COMPOSITION AND YIELD OF EIGHT SWITCHGRASS CULTIVARS

IN ALABAMA

Except where reference is made to the work of others, the work described in this thesis is my own or was done in collaboration with my advisory committee. This thesis does not include proprietary or classified information.

Lindsay J. Crider

Certificate of Approval:

Mary S. Goodman Associate Professor Agronomy and Soils	David I. Bransby, Chair Professor Agronomy and Soils
Patricia A. Duffy Alumni Professor Agriculture Economics	George T. Flowers Dean Graduate School

COMPOSITION AND YIELD OF EIGHT SWITCHGRASS CULTIVARS IN ALABAMA

Lindsay J. Crider

A Thesis

Submitted to

the Graduate Faculty of

Auburn University

in Partial Fulfillment of the

Requirements for the

Degree of

Master of Science

Auburn, Alabama
May 9, 2009

COMPOSITION AND YIELD OF EIGHT SWITCHGRASS CULTIVARS

IN ALABAMA

Lindsay J. Crider

Signature of Author

Date of Graduation

VITA

Lindsay Jeanne Catherine Crider, daughter of Claude Jackson and Melinda Gray Crider, was born May 27, 1983 in Atlanta, Georgia. She graduated from Cherokee High School in Canton, Georgia in May of 2001. She attended Berry College in Rome, Georgia and graduated in May of 2005 with a Bachelor of Science degree in Environmental Science. In January of 2007 she entered Graduate School at Auburn University where she was appointed to a Graduate Research Assistantship and a Graduate Teaching Assistantship. She received a Master of Science degree in Agronomy and Soils in May of 2009.

THESIS ABSTRACT

COMPOSITION AND YIELD OF EIGHT SWITCHGRASS CULTIVARS

IN ALABAMA

Lindsay J. Crider

Master of Science, May 9, 2009
(B.S., Berry College, May 2005)

67 Typed Pages

Directed by David I. Bransby

Switchgrass (*Panicum virgatum*) is a viable cellulosic energy crop. Energy conversion technologies prefer cellulosic feedstock to contain low concentrations of lignin and ash and high concentrations of fermentable sugars. Research into chemical composition across species of cellulosic feedstocks has been analyzed. There has been little research however, dedicated to interspecies analysis between switchgrass cultivars.

The research objectives of this study were to analyze chemical composition and biomass yields of eight switchgrass cultivars in a twenty-year (1989–2008) randomized complete block (rep = 4) experiment in Alabama. Near-infrared spectroscopy was used to evaluate concentrations of acetyl, arabinan, ash, glucan, lignin, protein, xylan in leaf and stem biomass for 2007 and 2008. Theoretical ethanol yields were determined from the composition of sugars using the National Renewable Energy Laboratory website's

‘Theoretical Ethanol Yield Calculator’. Biomass yield data of eight cultivars in a twenty-year (1989-2008) study was analyzed using multiple linear regression analysis in SAS v9.1, proc STEPWISE and proc MIXED. Biomass yield data was regressed against weather and harvest data. Total biomass yields were affected significantly by the weather factors precipitation, harvest and frostdate. The months of March, May and September appeared in highest frequency across cultivars as significant and positive to biomass yields.

Highest biomass yields across 1989–2008 were observed in cultivars Alamo, Kanlow and Cave-In-Rock with averages of 10.27, 8.22 and 6.57 tons/acre respectively. Average annual ethanol yield totals from 2007 and 2008 for Alamo, Kanlow and Cave-In-Rock were 336.28, 248.75 and 201.03 gallons/acre respectively.

Leaf and stem biomass had different composition and were analyzed using SASv9.1 proc GLIMMIX and proc CANDISC. Leaf biomass was higher in ash and protein while stem biomass was higher in glucan and lignin. Leaf and stem biomass composition analysis with ANOVA tests showed significance among chemistry at the interactions cultivar x year, cultivar x harvest and year x harvest.

Differences in total chemical composition were analyzed for all cultivars using canonical discriminant analysis. Alamo, Kanlow and Trailblazer were significantly different from all other cultivars with respect to their composition. The other six cultivars were all similar to one another in composition. Desired composition of switchgrass could be manipulated for improved cultivars using genetic and plant breeding techniques.

ACKNOWLEDGMENTS

The author would like to thank Dr. David Bransby for the inspiration and guidance provided throughout this journey. The author would also like to thank the advisory committee, Dr. Mary Goodman and Dr. Patricia Duffy for their help and support throughout and for input in editing. A special thanks to Ceres, Inc., especially to Dr. Bonnie Hames and Dr. Steve Thomas for the use of their laboratories, help with data analysis and teaching tenacity in the quest for knowledge. Thank you to Dr. van Santen for help and guidance through statistical analysis. The author would also like to thank the team at the E.V. Smith Plant Breeding Unit for their help with data collection. Thank you to the rest of the Agronomy and Soils department for making my experience enjoyable and intellectually fulfilling. Special thanks are also due to my family and friends who gave me confidence, support and love throughout this process.

Style manual or journal used Biomass and Bioenergy Journal

Computer software used Microsoft Word 2007, Excel 2007 and SAS v9.1

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

COMPOSITION AND YIELD OF EIGHT SWITCHGRASS CULTIVARS IN ALABAMA[1]

LINDSAY JEANNE CATHERINE CRIDER[2]

Abstract. Switchgrass (*Panicum virgatum*) is a viable cellulosic energy crop. Energy conversion technologies prefer cellulosic feedstock to contain low concentrations of lignin and ash and high concentrations of fermentable sugars. Research into chemical composition across species of cellulosic feedstocks has been analyzed. There has been little research however, dedicated to interspecies analysis between switchgrass cultivars.

The research objectives of this study were to analyze chemical composition and biomass yields of eight switchgrass cultivars in a twenty-year (1989-2008) randomized complete block (rep = 4) experiment in Alabama. Near-infrared spectroscopy was used to evaluate concentrations of acetyl, arabinan, ash, glucan, lignin, protein, xylan in leaf and stem biomass for 2007 and 2008. Theoretical ethanol yields were determined from the composition of sugars using the National Renewable Energy Laboratory website's 'Theoretical Ethanol Yield Calculator'. Biomass yield data of eight cultivars in a twenty-year (1989–2008) study was analyzed using multiple linear regression analysis in SAS

---

[1]Received for Publication March 13, 2009, and in revised form April, 10 2009.
[2] Grad. Res. Assis., Agron. and Soils Dept., Auburn Univ., Auburn, Al. 36849.

Corresponding author's email: cridelj@auburn.edu

v9.1, proc STEPWISE and proc MIXED. Biomass yield data was regressed against weather and harvest data. Total biomass yields were affected significantly by the weather factors precipitation, harvest and frostdate. The months of March, May and September appeared in highest frequency across cultivars as significant and positive to biomass yields. Highest biomass yields across 1989–2008 were observed in cultivars Alamo, Kanlow and Cave-In-Rock with averages of 10.27, 8.22 and 6.57 tons/acre respectively. Average annual ethanol yield totals from 2007 and 2008 for Alamo, Kanlow and Cave-In-Rock were 336.28, 248.75 and 201.03 gallons/acre respectively.

Leaf and stem biomass had different composition and were analyzed using SASv9.1 proc GLIMMIX and proc CANDISC. Leaf biomass was higher in ash and protein while stem biomass was higher in glucan and lignin. Leaf and stem biomass composition analysis with ANOVA tests showed significance among chemistry at the interactions cultivar x year, cultivar x harvest and year x harvest.

Differences in total chemical composition were analyzed for all cultivars using canonical discriminant analysis. Alamo, Kanlow and Trailblazer were significantly different from all other cultivars with respect to their composition. The other six cultivars were all similar to one another in composition. Desired composition of switchgrass could be manipulated for improved cultivars using genetic and plant breeding techniques.

