedstock. Total carbon was not significantly different between varieties but rather the allocation of carbon to the different fractions was observed. Similar to Lemus et al. (2008) no consistent pattern of quality measures was determined as differences between landscape position, variety, and the interaction of the two were observed in this one year. Other measures of quality were comparable to values for switchgrass from Waramit et al. (2011).

N export is an important consideration as it can represent a large portion of total production costs and energy expenditures. Nutrient cycling is intended to be maximized by waiting until translocation removes a majority of N from aboveground to below-ground tissues prior to harvest. Aside from the influence of N on the optimization of biomass yields annual removal should be understood. So far it is not possible to determine whether landscape position influences quantity of N required to maintain high productivity because maximum productivity has yet to be obtained. Future years will determine whether differences in total N export by landscape position are maintained or normalize. Ash concentrations in the floodplain position were higher than all other locations (Fig. 12). Future years sampling will determine whether this is a consistent trend over years or attributable to

the flooding event. Most of the differences in quality attributed to landscape position were between the floodplain and other positions (Table 3). Again, future years data will help indicate whether these differences are consistent over time or caused by the flooding event.

Management of these plots is ongoing with fertilization and weed management strategies implemented in 2011. Following analysis of future samples, correlations between quality characteristics, yield, and removal of specific components can be more accurately described. Future samples and analysis are needed to determine if these or other significant differences not observed in these sample can be determined.

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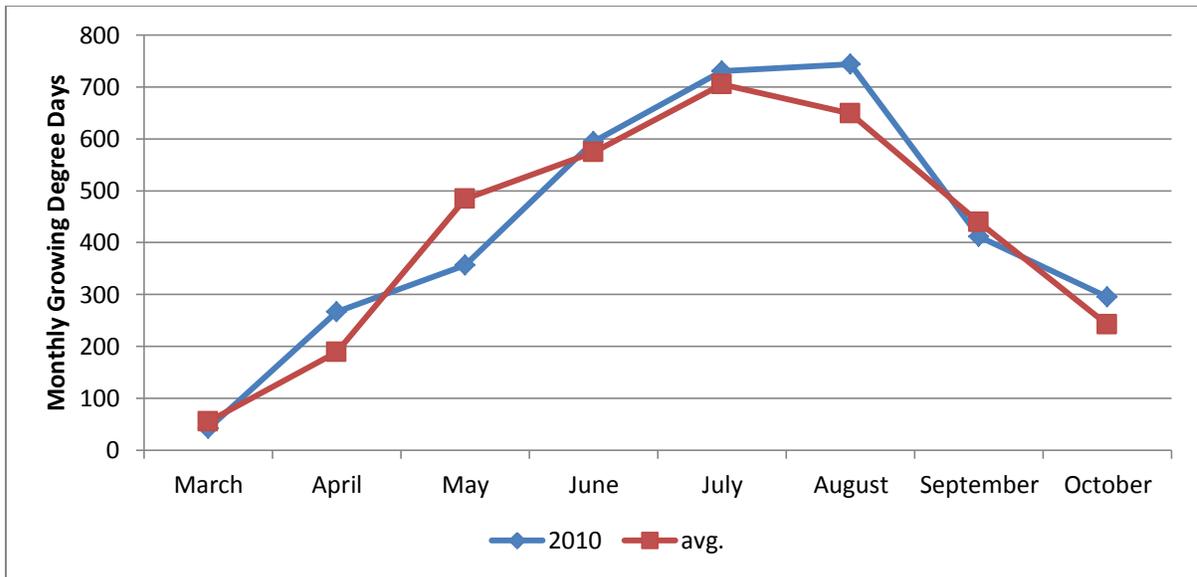


Figure 1. 2010 and 60 year average monthly accumulated GDD (base 50°F) weather station at Agronomy/Ag engineering farm located near Boone,IA.

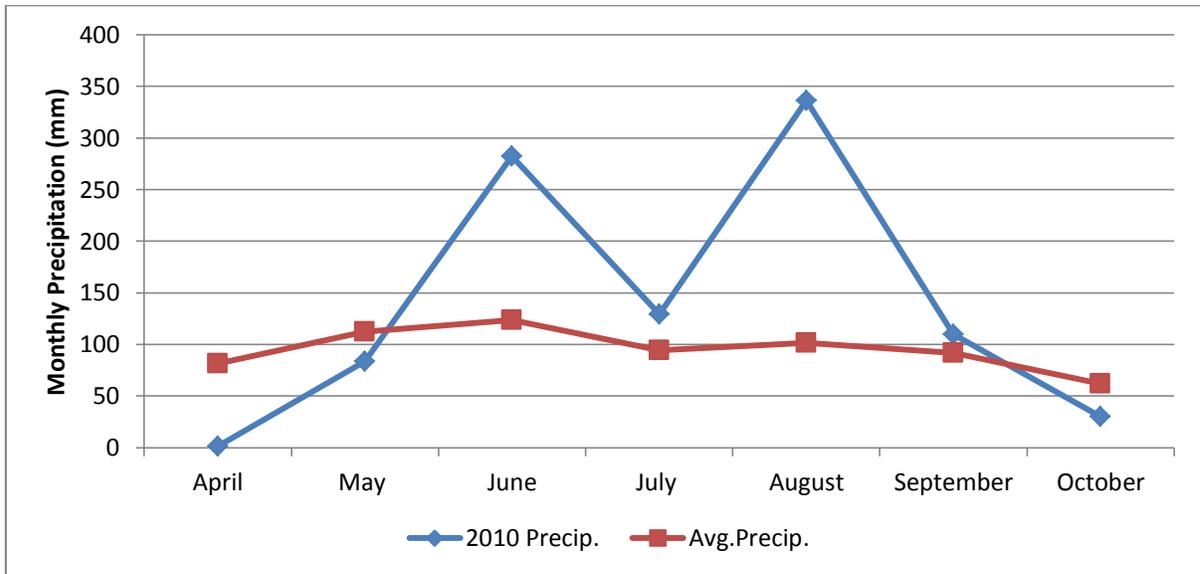


Figure 2. 2010 and 60 year average monthly precipitation (mm) at Agronomy/Agricultural Engineering farm near Boone, IA, USA.

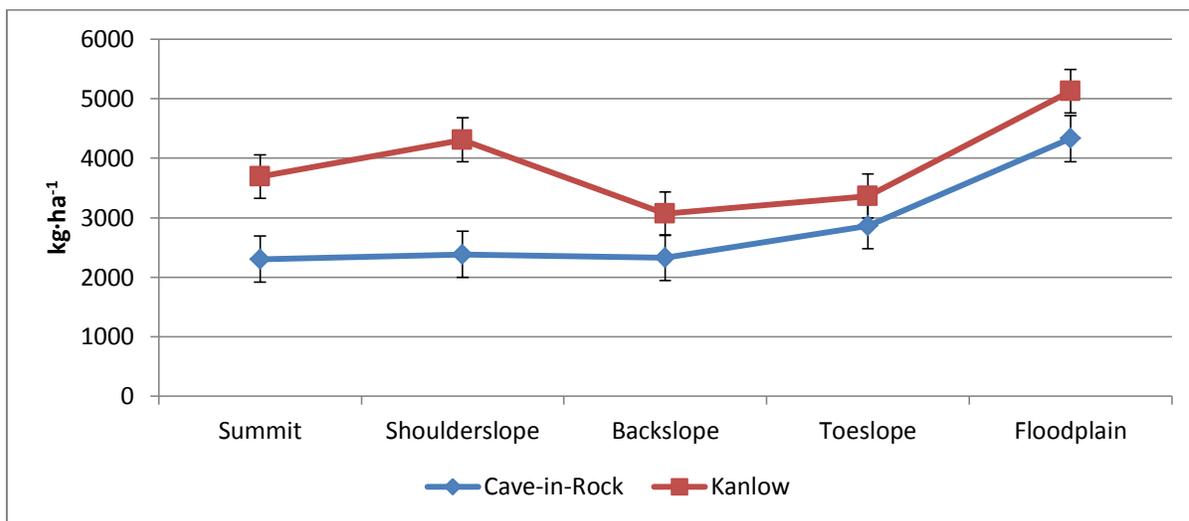


Figure 3. Mean dry matter yield of 'Cave-in-Rock' and 'Kanlow' switchgrass across five landscape positions at Uthe Farm in Luther, IA, USA November 2010. Error bars represent overall standard error for corresponding variety.

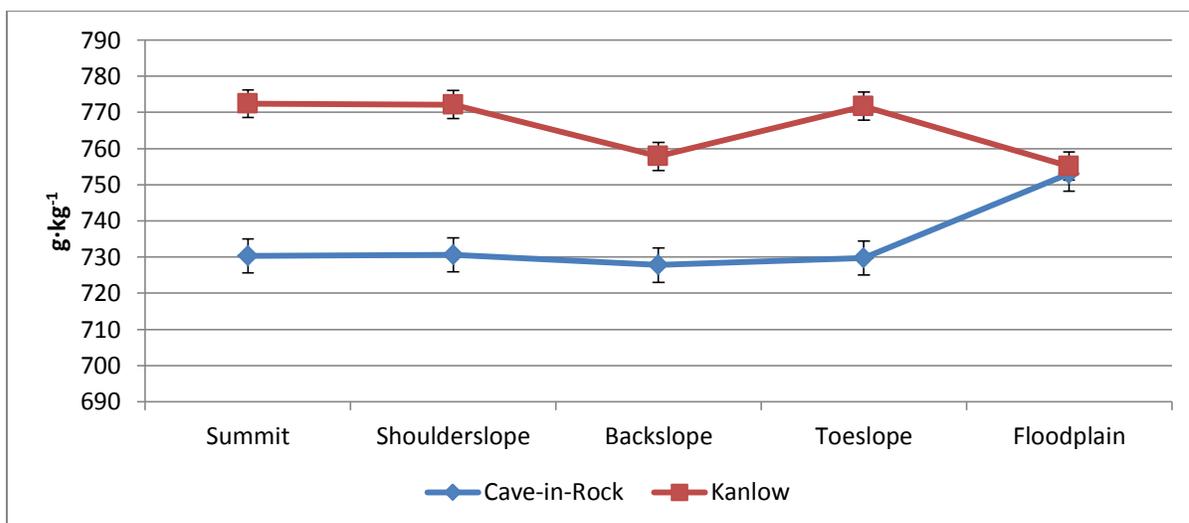


Figure 4. Mean neutral detergent fiber (NDF) concentration of 'Cave-in-Rock' and 'Kanlow' switchgrass across five landscape positions at Uthe Farm in Luther, IA, USA November 2010. Error bars represent overall standard error for corresponding variety.