LITERATURE REVIEW

Switchgrass (*Pancium virgatum*) has shown potential as a dedicated bioenergy crop in the United States (Douglas et al. 2004, Cassida et al. 2002, Cassida et al. 2005, Bransby et al. 1999). The Bioenergy Feedstock Development Program at the US Department of Energy has chosen switchgrass as a model biomass energy crop for alternative sources of energy to fossil fuels (Missaoui et al. 2006). Switchgrass is a North American native, perennial, C4 grass that ranges from Quebec to Central America (Bransby et al. 1999, Missaoui et al. 2006). This dynamic species has two main ecotypes with many genetically varying varieties which have allowed it to encompass a vast range of adaptation (Cassida et al. 2005). The two main ecotypes of switchgrass are lowland and upland. The lowland ecotype is heat and drought tolerant, thick stemmed and ranges through the lower plains of the Midwest into the Southeastern United States. The upland ecotype is cold tolerant, thin stemmed and ranges through the northern latitudes of North America (Bransby et al. 1999).

Switchgrass is an open-pollinated species which reproduces both by seed and vegetatively. The two ecotypes of switchgrass have different chromosome ploidy levels, the upland accessions being mostly octaploid ($2n = 8x = 72$) and the lowland accessions being mainly tetraploid ($2n = 4x = 36$) (Missaoui et al. 2006). Both upland and lowland ecotypes of switchgrass are highly self incompatible and cross pollination is only possible between cytotypes with similar ploidy level (Missaoui, et al. 2006).

The ethanol industry is facing fast-approaching problems in regard to the domestic corn feedstock supply competing with food prices and meeting the increasing public demand for domestic fuel over foreign oil (Bransby et al. 1999).

The ethanol industry is gradually making the switch from grain feedstock produced ethanol to exploring new technology and viability of cellulosic-based conversion technologies that utilize switchgrass and other cellulose-rich feedstocks (Douglas et al. 2004, Bransby et al. 1999).

The varieties that have shown greatest potential for biomass production for energy in the U.S. have been the high-biomass yielding lowland cultivars of Alamo and Kanlow for the Southern portion of the U.S. and the upland cultivar Cave-In-Rock for the mid and northern ranges of the U.S. (Douglas et al. 2004, McLaughlin et al. 2005). Current evidence shows that lowland cultivars Alamo, Kanlow and the upland Cave-In-Rock cultivar are the best lines to cultivate for bioenergy in the U.S. (Bransby et al. 1999, Cassida et al. 2002, McLaughlin et al. 2005). Lowland switchgrass cultivars can grow over three meters tall, are heat resistant and have a deep root system making them drought resistant (Bransby et al. 1999, Cassida et al.2002).

Harvest management regimes for increased yields of switchgrass have been explored in one and two cut harvest systems. To achieve optimum biomass yield from switchgrass, the lowland cultivars should be harvested once a year near the end of the growth period (Bransby et al. 1999, Cassida et al.2002). Upland cultivars yield about two to three times less per acre than lowland cultivars. Upland cultivars mature faster than lowland cultivars and therefore a two cut harvest system may be more advantageous to biomass yields for the upland cultivars (Bransby, et al. 1999, Cassida et al. 2002). Perennial forage grasses such as bermudagrass and big bluestem benefit from multiple harvest cuts per year but do not have the biomass yield potential that lowland Alamo and Kanlow switchgrass cultivars possess (Douglas et al. 2004, Daniels et al.2001).

There are several environmental benefits to establishing switchgrass, including soil and water conservation, carbon sequestration, bioremediation in buffer strips, and improved wildlife habitat (Bransby et. al. 1998, Cheng et. al. 2009). Soil nutrients are better retained within the soil when one annual harvest cut management is used versus multiple harvest cuts per year (Daniels et al.2001). Switchgrass helps to preserve and store soil nutrients Nitrogen, Calcium, Potassium, Carbon and particulate organic matter within the soil (Daniels et al. 2001, Cassida et al.2002, Bransby et al. 1999). No till methods are recommended for production of biomass from Alamo and Kanlow varieties of switchgrass (Daniels et al. 2001, Bransby et al. 1999). Carbon sequestration is the accumulation of carbon from the atmosphere into plant mass through photosynthetic processes (Bransby et al. 1999). Lowland ecotype switchgrass deep, vigorous root systems allow for immense root system carbon sequestration (Daniels et al. 2001, Cassida et al.2002, Bransby et al. 1999). Carbon is sequestered into the roots of the perennial plant and stored there even after a harvest cut of the above ground plant matter has taken place (Daniels et al. 2001, Bransby et al. 1999). Carbon sequestration in this way by switchgrass helps to deplete the carbon pool in the atmosphere and therefore helps to deplete the carbon dioxide pool in the atmosphere (Bransby et al. 1999). The growth cycle and utilization of switchgrass is considered to be a carbon neutral cycle (Bransby et al. 1999).

As a bioenergy crop, switchgrass will be used in thermal and biochemical conversion technologies to produce electricity and transportation fuel. Thermal conversion technologies require that biomass feedstock firing material possess low ash and nitrogen concentrations in order to increase energy conversion efficiency and to prevent slagging (Sanderson et al. 1996). Slagging is a build-up of material on the inside of a boiler caused by ash and inorganic deposits. The slagging build up prevents efficient heat transfer and can render a power plant inoperable. Nitrogen has been shown to cause an increase in NOX emissions and is therefore a negative attribute in a biomass feedstock used in thermal conversion systems (Burner, et. al. 2008). Biochemical conversion technologies prefer biomass materials with high cellulose, high fermentable sugars, and low ash content. Thermal conversion technologies prefer biomass feedstock to contain low ash, inorganics and nitrogen.

Much has been concluded regarding appropriate management practices and yields for switchgrass. However, due to tremendous genetic variability, little is known about switchgrass varieties' biomass composition. Plant material composition in switchgrass cultivars must be defined in order to meet current and future alternative energy industry demands for quality biomass. Near infrared spectroscopy has been used to determine biomass composition of several different biomass species including that of switchgrass. The compositional components of glucose, lignin, ash, acetyl, arabinan and xylan have been determined in biomass samples with great accuracy using near infra red spectroscopy (Sanderson, et al. 1996).

In order for an increase in conversion efficiency of cellulosic rich feedstocks such as switchgrass to occur research is needed to investigate plant material composition of different genetic lines (Bransby, et. al. 1999). If certain varieties contain high concentrations of cellulose, for example, plant breeding could be used to improve varieties for that genetic trait. These types of future plant breeding goals will increase biomass yields of convertible cellulosic biomass per acre. Increasing cellulosic material per acre will therefore increase gallons of convertable fuel per acre. Using switchgrass as an energy crop could provide a new and viable market for farmers as well as decrease our nation’s dependency on foreign oil (Bransby et al. 1999). This type of research into greater yields and biomass quality of switchgrass will help improve its viability as an alternative energy resource.

INTRODUCTION

The southeastern U.S. has been identified as having great potential for growing high biomass yielding energy crops to offset national consumption of foreign oil. Research results indicate lowland cultivars are better adapted than upland for the southeast region in terms of biomass yield. There is little research available which examines interspecies composition between switchgrass cultivars. Chemical composition may give an indication as to the quality of the biomass being produced from different cultivars and therefore be useful for future plant breeding for improved switchgrass cultivars. Quality of biomass is an important variable for existing conversion technologies which use cellulosic rich feedstocks in conversion processes to ethanol and other alternative fuels. If a producer can guarantee feedstock quality a higher price per ton may be attained.

The sectors of energy conversion technology that switchgrass may be used as a raw cellulosic rich biomass material are thermal and biochemical conversions. Each conversion technology has different criteria for the raw material composition that optimize conversion efficiency in their combustion and fermentation systems.