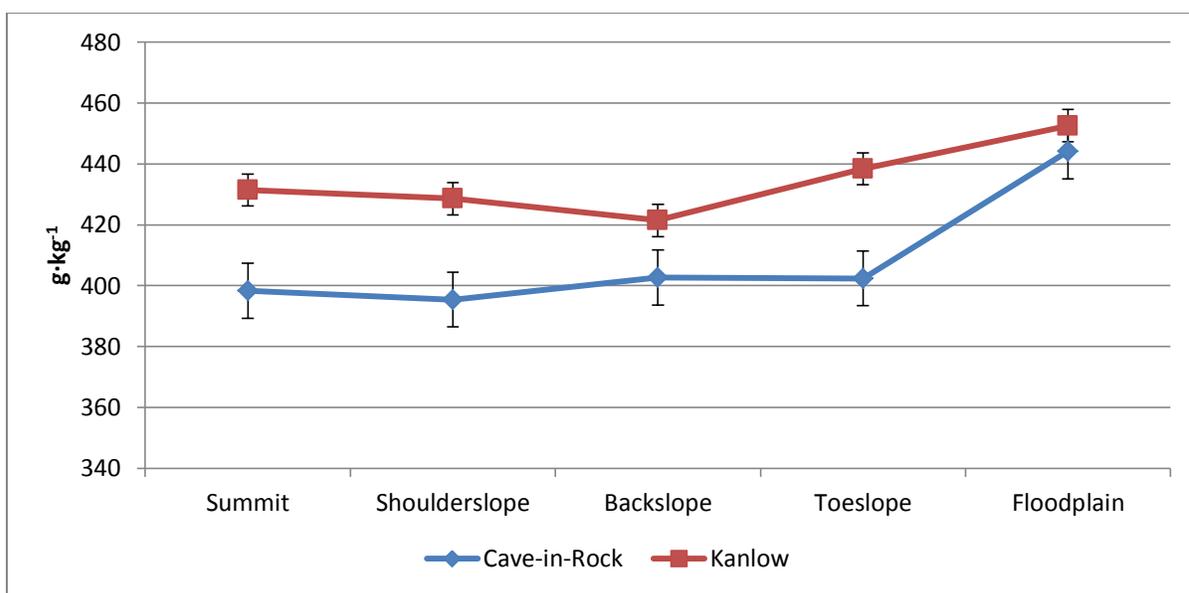


Figure 5. Mean acid detergent fiber (ADF) concentration of 'Cave-in-Rock' and 'Kanlow' switchgrass across five landscape positions at Uthe Farm in Luther, IA, USA November 2010. Error bars represent overall standard error for corresponding variety.

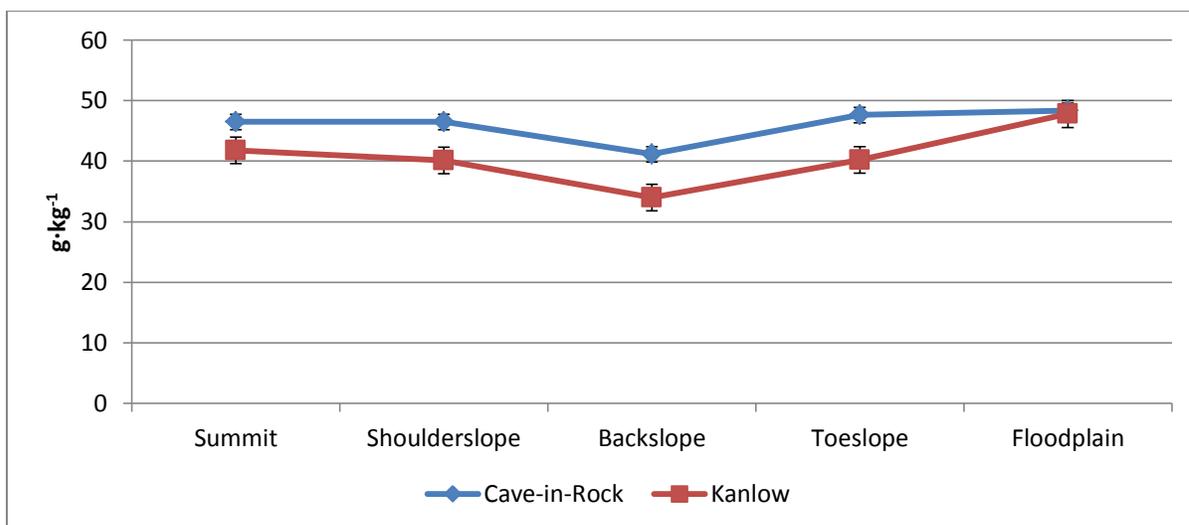


Figure 6. Mean acid detergent lignin (ADL) concentration of 'Cave-in-Rock' and 'Kanlow' switchgrass across five landscape positions at Uthe Farm in Luther, IA, USA November 2010. Error bars represent overall standard error for corresponding variety.

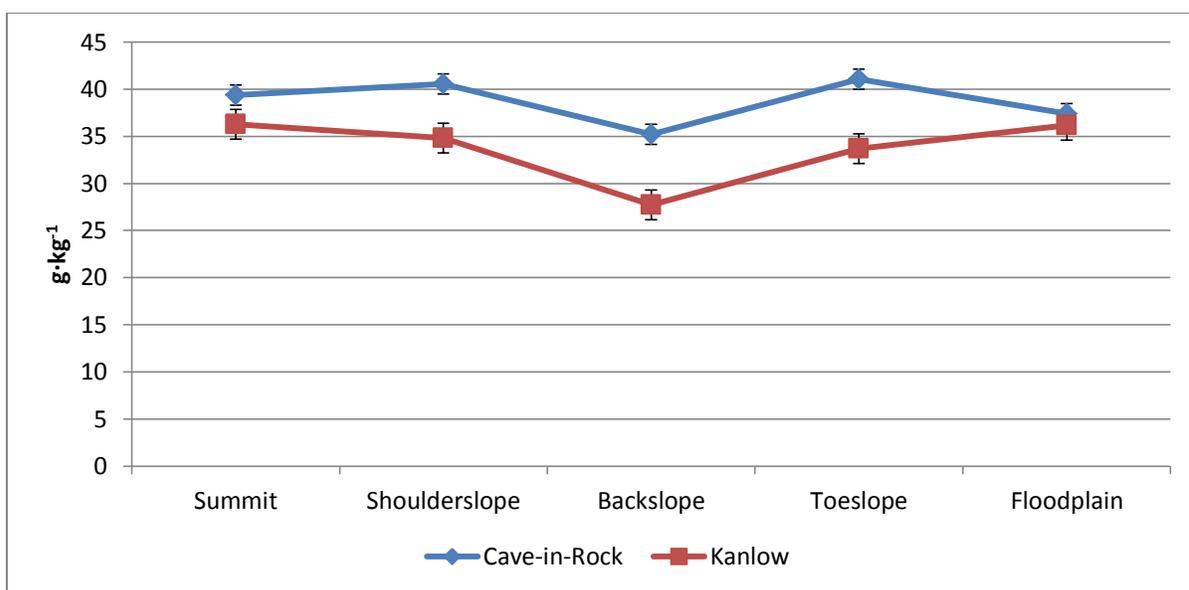


Figure 7. Mean lignin concentration of 'Cave-in-Rock' and 'Kanlow' switchgrass across five landscape positions at Uthe Farm in Luther, IA, USA November 2010. Error bars represent overall standard error for corresponding variety.

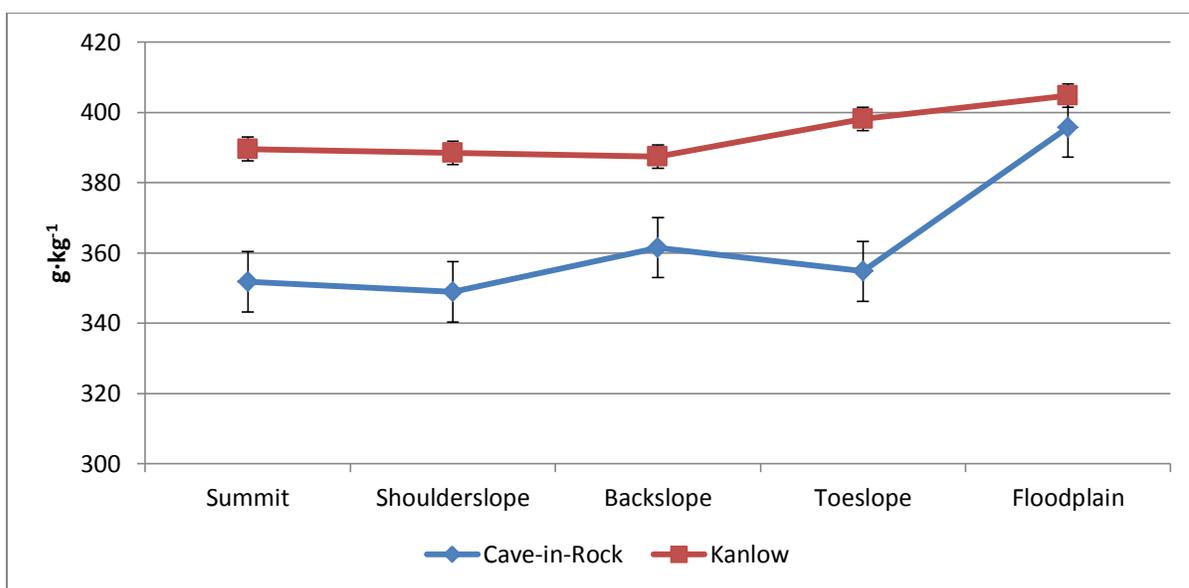


Figure 8. Mean cellulose concentration of 'Cave-in-Rock' and 'Kanlow' switchgrass across five landscape positions at Uthe Farm in Luther, IA, USA November 2010. Error bars represent overall standard error for corresponding variety.