Thermal conversion technology includes co-firing switchgrass with coal in power plants. The main concern for thermal conversion of switchgrass to energy is the prevention of slagging. Slagging occurs when ash, nitrogen and alkali metal particulates such as silica, and potassium, are heated up in the boiler and coat the boiler making it inefficient at heat conversion. Slagging is expensive to remediate and can cause plants to become inoperable. Quality biomass for thermal conversion should contain low ash, nitrogen, and alkali metal concentrations.

Biochemical conversion technologies prefer cellulosic feedstocks to contain low ash concentrations and high concentrations of fermentable sugars. Fermentable sugars recognized as the main components of ethanol conversion by the National Renewable Energy Laboratory, are arabinan, xylan and glucan (NREL, 2008). Depending on the efficiency of conversion technology, lignin can be considered both a positive and negative composition attribute. Current biochemical conversion technologies are able to convert a high proportion of lignin content into fermentable sugars through the use of pretreatment techniques (Cheng et al. 2009). Through advancement in conversion technology lignin may become a more valuable component to feedstock composition for conversion to liquid fuels.

Future plant breeding of switchgrass should be focused on optimizing yields and biomass composition quality to increase conversion efficiency. Currently there is little data on plant material composition specific to lowland and upland cultivars of switchgrass. Compositional analysis should be focused on evaluation of ash, lignin, and fermentable sugars including glucose, xylose, and arabinose. The overall objective of this study was to collect switchgrass cultivar biomass composition information from an existing twenty-year variety trial experiment at the E.V. Smith Research Center in Shorter, Alabama. The experiment plot included eight switchgrass cultivars, Alamo, Kanlow, Cave-In-Rock, Blackwell, Pathfinder, Trailblazer, Summer and Kansas Native. Alamo and Kanlow are the two lowland cultivars while the other six cultivars are upland ecotype cultivars. Compositional analysis for acetyl, arabinan, ash, glucan, lignin, protein and xylan were performed through Near Infrared (NIR) analysis. Leaf and stem biomass were examined separately. The goals of this research project were to identify plant matter composition specific to the eight different switchgrass cultivars and relate the data to each cultivar's biomass yield data. Differences in composition and yield among biomass samples and cultivars will be defined.

RESEARCH OBJECTIVES

The main research objective of this study was to analyze eight cultivars of switchgrass in Alabama for differences in chemical composition using near infrared spectroscopy. Chemical constituents analyzed were acetyl, arabinan, ash, glucan, lignin, protein and xylan. Arabinan, glucan and xylan are the prime fermentable sugars responsible for ethanol production. Theoretical ethanol yields were determined from the fermentable sugar concentration in leaf and stem biomass samples using the NREL website ‘Theoretical Ethanol Yield Calculator’ (http://www.nrel.gov/biomass/energy_analysis.html). Variables used in analysis for composition differences were cultivar, harvest and year. Cultivars as a whole and their leaves and stem biomass were analyzed for significant differences in chemical composition.

The second objective of this study was to determine the effects of weather factors on biomass yields of eight switchgrass cultivars over a twenty-year period from 1989 to 2008. Biomass yield data was regressed against weather and harvest data. Weather factors explored in relation to their effects of biomass yield were monthly precipitation, previous year precipitation, date of last spring frost, harvest and year. Positive and negative factors for annual biomass yields across cultivars were determined.

MATERIALS AND METHODS

Biomass samples of eight switchgrass cultivars were gathered from an existing switchgrass cultivar test experiment plot at E.V. Smith Research Station in Shorter, Alabama in 2007 and 2008. The research plot is organized in a randomized complete block design with four replications representing eight varieties. The varieties represented within the experiment are the lowland varieties Alamo and Kanlow and upland varieties Blackwell, Cave-In-Rock, Kansas Native, Pathfinder, Summer, and Trailblazer. The experiment plot was established in the spring of 1988. Seed was drilled into plots at a rate of 11.3 kg ha^{-1}, with 18cm between rows. Each plot is 1.5 m x 6.0 m with 1.5 m alleys in between each plot row. All plots received 84 kg N ha^{-1}, split into two equal applications in March and again after the first harvest cut. The experiment site is on a Wickham soil (fine-loam, mixed, thermic Typic Hapludult).

Samples were collected twice each year, just prior to each harvest, to represent the two harvest system under which the experiment plot was managed. Harvests occurred in the summer, between July and August, and again in late fall, between October and November. Samples were hand-collected randomly in each plot, cut 10cm above the soil surface. The biomass samples were then oven dried at 60 degrees Celsius for 48 hours. Once the samples were dried, biomass was separated into leaf and stem samples and weighed.

The dry, separated biomass samples from each plot were then ground using a Wiley mill to pass through a 2-mm screen prior to near-infrared spectroscopy analysis (NIR). NIR analysis was done at Ceres, Inc. plant biotechnology laboratories in Thousand Oaks, California using their proprietary materials and methods.

The NIR spectrometer used for method development was a Bruker Optics model MPA FT-NIR Spectrometer, which integrates sphere with a rotating sample cup assembly. Analysis of the switchgrass varietal biomass samples was done using the rotating sample cup assembly. The rotating sample cup assembly is used to obtain accurate measurement results of heterogeneous samples or samples with large particle sizes. A standard lead-sulfide detector array to monitor NIR light from 12,800 – 5,800 cm^{-1}. A Blackman-Harris 3-term apodization function was selected with a zero filling factor of 2. This instrument has a maximum resolution of $2cm^{-1}$. Spectroscopic techniques were developed which enabled a high quality, reproducible and representative NIR reflectance spectrum to be obtained for each of the calibration samples. To minimize the effect of water in the biomass spectra, each sample was dried to less than 10% moisture prior to NIR analysis using a biomass oven drier at 60 degrees Celsius for 48 hours. Spectral information was collected from 12,500 cm^{-1} - 3600 cm^{-1} with a resolution of 8 cm^{-1}.

For each spectroscopic sample, a total of 64 spectra were collected and averaged to compensate for sample heterogeneity. Each calibration sample was sub-sampled three times and the sub-sample spectra were averaged. Only final averaged spectra were used in the method calibration. Instrument reproducibility tests demonstrated that the reproducibility limits of the NIR spectrometer contributed less than 0.2% to the absolute prediction errors in NIR/PLS methods. Compositional data was obtained using Ceres proprietary NIR/PLS method SWG_5. Compositional constituents analyzed for in the biomass samples were acetyl, arabinan, ash, glucan, lignin, protein and xylan.

Biomass yield data was collected on the switchgrass variety test experiment plot since 1989. The yields for all eight cultivars were collected on a twice annual basis at each harvest. Yield data from this experiment plot was analyzed from the years 1989 to 2008. Weather data was also collected from the E.V. Smith Research station at Shorter, Alabama and used in multiple regression analysis with yield data to determine any relationships of weather factors and yield.

Cultivar composition was also analyzed for ethanol yield using the NREL website theoretical ethanol yield calculator (http://www.nrel.gov/biomass/energy_analysis.html). Theoretical ethanol yields were used to evaluate gallons ton^{-1} yield extrapolated from biomass chemical compositions in years 2007 and 2008. This component was added in order to evaluate not only total biomass yield quantity but also, biomass yield quality in terms of the amount of ethanol convertible biomass material per ton produced per cultivar.

Statistical analysis of biomass yield data in multiple linear regression against weather data was evaluated using SAS v9.1 proc STEPWISE and proc MIXED. Weather variables analyzed were each month precipitation, total annual precipitation, previous year total precipitation of September through December, previous year monthly precipitation September through December, last spring frost date, and days between harvest. Stepwise regression was used to base separation for cultivar and cut date. Default p value of 0.15 was used for terms to enter and remain in the model. Year was of prime interest and was therefore forced as the first term in the model irrespective of significance. Weather data was then analyzed above and beyond year variable. Regression was performed for each of the eight cultivars and harvest times separately. Weather data were evaluated independent from age of the stand in order to clearly determine relationship correlations. Significance of variables was determined by p-values ≤ 0.05. Proc STEPWISE was also used to analyze the mean values. Proc STEPWISE cannot account for random effects so proc MIXED was used to calculate proper error terms. Predictions were made using proc MIXED in order to account for repeated effects and to calculate proper error terms.

Statistical analysis of composition data was performed using SAS v9.1 proc GLIMMIX for mixed model analysis, proc CANDISC for canonical discriminant analysis between cultivar compositions. The reason proc GLIMMIX was used rather than proc MIXED was for the slice-diff option available in GLIMMIX. The slice-diff option is used to compare and evaluate interaction means. Interactions of Cultivar x Harvest, Cultivar x Year and Year x Harvest were evaluated. Interaction means between individual cultivars were evaluated by least square means using slice-diff in proc GLIMMIX. The cultivar, Alamo is considered to be the “model” herbaceous energy crop (Sanderson et al., 1996). Alamo was chosen as the control because it is the most productive cultivar and the standard for bioenergy production. Whole composition between cultivars was analyzed using a matrix of p-values in proc CANDISC. CANDISC was performed on year with interaction cultivar x year x rep. Proc STEPDISC was used to narrow variables with a default p value of 0.15. The default p-value reduced the number of variables that would influence the difference among cultivars. Class variable was cultivar. Discriminant analysis was performed with maximum within class and minimum within variables. Six variables were discovered which drove differences among cultivar compositions.

RESULTS

Highest biomass yields were observed in Alamo, Kanlow and Cave-In-Rock with average totals from 1989-2008 of 10.27, 8.22 and 6.57 tons dry matter acre^{-1} (Table 1, Figure 1). Average annual theoretical ethanol yield totals from 2007 and 2008 for Alamo, Kanlow and Cave-In-Rock were 336.28, 248.75 and 201.03 gallon acre^{-1} (Table 2). Monthly precipitation total inches from years 1988 – 2008 showed lowest annual rainfall in the twenty year period occurred in 2007 with 35.97 inches (Table 3). Spring frost date from 1989-2008 showed the latest date of 102 days from January first occurred in 1996 followed by the earliest frost date for the twenty year period in 1997 with 48 days after January first (Table 4).

Stepwise regression for each cultivar and harvest in Table 5, show significant factors with their positive or negative effect on biomass yield per cultivar. Alamo first harvest yields were significantly affected by precipitation in the months of August, June, and May with p-values of 0.0016, 0.0001, and 0.0000 respectively (Table 6). Spring frost date and previous year precipitation in October were also significant with p-values of 0.0014 and 0.0275 respectively. Alamo first harvest yields were positively affected by precipitation in May with a 1.4996 unit increase in Mg DM ha^{-1} yield for every inch increase in precipitation received in May. Spring frost date also had positive effect on Alamo's first harvest yields with a 0.1256 unit increase in Mg DM ha^{-1} for every day later from January first in last spring frost date. Precipitation in August, June and previous year precipitation in October all had negative effects on Alamo first harvest biomass yields with -0.68484, -0.64609, and -0.48081 units Mg DM ha^{-1} respectively for every inch increase in precipitation in those months.

Alamo second harvest yields were significantly affected by precipitation in the months of October, March, July, December and the previous year precipitation between the months of September and December with p-values of 0.0000, 0.0000, 0.0000, 0.0122 and 0.0000 respectively (Table 6). Alamo second harvest yields were positively affected by precipitation in March with a 0.3067 unit increase in Mg DM ha^{-1} with every inch increase of precipitation in March. Alamo second harvest yields were negatively affected by precipitation in months of October, July, December and previous year precipitation between September and December with values of -0.6773, -0.4621, -0.5303 and -0.3019 units Mg DM ha^{-1} respectively for every inch increase in precipitation in those months.

Kanlow first harvest yields were significantly affected by precipitation in the months of March, July and October with p-values of 0.0145, 0.0008, and 0.0134 respectively (Table 7). Kanlow first harvest yields were positively affected by precipitation in March with a 0.2263 unit increase in Mg DM ha^{-1} yield for every inch increase in precipitation received in that month. Precipitation in July and October had a negative effect on first harvest biomass yields with -0.4618 and -0.3467 units Mg DM ha^{-1} respectively for every unit decrease in precipitation.

Kanlow second harvest yields were significantly affected by precipitation in December and previous year precipitation in October with p-values of 0.0000 and 0.0016 respectively (Table 7). December and previous year October precipitation both had negative effects on biomass yield with -0.8029 and -0.2743 unit decrease in Mg DM ha^{-1} for every inch increase in precipitation received respectively.

Cave-In-Rock first harvest yields were significantly affected by precipitation in the months of September and March with p-values of 0.0000 and 0.0000 respectively (Table 8). September and March both had positive effects on Cave-In-Rock first harvest yields with0.7754 and 0.3354 unit increases in Mg DM ha^{-1} for every inch increase in precipitation received. Cave-In-Rock second harvest yields were significantly affected by precipitation in May with a p-value of 0.0009 (Table 8). Precipitation in May had a positive effect on biomass yield with 0.5349 increase in Mg DM ha^{-1} for every inch increase in precipitation received.

Pathfinder first harvest yields were significantly affected by precipitation in the month of January, and previous year precipitation in October with p-values of 0.0281, and 0.0173 respectively (Table 9). Pathfinder first harvest yields were positively affected by precipitation in the previous year's October with a 0.3280 unit increase in Mg DM ha^{-1} for every inch increase in precipitation received in previous year precipitation in October. Precipitation in January had a negative effect on Pathfinder first harvest biomass yields with -0.4581 units Mg DM ha^{-1} respectively for every inch increase in precipitation.

Pathfinder second harvest yields were significantly affected by precipitation in March with a p-value of 0.0000 (Table 9). March precipitation had a positive effect on biomass yield with a 0.2118 unit increase in Mg DM ha^{-1} yield for every unit increase in precipitation received.

Blackwell first harvest yields were significantly affected by precipitation in the months of September, March and August with p-values of 0.0001, 0.0045 and 0.0464 respectively (Table 10). All three months had positive effects on Blackwell first harvest yields with 0.4428, 0.1596 and 0.1929 unit increases in Mg DM ha^{-1} for every inch increase in precipitation received in those months.

Blackwell second harvest yields were significantly affected by precipitation in May and December with p-values of 0.0003 and 0.0032 respectively (Table 10). Precipitation in May had a positive effect on biomass yield in second harvest of Blackwell with 0.4159 increase in Mg DM ha^{-1} for every inch increase in precipitation received. Precipitation in December had a negative effect on biomass yield with a -0.3155 unit decrease in Mg DM ha^{-1} for every inch increase in precipitation.

Kansas Native first harvest yields were significantly affected by precipitation in the months of September, March and January with p-values of 0.0000, 0.0000 and 0.0085 respectively (Table 11). September and March both had positive effects on Kansas Native first harvest yields with 0.5646 and 0.2462 unit increases in Mg DM ha^{-1} yield for every inch increase in precipitation received.

Kansas Native second harvest yields were significantly affected by precipitation in March, June, July and October with p-values of 0.0000, 0.0000, 0.0001 and 0.0013 respectively (Table 11). Precipitation in March and June had positive effects on biomass yield in second harvest of Kansas Native with 0.2294 and 0.2430 increase in Mg DM ha^{-1}

for every inch increase in precipitation. Precipitation in July and October had negative effects on biomass yield with a -0.2903 and -0.2442 unit decrease in Mg DM ha^{-1} for every inch increase in precipitation.