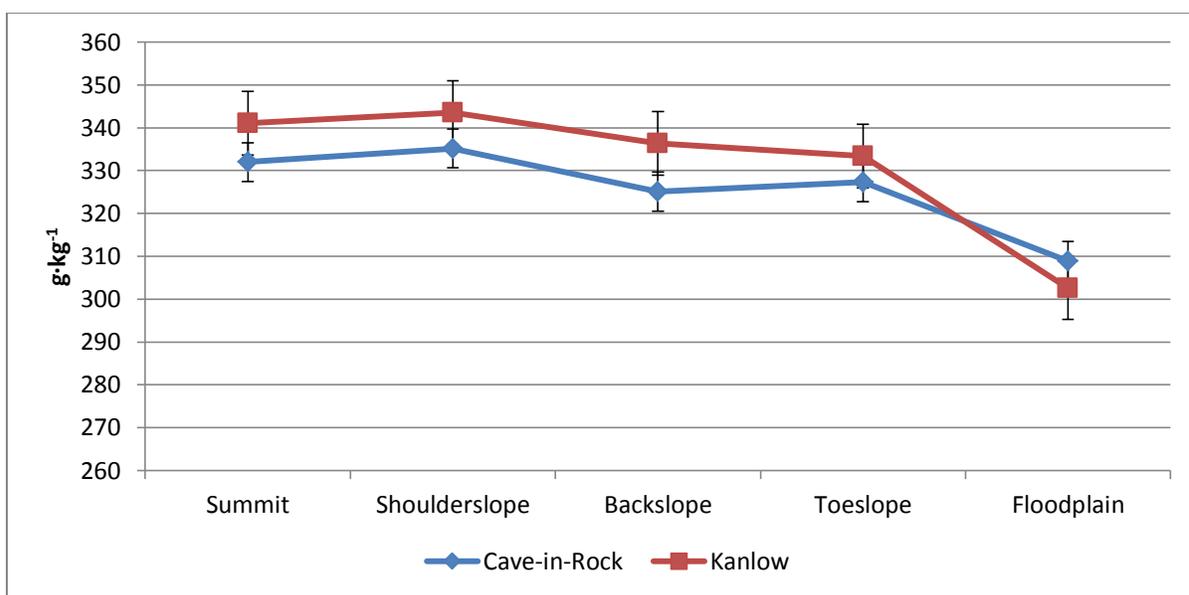


Figure 9. Mean hemicellulose concentration of 'Cave-in-Rock' and 'Kanlow' switchgrass across five landscape positions at Uthe Farm in Luther, IA, USA November 2010. Error bars represent overall standard error for corresponding variety.

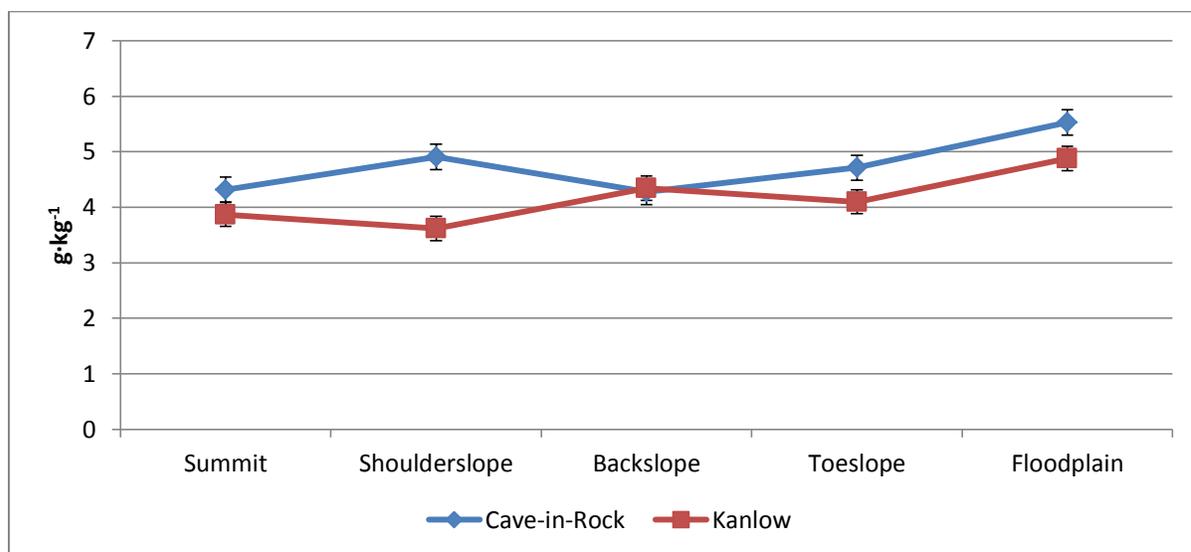


Figure 10. Mean nitrogen (N) concentration of 'Cave-in-Rock' and 'Kanlow' switchgrass across five landscape positions at Uthe Farm in Luther, IA, USA November 2010. Error bars represent overall standard error for corresponding variety.