Summer first harvest yields were significantly affected by precipitation in the months of March and September with p-values of 0.0005, 0.0007 respectively (Table 12). March and September both had positive effects on Summer first harvest yields with 0.2321 and 0.4085 unit increases in Mg DM ha^{-1} for every inch increase in precipitation received. Summer second harvest yields were significantly affected by precipitation in May with a p-value of 0.0004. Precipitation in May had a positive effect on biomass yield with 0.5565 increase in Mg DM ha^{-1} yield for every inch increase in precipitation received.

Trailblazer first harvest yields were significantly affected by precipitation in the months of January and previous year October with p-values of 0.0003, and 0.0200 respectively (Table 13). Precipitation in previous year October had a positive effect on Trailblazer first harvest yields with 0.1651 unit increase in Mg DM ha^{-1} for every inch increase in precipitation received. Precipitation in January had a negative effect on Trailblazer first harvest yields with a -0.4004 unit decrease in Mg DM ha^{-1} yield for every inch increase in precipitation received.

Trailblazer second harvest yields were significantly affected by precipitation in March with a p-value of 0.0000 (Table 13). Precipitation in March had a positive effect on biomass yield in second harvest of Trailblazer with 0.1851 increase in Mg DM ha^{-1} yield for every inch increase in precipitation received.

Composition analysis was evaluated in SAS v9.1 using analysis of variance (ANOVA) tests in proc GLIMMIX. Leaf and stem biomass composition were analyzed against cultivar, year, harvest, cultivar by year, cultivar by harvest and year by harvest factors and interactions. Leaf and stem composition concentrations of acetyl, arabinan, ash, glucan, lignin, protein and xylan were analyzed against variables and evaluated for significance.

Leaf biomass composition has more ash and protein than stem biomass (Figure 2 and Figure 3). Stem biomass composition has more glucan and lignin than leaf biomass (Figure 4 and Figure 5). Concentrations of acetyl, arabinan, and xylan are not clearly separated by leaf or stem biomass populations (Figure 6, Figure 7, and Figure 8). Characteristics of leaf and stem biomass composition are important to note when analyzing ANOVA tables for leaf and stem biomass.

Leaf biomass ANOVA tests indicated that acetyl concentrations in leaf biomass were significantly affected by cultivar, year, and harvest with p-values of 0.0269, 0.0000 and 0.0000 respectively (Table 14). Arabinan concentrations in leaf biomass were significantly affected by cultivar, year, and harvest with p-values of 0.0096, 0.0000 and 0.0000 respectively. Glucan concentrations in leaf biomass are significantly affected by cultivar, year, and harvest with p-values of 0.0242, 0.0000 and 0.0001 respectively. Xylan concentrations in leaf biomass are significantly affected by cultivar, year, harvest, and cultivar by year with p-values of 0.0007, 0.0000, 0.0000 and 0.0441 respectively. Protein concentrations in leaf biomass are significantly affected by year, harvest and year by harvest with p-values of 0.0635, 0.0000 and 0.0000 respectively. Lignin concentrations in leaf biomass are significantly affected by cultivar and year with p-values of 0.0048 and 0.0000 respectively. Ash concentrations in leaf biomass are significantly affected by cultivar, year, harvest and cultivar by harvest with p-values of 0.0013, 0.0000, 0.0268 and 0.0015 respectively. Ethanol yields in leaf biomass are significantly affected by cultivar, year, harvest, cultivar by year and cultivar by harvest with p-values of 0.0006, 0.0000, 0.0000, 0.0452 and 0.0020 respectively.

Stem biomass ANOVA tests indicated that acetyl concentrations in stem biomass were significantly affected by year, harvest, cultivar by year and year by harvest with p-values of 0.0000, 0.0000, 0.0918 and 0.0001 respectively (Table 15). Arabinan concentrations in stem biomass are significantly affected by cultivar, year, harvest, and year by harvest with p-values of 0.0302, 0.0000, 0.0000 and 0.0000 respectively. Glucan concentrations in stem biomass are significantly affected by cultivar, year, harvest, cultivar by harvest and year by harvest with p-values of 0.0002, 0.0002, 0.0185, 0.0429 and 0.0000 respectively. Xylan concentrations in stem biomass are significantly affected by cultivar and year with p-values of 0.0034 and 0.0000 respectively. Protein concentrations in stem biomass are significantly affected by year, harvest and cultivar by year with p-values of 0.0000, 0.0000 and 0.0051 respectively. Lignin concentrations in stem biomass are significantly affected by cultivar, year, harvest, cultivar by year, cultivar by harvest and year by harvest with p-values of 0.0536, 0.0000, 0.0000, 0.0499, 0.0387 and 0.0535 respectively. Ash concentrations in stem biomass are significantly affected by cultivar, year, harvest, cultivar by harvest and year by harvest with p-values of 0.0241, 0.0000, 0.0000, 0.0300 and 0.0000 respectively. Ethanol yields in stem biomass are significantly affected by cultivar, year, and year by harvest with p-values of 0.0043, 0.0002 and 0.0000 respectively.

Canonical discriminant analysis (CDA) was applied to determine differences among cultivars relating to their total chemical composition (Figure 9). Differences in composition among cultivars are shown in Table 16 as a p-value matrix. Alamo, Kanlow and Trailblazer are all significantly different from each other and all other cultivars. There are no other cultivars similar to any one of these three unique cultivars. Blackwell, Cave-In-Rock, Kansas Native, Pathfinder and Summer are significantly different from Alamo, Kanlow and Trailblazer. Blackwell, Cave-In-Rock, Kansas Native, Pathfinder and Summer are all similar in composition to one another. Summer and Cave-In-Rock are 93% similar in composition. Pathfinder and Blackwell are 89% similar in composition. Kansas Native and Cave-In-Rock are 88% similar in composition. Cave-In-Rock is 80% similar to Blackwell in composition.

Composition components which were determined significant to cultivar chemical differences in CDA were stem glucan in first harvest, stem xylan in first harvest, leaf protein in second harvest, leaf lignin in second harvest and leaf ethanol in second harvest. Alamo variance from the other cultivars is explained in the x-axis (CAN 1) variables of stem glucan in first harvest, stem xylan in first harvest and leaf protein in second harvest (Figure 9). The composition of Alamo which make it significantly different from all other cultivars are that it is highest in stem glucan concentration in first harvest, highest in leaf protein concentration in second harvest and lowest in stem xylan concentration in first harvest.

Trailblazer, Kanlow and the five other cultivars variance in composition from other cultivars is explained in the y-axis (CAN 2) variables of leaf lignin in second harvest and leaf ethanol in second harvest (Figure 9). Trailblazer ranks highest followed by Kanlow for concentrations of lignin in leaf biomass in second harvest. The other five cultivars are lower in lignin concentrations than Trailblazer and Kanlow. Trailblazer ranked lowest in leaf ethanol yield in second harvest. Kanlow ranked low in leaf ethanol yield.

CONCLUSIONS

The variety test experiment used was located in south central Alabama, not replicated in other locations therefore a prescription of interspecies switchgrass composition and yield for the southeast cannot be determined. Replications of variety tests would be needed across regions to make a determination of cultivar biomass composition or yield and weather relationships.

Highest biomass yields averaged over 1989–2008 within this experiment were observed in Alamo, Kanlow and Cave-In-Rock with yields of 10.27, 8.22 and 6.57 tons dry matter acre^{-1}. The theoretical ethanol yields determined from the chemical composition of these three cultivars were lower than average ethanol yield determinations for switchgrass. Ethanol yields for Alamo, Kanlow and Cave-In-Rock were 336.28, 248.75 and 201.03 gallons acre^{-1} respectively. Ethanol yield data showed higher yields for stem biomass than leaf biomass given tons DM acre^{-1} and fermentable sugar concentrations per the separated biomass. Ethanol yields from 2007 and 2008 for Alamo stem biomass averaged 279.97 gallons acre^{-1} while leaf biomass averaged 56.31 gallons acre^{-1}. Stem biomass had higher total dry matter yield and higher fermentable sugar yields than leaf biomass.