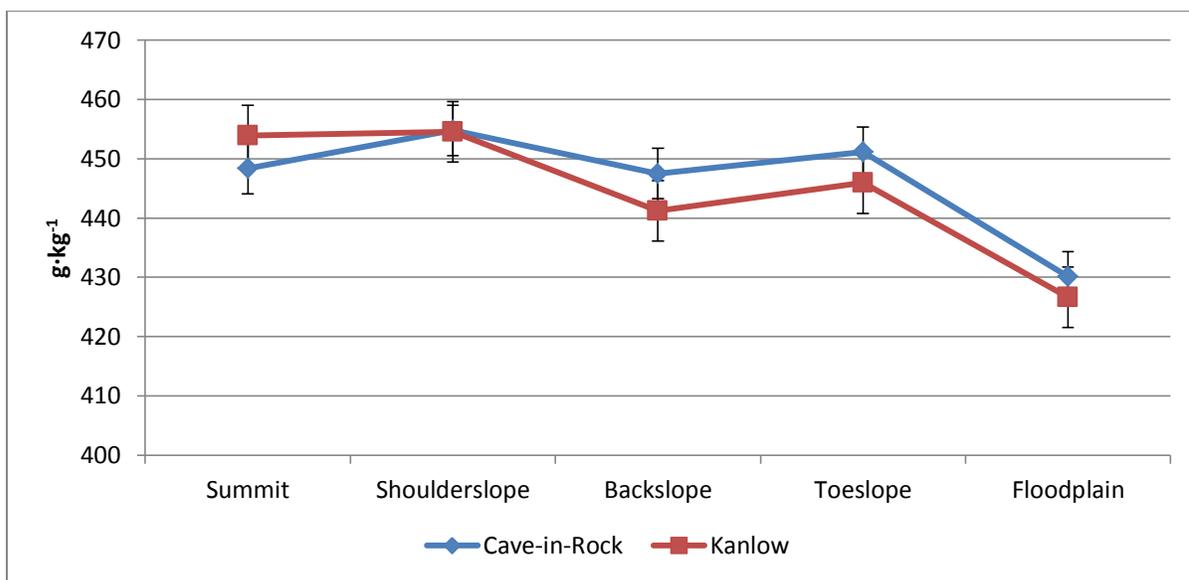


Figure 11. Mean carbon (C) concentration of 'Cave-in-Rock' and 'Kanlow' switchgrass across five landscape positions at Uthe Farm in Luther, IA, USA November 2010. Error bars represent overall standard error for corresponding variety.

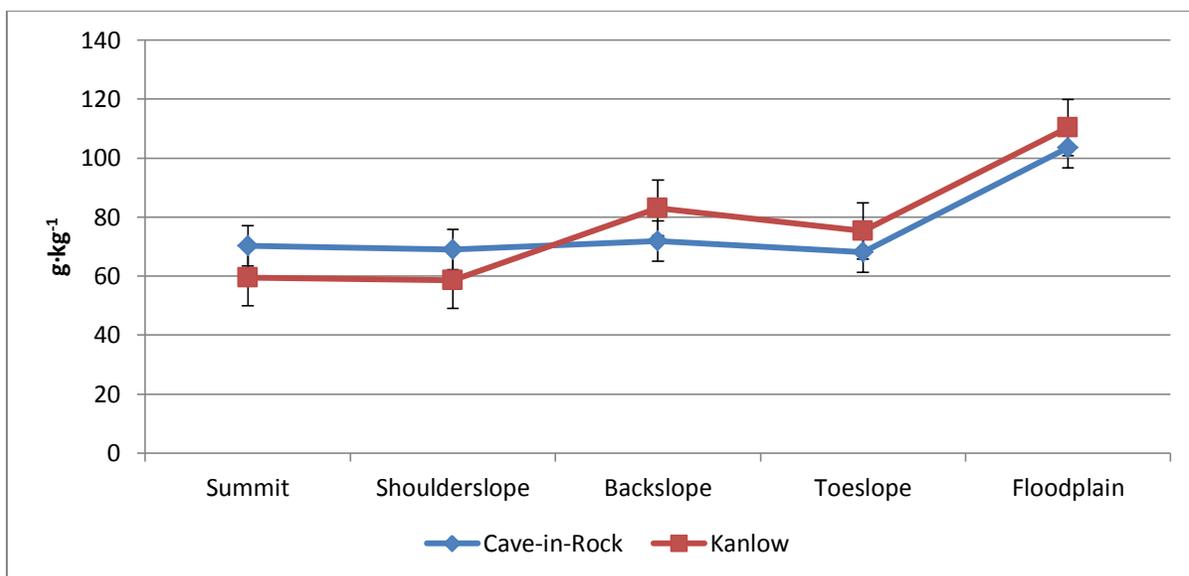


Figure 12. Mean ash concentration of 'Cave-in-Rock' and 'Kanlow' switchgrass across five landscape positions at Uthe Farm in Luther, IA, USA November 2010. Error bars represent overall standard error for corresponding variety.