Chemical composition was different among cultivars with Alamo, Kanlow and Trailblazer being significantly different from other cultivars. Alamo had the highest glucan concentration in stem biomass, highest protein concentration in leaf biomass and lowest xylan concentration in stem biomass. Trailblazer had the highest lignin concentration in leaf biomass and the lowest ethanol yield in leaf biomass. Kanlow was among the highest in leaf biomass lignin and among the lowest in ethanol yield in leaf biomass. The other five cultivars were similar to one another but significantly different from Alamo, Kanlow and Trailblazer. Biomass chemical composition is controlled somewhat by the genetic makeup of cultivars. Biomass composition in cultivars is also influenced and changed by year and harvest.

The determination of best harvest cut systems should be studied further along with maturation stages of different cultivars at time of harvest for optimal biomass composition. Cuts at maturity prior to senescence and entrance to reproductive stage may improve biomass yields as well as biomass composition for higher concentrations of fermentable sugars. It may be of economic value in switchgrass management systems to develop cultivars which mature to biomass yield potential and quality twice per year.

Because multiple linear regression was used to analyze biomass yields against weather data for the eight cultivars a multiple effect of precipitation months was observed. The positive or negative effect of one month's precipitation was analyzed and predicted as such given the other weather variable effects on that cultivar's biomass yield. The effect of weather on yield therefore is a multiple factored effect.

Precipitation received in March and September was significant for all eight cultivars in either one harvest or in both. March and September either were significant in combination or separately for each cultivar. September precipitation was significant to biomass yield in the first harvest only and had a positive relationship to yield in all cultivars which it appeared significant except for Alamo where it had a negative relationship to yield. March precipitation was significant and positive to biomass yield for each cultivar in combination with September or independent from September in first and second harvests. An optimal irrigation management system may exist for switchgrass given certain months having highest positive relationships with biomass yield.

LITERATURE CITED

Bransby D.I., Bouton J, Conger B, McLaughlin S. B., Ocumpaugh W. R., Parrish D., Taliaferro K., Vogel K., Wallschleger S. 1999. Developing Switchgrass as a Bioenergy Crop. PotNewCropNewUses. AgronSHS. 282-299.

Bransby D.I., McLaughlin S.B. Parrish D.J. 1998. A Review of Carbon and Nitrogen Balances in Switchgrass Grown for Energy. Biomass Bioenergy. Vol 14; No. 4: 379-384.

Bransby D.I., Sladden S.E., Aiken G.E. 1991. Biomass Yield, Composition and Production Costs for Eight Switchgrass Varieties in Alabama. Biomass Bioenergy. Vol 1; No. 2: 119-122.

Burner D.M., Belesky D.P., Harvey J.J., Tew T.L. 2008. Dry Matter Partitioning and Quality of Miscanthus, Panicum, and Saccharum, genotypes in Arkansas, USA. Biomass Bioenergy. online.

Cassida K.A., Hussey M.A., Muir J.P., Ocumpaugh W.R., Read J.C., Venuto B.C. 2005. Biofuel Component Concentrations and Yields of Switchgrass in South Central U.S. Environments. CropSci.SA. 45:682-692.

Cassida K.A., Hussey M.A., Muir J.P., Ocumpaugh W.R., Read J.C., Venuto B.C. 2005. Biomass Yield and Stand Characteristics of Switchgrass in South Central U.S. Environments. CropSci.SA. 45:673-681.

Cassida K.A., Evers G., Grichar J., Hons F., Hussey M.A., Muir J.P., Ocumpaugh W.R., Read J.C., Tischler C., Venuto B.C. 2002. Evaluation of Switchgrass Cultivars and Cultural Methods for Biomass Production in the South Central U.S. OakRidgeNL.TAMU.

Cheng J.J., Keshwani D.R. 2009. Switchgrass for bioethanol and other value-added applications: A Review. Bioresource Tech. 100:1515-1523.

Daniels W.L., Fike J.H., Parrish D.J., Wolf D.D. 2001. Switchgrass as a Biofuels Crop for the Upper Southeast: Variety Trials and Cultural Improvements. OakRidgeNL.VPISU.

Douglas J.L., Edwards S.D., Grabowski J.M. 2004. Evaluation of Warm Season Grass Species and Management Practices to Improve Biomass Production Potential in the Mid-South. USDA. NatResConS.

Missaoui A.M., Bouton J.H., Paterson A.H. 2006. Molecular Markers for the Classification of Switchgrass (*Panicum virgatum* L.) Germplasm and to assess genetic diversity in three synthetic switchgrass populations. Genetic Resources and Crop Evolution. 53:1291-1302.

McLaughlin S.B., Kszos L.A. 2005. Development of Switchgrass (*Panicum virgaturm*) as a bioenergy feedstock in the United States. Biomass Bioenergy. Vol. 28; No. 6: 515-535.

Moore K.J., Moser L. E., Vogel K.P., Waller S.S., Johnson B.E., Pedersen J.F. 1991. Describing and Quantifying Growth Stages of Perennial Forage Grasses. Agron. J. 83:1073-1077.

NREL Theoretical Ethanol Yield Calculator, 2006. Available from <http://www.nrel.gov/biomass/energy_analysis.html>.

NREL Glossary of Biomass Terms, 2008. Available from <http://www.nrel.gov/biomass/energy_analysis.html>.

Sanderson M.A., Agblevor, F., Collins, M., Johnson, D.K., 1996. Compositional Analysis of Biomass Feedstocks By Near Infrared Reflectance Spectroscopy. Biomass Bioenergy. Vol. 11; No. 5: 365-370.

Sanderson M.A., Reed R.L., McLaughlin S.B., Wullschleger S.D., Conger B.V., Parrish D.J., Wolf D.D., Taliaferro C., Hopkins A.A., Ocumpaugh W.R., Hussey M.A., Read J.C., Tischler C.R. 1996. Switchgrass As A Sustainable Bioenergy Source. Bioresource Technol. 56:83-93.

SAS Institute Inc. 2008. SAS online doc, Version 9.1. SAS Institute Inc., Cary, NC.

APPENDIX

Table 1. Average Biomass Yields per Cultivar per year from 1989 - 2008 (Tons DM $Acre^{-1}$)

Average Biomass Yield per cultivar (1989- 2008) , Range of Biomass Yield (Minimum & Maximum) and Standard Deviation

	Cultivar							
Year	Alamo	Blackwell	Cave-In-Rock	Kanlow	Kansas Native	Pathfinder	Summer	Trailblazer
1989	7.58	3.42	4.20	6.16	4.03	4.56	4.31	4.32
1990	15.43	3.02	4.64	10.36	3.85	4.56	4.71	4.24
1991	12.62	4.18	5.35	8.00	4.55	5.54	5.95	5.07
1992	10.81	2.45	3.05	7.92	2.91	3.18	3.45	3.12
1993	10.11	4.12	5.10	7.77	5.34	5.32	6.03	5.23
1994	8.71	5.73	6.40	7.24	5.67	6.69	7.48	6.04
1995	7.56	3.20	4.78	5.82	4.11	3.60	4.34	3.73
1996	7.04	4.92	6.20	6.40	5.61	5.80	5.79	4.85
1997	6.78	4.90	6.18	6.33	5.70	4.28	5.97	4.31
1998	9.43	6.60	9.49	8.15	8.39	6.00	7.95	6.01
1999	10.38	5.04	7.00	9.59	6.64	5.09	6.64	4.60
2000	13.28	6.20	9.24	11.93	8.70	8.72	8.60	5.93
2001	13.68	7.29	10.00	10.82	9.67	7.81	9.37	7.10
2002	11.57	5.42	7.70	8.47	8.17	7.14	7.73	6.13
2003	10.81	6.19	8.16	9.94	8.79	7.32	7.96	5.46
2004	9.72	5.57	6.74	8.23	6.68	5.91	6.17	5.72
2005	10.35	6.45	7.41	8.67	7.69	7.32	7.40	6.11
2006	11.27	6.98	8.21	8.56	8.00	7.63	8.71	7.22
2007	9.00	3.42	5.27	5.55	5.57	4.31	4.57	3.72
2008	9.27	5.72	6.36	8.41	6.88	7.06	6.94	6.66
Average (1989 - 2008)	10.27	5.04	6.57	8.22	6.35	5.89	6.50	5.28
Minimum	6.78	2.45	3.05	5.55	2.91	3.18	3.45	3.12
Maximum	15.43	7.29	10.00	11.93	9.67	8.72	9.37	7.22
Standard Deviation	2.29	1.42	1.86	1.71	1.92	1.53	1.66	1.15

Table 2. Average annual ethanol yield totals of switchgrass cultivars grown in Alabama (gallons acre^{-1})

Cultivar	Year	Harvest	Leaf	Stem	Total	Annual Total	Average
Alamo							
	2007	First	32.24	249.67	281.91	357.78	336.28
		Second	13.30	62.57	75.87		
	2008	First	43.54	165.48	209.02	314.77	
		Second	23.54	82.21	105.75		
Kanlow							
	2007	First	19.41	163.01	182.42	212.77	248.75
		Second	6.54	23.81	30.35		
	2008	First	41.18	162.62	203.80	284.73	
		Second	17.02	63.91	80.93		
Cave-In-Rock							
	2007	First	21.33	142.07	163.40	207.08	201.03
		Second	6.85	36.83	43.68		
	2008	First	29.15	97.59	126.74	194.98	
		Second	21.00	47.24	68.24		

Table 3. Monthly precipitation 1988 - 2008 (Inches Month^{-1}) E.V. Smith Research Station: Shorter, Alabama

	Month												
Year	January	February	March	April	May	June	July	August	September	October	November	December	Total in.
1988	6.02	3.97	3.48	4.25	2.59	3.19	4.48	2.45	9.68	1.98	6.47	3.61	52.17
1989	1.55	2.82	7.29	7.39	5.33	13.72	7.51	1.68	3.30	4.72	3.00	8.17	66.48
1990	5.79	5.74	11.69	2.77	4.14	1.99	2.82	1.33	1.29	1.40	1.57	3.50	44.03
1991	7.06	2.59	7.51	3.08	4.27	4.18	8.97	4.25	2.51	0.17	4.90	3.57	53.06
1992	6.52	6.30	4.16	2.84	0.72	4.09	5.12	2.80	2.73	3.21	9.80	4.96	53.25
1993	3.64	4.39	6.26	3.22	2.57	3.54	1.59	5.46	2.00	4.02	4.32	3.89	44.90
1994	4.76	4.92	5.64	2.42	1.58	4.88	11.06	4.12	2.27	4.46	2.85	2.60	51.56
1995	4.32	4.92	3.68	3.55	1.33	1.77	1.88	2.65	4.37	12.41	2.77	7.92	51.57
1996	5.87	3.73	8.72	3.59	3.25	1.77	7.59	5.83	7.53	1.44	3.81	3.88	57.01
1997	5.12	8.15	1.47	7.74	5.12	8.72	2.12	3.38	4.50	4.95	6.93	6.64	64.84
1998	4.99	7.43	6.33	7.48	1.69	3.95	6.11	1.43	8.84	0.49	1.82	3.10	53.66
1999	8.16	3.28	5.90	1.40	3.62	12.18	3.12	1.92	4.01	4.27	2.63	4.07	54.56
2000	5.13	1.29	5.51	3.64	1.69	1.63	3.05	3.46	4.96	0.95	7.07	5.60	43.98
2001	3.75	3.82	16.07	5.18	5.47	5.84	4.15	4.69	0.97	1.18	2.74	3.25	57.11
2002	4.29	3.32	7.51	3.73	3.58	4.76	2.96	1.76	4.29	4.79	4.35	5.89	51.23
2003	1.68	7.32	8.98	9.23	4.72	8.30	7.79	4.44	3.66	0.86	5.10	3.59	65.67
2004	2.25	4.89	0.91	3.12	3.21	6.57	4.05	4.94	5.66	1.49	7.33	2.77	47.19
2005	2.28	5.19	14.37	7.51	3.32	2.61	8.94	7.71	1.29	2.52	4.37	2.57	62.68
2006	4.39	5.38	4.07	1.94	3.64	0.96	4.31	4.40	2.71	4.18	6.24	3.27	45.49
2007	6.27	3.33	2.25	2.63	0.34	1.09	5.69	1.49	1.96	3.51	2.47	4.94	35.97
2008	5.23	2.61	3.31	4.35	2.94	2.87	4.52	10.18	0.49	4.08	3.49	3.19	47.26
Average	4.72	4.54	6.43	4.34	3.10	4.70	5.13	3.83	3.76	3.19	4.48	4.33	52.56
Minimum	1.55	1.29	0.91	1.40	0.34	0.96	1.59	1.33	0.49	0.17	1.57	2.57	35.97
Maximum	8.16	8.15	16.07	9.23	5.47	13.72	11.06	10.18	9.68	12.41	9.80	8.17	66.48

Table 4. Total annual precipitation (inches $year^{-1}$) and date of last spring frost (January 1=1)

E.V. Smith Research Station: Shorter, Al.		
Year	Precipitation	Frost Date
1988	52.17	80
1989	66.48	68
1990	44.03	98
1991	53.06	74
1992	53.25	95
1993	44.90	93
1994	51.56	91
1995	51.57	70
1996	57.01	102
1997	64.84	48
1998	53.66	81
1999	54.56	78
2000	43.98	101
2001	57.11	69
2002	51.23	83
2003	65.67	90
2004	47.19	84
2005	62.68	68
2006	45.49	86
2007	35.97	98
2008	47.26	86
Average	52.56	83
Minimum	35.97	48
Maximum	66.48	102

Table 5. Stepwise regression table of significant weather factors to biomass yields per cultivar; months listed represent Precipitation in those months, Frost Date = Last spring frost, p-values less than 0.05, (+) and (-) represent positive or negative effect

Cultivar	Harvest	Pred 1	Pred 2	Pred 3	Pred 4	Pred 5	Pred 6
Alamo	First	Sept (-)	Aug (-)	June (-)	May (+)	Frost Date (+)	Prev Oct (-)
Alamo	Second	Oct (-)	Prev Sept-Dec (-)	March (+)	July (-)	Dec (-)	
Blackwell	First	Prev Sept-Dec (+)	Sept (+)	March (+)		Aug (+)	
Blackwell	Second	May (+)	Dec (-)				
Cave In Rock	First	Sept (+)	March (+)				
Cave In Rock	Second	May (+)					
Kanlow	First	March (+)	July (-)	Oct (-)			
Kanlow	Second	Dec (-)	Prev Oct (-)				
Kansas Native	First	Sept (+)	March (+)	Jan (-)			
Kansas Native	Second	March (+)	June (+)	July (-)	Oct (-)		
Pathfinder	First	Prev Oct (+)	Jan (-)				
Pathfinder	Second	March (+)					
Summer	First	March (+)	Sept (+)				
Summer	Second	May (+)					
Trailblazer	First	Jan (-)	Prev Oct (+)				
Trailblazer	Second	March (+)					

Table 6. Alamo biomass yield and weather factors regression

Months listed represent precipitation in those months, Frostdate = last spring frost