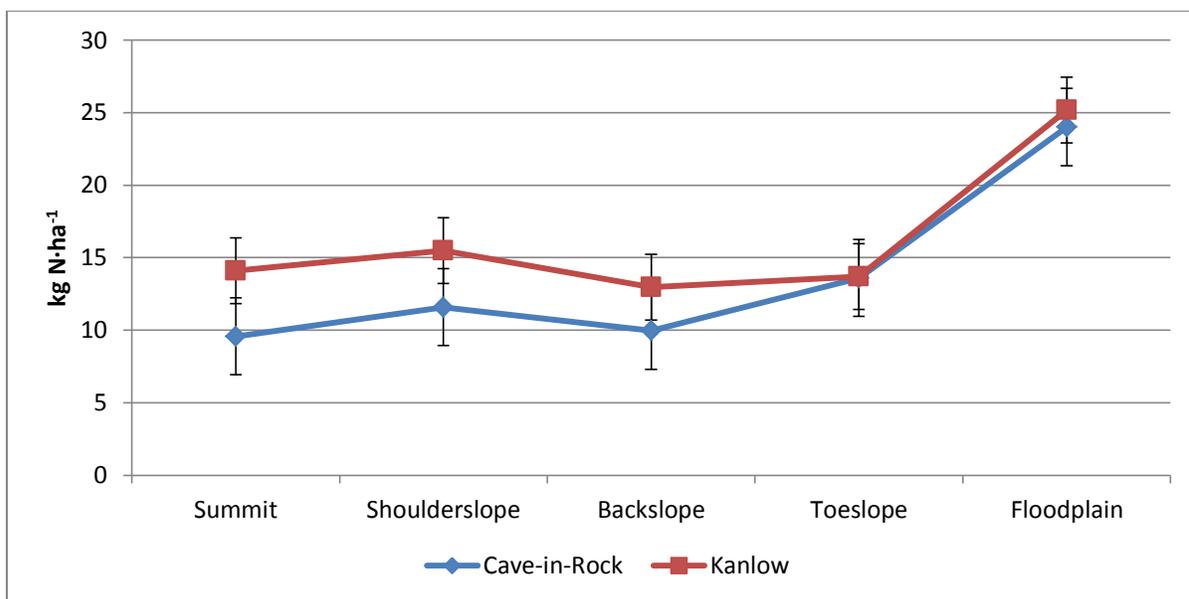


Figure 12. Mean N removal of 'Cave-in-Rock' and 'Kanlow' switchgrass across five landscape positions at Uthe Farm in Luther, IA, USA November 2010. Error bars represent overall standard error for corresponding variety.

Table 1. Expected Means Square for analysis of variance. F test values for Location and Variety are  $L_j/RL_{ij}$  and  $V_k/RV_{ik}$ , respectively and all interactions are tested by the overall error  $RLV_{ijk}$

<u>Source</u>	<u>df</u>	<u>EMS</u>
$R_i$	2	$10\sigma_{\delta}^2 + 10\sigma^2$
$\delta_{(i)}$	0	$10\sigma_{\delta}^2$
$L_j$	4	$2\sigma_v^2 + 6\Phi_L$
$RL_{ij}$	8	$2\sigma_v^2$
$V_k$	1	$5\sigma_{RV}^2 + 15\Phi_V$
$RV_{ik}$	2	$5\sigma_{RV}^2$
$LV_{jk}$	4	$\sigma_{RLV}^2 + 3\Phi_{LV}$
$RLV_{ijk}$	8	$\sigma_{RLV}^2$

Table 2. Yield, NDF, ADF, ADL, lignin, total carbon (TC), total nitrogen (TN), ash, cellulose, hemicellulose, and N removal mean square and significance for five landscape positions and two cultivars of switchgrass for 2010.

Effect	df	Yield	NDF	ADF	ADL	Lignin	TC	TN	Ash	Cellulose	Hemicellulose	N Removal
L	4	7495146	218.2	2832.7§	169.6	86.6	1257.4*	2.2	3747.5*	1949.7§	2123.9*	355.6*
R*L	8	3652714	1088.7	862	95	65.8	226.6	1.1	973.1	567.7	329.9	80.3
V	1	17129658*	14966**	10046**	410.7§	374.9§	55	5.1*	9.5	14519.6**	488.2	96.4
R*V	2	453125	90	15.6	29.1	37.1	37.2	0.2	67.7	62.4	159	15.2
L*V	4	1009218**	889.5*	420.9§	23.8	22.6	68.71	0.7	336.4*	586.5**	578.1	10.3

§ Significant at  $P \leq 0.10$

\* Significant at  $P \leq 0.05$

\*\* Significant at  $P \leq 0.01$

L- Landscape Position

R- Replication

V- Variety/Cultivar

Table 3. Selected means of quality measures for 'Kanlow' and 'Cave-in-Rock' switchgrass.

Differences in means are at the probability accompanying the measurement

<u>Measure</u>		<u>'Cave-in-Rock'</u>	<u>'Kanlow'</u>
Yield *	(kg·ha <sup>-1</sup> )	2843.1 ±1037	3911.9±1193
NDF **	(g·kg <sup>-1</sup> )	734.2 ±19.1	765.8±21.0
ADF **	(g·kg <sup>-1</sup> )	408.5 ±22.5	434.4±19.6
ADL§	(g·kg <sup>-1</sup> )	46.0 ±5.8	40.7±7.0
TN *	(g·kg <sup>-1</sup> )	4.7 ±0.89	4.1±0.75
Lignin §	(g·kg <sup>-1</sup> )	38.7 ±5.2	33.7±5.5
Cellulose **	(g·kg <sup>-1</sup> )	362.5 ±20.3	393.6±15.6

§ Differences significant at  $P \leq 0.10$ \* Differences significant at  $P \leq 0.05$ \*\* Differences significant at  $P \leq 0.01$

Table 4. Selected means and standard deviations of landscape position effect with mean separation by LSD at  $\alpha=0.10$  within columns. Significance of landscape position effect from analysis of variance shown in column heading.

Landscape Position	ADF§	Total C*	Total Ash*	Cellulose§	Hemi-cellulose*	N Removal*
	(g·kg <sup>-1</sup> )	(kg N·ha <sup>-1</sup> )				
Summit	414.8 b	451.1 a	64.8 b	370.7 b	336.5 a	11.8 b
	±26.5	±6.8	±13.4	±23.2	±12.7	±5.0
Shoulderslope	411.9 b	454.6 a	63.7 b	368.7 b	339.3 a	13.5 b
	±20.3	±2.2	±6.5	±21.6	±7.4	±3.0
Backslope	412.0 b	444.3 a	77.4 b	374.4 b	330.7 a	11.4 b
	±11.53	±5.5	±7.6	±14.5	±9.2	±2.4
Toeslope	420.3 b	448.4 a	71.6 b	376.4 b	330.3 a	13.6 b
	±25.9	±5.8	±9.0	±26.9	±5.8	±4.6
Floodplain	448.3 a	428.3 b	106.9 a	400.2 a	305.7 b	24.6 a
	±14.5	±13.3	±26.5	±16.3	±18.0	±6.1

§ Differences significant at  $P \leq 0.10$

\* Differences significant at  $P \leq 0.05$

\*\* Differences significant at  $P \leq 0.01$

## Chapter 4

### SUMMARY AND CONCLUSION

Switchgrass was successfully established into corn with evident yield reductions for both grain and stover. Grain yield reduction of approximately  $2.0 \text{ Mg}\cdot\text{ha}^{-1}$  and stover reduction of  $2.6 \text{ Mg}\cdot\text{ha}^{-1}$  were significant reductions in yield. Though the switchgrass seeding treatment reduced yield, the effect of landscape position was greater with reductions of grain and stover of  $3.2 \text{ Mg}\cdot\text{ha}^{-1}$  and  $2.9 \text{ Mg}\cdot\text{ha}^{-1}$ , at the highest and lowest yielding landscape positions, respectively. Both effects are significant and should be considered when implementing this establishment method. Though differences in performance of corn existed there were far fewer differences in switchgrass establishment success. Within any given landscape position, both varieties did not have differences in stand frequency. Higher counts were observed in different positions but only the backslope and floodplain had different stand frequencies compared to all other positions for 'Cave-in-Rock' and 'Kanlow', respectively. All combinations of landscape position and variety achieved >40 percent stand frequency except 'Kanlow' in the floodplain position which achieved 39 percent. This shows the potential for using this strategy in all parts of the landscape and achieving adequate stands. The year this study was conducted, 2009, was an ideal year for this establishment method as neither moisture nor temperature contributed to stress of the corn or switchgrass.

These results are consistent with other establishment studies finding that establishment in corn (Hintz et al., 1998) and no-till (Withers, 2010) along with many other studies summarized by Parrish and Fike (2005) are able to achieve adequate stands. Because early success of the stand is crucial to mitigating risk and achieving profitability, future

studies could examine the effect of seeding rate, fertilizer rate, preceding crop, or herbicide formulations to achieve consistent stands and measure subsequent swards for differences in yield relating to management in corn during establishment.

Yield and quality of the newly established switchgrass was found to be variable between varieties and landscape positions. Composition measures varied between the two varieties with higher cellulose concentration and total N export for 'Kanlow' while 'Cave-in-Rock' had higher N concentration and lower total yield. In this case low yield, rust, and a flooding event likely contributed to many of the differences in yield or quality. These findings need to be repeated to definitively conclude the impact of variety and landscape position on the yield and quality of switchgrass. Also other comparisons, such as environmental consequences, energy balance, or economic models, not examined in this thesis regarding the relative differences between this and other cropping systems, can be used to understand impacts and determine best practices for different parts of the landscape over time.

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interdisciplinary. Thanks also to the other students and employees who have assisted the process of data collection, site maintenance, and lab analysis.

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