Harvest	Effect	Estimate	StdErr	p-Value
First	Intercept	128.1225	145.2472	0.4427
First	year	-0.0596	0.0729	0.4165
First	September	-0.4398	0.2339	0.0643
First	August	-0.6848	0.2085	0.0016
First	June	-0.6461	0.1527	0.0001
First	May	1.4996	0.3450	0.0000
First	Last Frost Date	0.1256	0.0376	0.0014
First	Previous October	-0.4808	0.2135	0.0275
Second	Intercept	132.0479	92.0946	0.2471
Second	year	-0.0572	0.0458	0.2158
Second	October	-0.6774	0.1217	0.0000
Second	Previous Sept-Dec	-0.3020	0.0525	0.0000
Second	March	0.3068	0.0693	0.0000
Second	July	-0.4621	0.0992	0.0000
Second	December	-0.5303	0.2061	0.0122

Table 7. Kanlow biomass yield and weather factors regression

Months listed represent precipitation in those months

Harvest	Effect	Estimate	StdErr	p-Value
First	Intercept	-69.3972	112.5098	0.5810
First	year	0.0424	0.0562	0.4533
First	March	0.2263	0.0903	0.0145
First	July	-0.4618	0.1312	0.0008
First	October	-0.3466	0.1367	0.0134
Second	Intercept	52.1569	81.5043	0.5677
Second	year	-0.0212	0.0407	0.6039
Second	December	-0.8029	0.1431	0.0000
Second	Previous October	-0.2743	0.0837	0.0016

Table 8. Cave-In-Rock biomass yield and weather factors regression

Months listed represent precipitation in those months

Harvest	Effect	Estimate	StdErr	p-Value
First	Intercept	-733.2402	66.7091	0.0016
First	year	0.3692	0.0333	0.0000
First	September	0.7754	0.0980	0.0000
First	March	0.3354	0.0536	0.0000
Second	Intercept	-322.6648	78.9519	0.0265
Second	year	0.1631	0.0395	0.0001
Second	May	0.5349	0.1542	0.0009

Table 9. Pathfiner biomass yield and weather factors regression

Months listed represent precipitation in those months				
Harvest	Effect	Estimate	StdErr	p-Value
First	Intercept	-588.6425	123.6123	0.0176
First	year	0.2996	0.0617	0.0000
First	Previous October	0.3280	0.1348	0.0173
First	January	-0.4581	0.2047	0.0281
Second	Intercept	-165.4379	58.7901	0.0671
Second	year	0.0841	0.0294	0.0055
Second	March	0.2118	0.0437	0.0000

Table 10. Blackwell biomass yield and weather factors regression

Months listed represent precipitation in those months

Harvest	Effect	Estimate	StdErr	p-Value
First	Intercept	-570.0119	66.6813	0.0034
First	year	0.2869	0.0334	0.0000
First	Previous Sept-Dec	0.0524	0.0411	0.2065
First	September	0.4428	0.1069	0.0001
First	March	0.1596	0.0544	0.0045
First	August	0.1929	0.0952	0.0464
Second	Intercept	-160.2515	59.1414	0.0732
Second	year	0.0821	0.0295	0.0068
Second	May	0.4159	0.1083	0.0003
Second	December	-0.3155	0.1034	0.0032

Table 11. Kansas Native Biomass Yield and Weather Factors Regression

Months listed represent precipitation in those months

Harvest	Effect	Estimate	StdErr	p-Value
First	Intercept	-773.3326	65.4508	0.0013
First	year	0.3905	0.0326	0.0000
First	September	0.5646	0.0925	0.0000
First	March	0.2462	0.0520	0.0000
First	January	-0.2942	0.1089	0.0085
Second	Intercept	-468.6752	61.8299	0.0048
Second	year	0.2367	0.0309	0.0000
Second	March	0.2293	0.0482	0.0000
Second	June	0.2430	0.0503	0.0000
Second	July	-0.2903	0.0700	0.0001
Second	October	-0.2442	0.0728	0.0013

Table 12. Summer biomass yield and weather factors regression

Months listed represent precipitation in those months

Harvest	Effect	Estimate	StdErr	p-Value
First	Intercept	-611.8331	79.1201	0.0045
First	year	0.3094	0.0395	0.0000
First	March	0.2321	0.0635	0.0005
First	September	0.4084	0.1163	0.0007
Second	Intercept	-289.6937	76.4404	0.0322
Second	year	0.1466	0.0382	0.0003
Second	May	0.5565	0.1493	0.0004

Table 13. Trailblazer biomass yield and weather factors regression

Months listed represent precipitation in those months

Harvest	Effect	Estimate	StdErr	p-Value
First	Intercept	-455.4750	63.6737	0.0056
First	year	0.2326	0.0318	0.0000
First	January	-0.4004	0.1054	0.0003
First	Previous October	0.1651	0.0695	0.0200
Second	Intercept	-120.5305	54.8288	0.1154
Second	year	0.0615	0.0274	0.0278
Second	March	0.1851	0.0408	0.0000

Table 14. Leaf biomass ANOVA test p-value table

Bold p-values are less than 0.05 for interactions

Source	Acetyl	Arabinan	Glucan	Xylan	Protein	Lignin	Ash	EtOH
Cultivar	0.0269	0.0096	0.0242	0.0007	0.1168	0.0048	0.0013	0.0006
Year	0.0000	0.0000	0.0000	0.0000	0.0635	0.0000	0.0000	0.0000
Cut_date	0.0000	0.0000	0.0001	0.0000	0.0000	0.2169	0.0268	0.0000
Cultivar*Year	0.5269	0.1112	0.1075	**0.0441**	0.1139	0.2106	0.9385	**0.0452**
Cultivar*Cut_date	0.3925	0.2872	0.1606	0.1069	0.1264	0.4945	**0.0015**	**0.0020**
Year*Cut_date	0.2783	0.8493	0.2782	0.7746	**0.0000**	0.1289	0.7313	0.2955

Table 15. Stem biomass ANOVA test p-value table

Bold p-values are less than 0.05 for interactions

Source	Acetyl	Arabinan	Glucan	Xylan	Protein	Lignin	Ash	EtOH
Cultivar	0.1443	0.0302	0.0002	0.0034	0.3220	0.0536	0.0241	0.0043
Year	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0002
Cut_date	0.0000	0.0000	0.0185	0.1303	0.0000	0.0000	0.0000	0.6451
Cultivar*Year	0.0918	0.3156	0.2289	0.6183	**0.0051**	**0.0499**	0.8253	0.7738
Cultivar*Cut_date	0.7291	0.5900	**0.0429**	0.3616	0.1812	**0.0387**	**0.0300**	0.6402
Year*Cut_date	**0.0001**	**0.0000**	**0.0000**	0.1307	0.2277	**0.0535**	**0.0000**	**0.0000**

Table 16. Difference among cultivars: total chemical composition p-value matrix

Bold p-values are less than 0.05

From Cultivar	Alamo	Blackwell	Cave in Rock	Kanlow	Kansas Native	Pathfinder	Summer	Trailblazer
Alamo	1.0000	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**
Blackwell	**0.0000**	1.0000	0.7990	**0.0570**	0.4690	0.8930	0.7580	**0.0230**
Cave in Rock	**0.0000**	0.7990	1.0000	**0.0040**	0.8780	0.4360	0.9300	**0.0030**
Kanlow	**0.0000**	**0.0570**	**0.0040**	1.0000	**0.0180**	**0.0880**	**0.0190**	**0.0020**
Kansas Native	**0.0000**	0.4690	0.8780	**0.0180**	1.0000	0.3710	0.7090	**0.0000**
Pathfinder	**0.0000**	0.8930	0.4360	**0.0880**	0.3710	1.0000	0.2270	**0.0780**
Summer	**0.0000**	0.7580	0.9300	**0.0190**	0.7090	0.2270	1.0000	**0.0010**
Trailblazer	**0.0000**	**0.0230**	**0.0030**	**0.0020**	**0.0000**	**0.0780**	**0.0010**	1.0000

Figure 1. Average biomass yields per cultivar per year 1989 - 2008: (tons Dry Matter acre $^{-1}$)

Average biomass yield per cultivar (1989-2008)

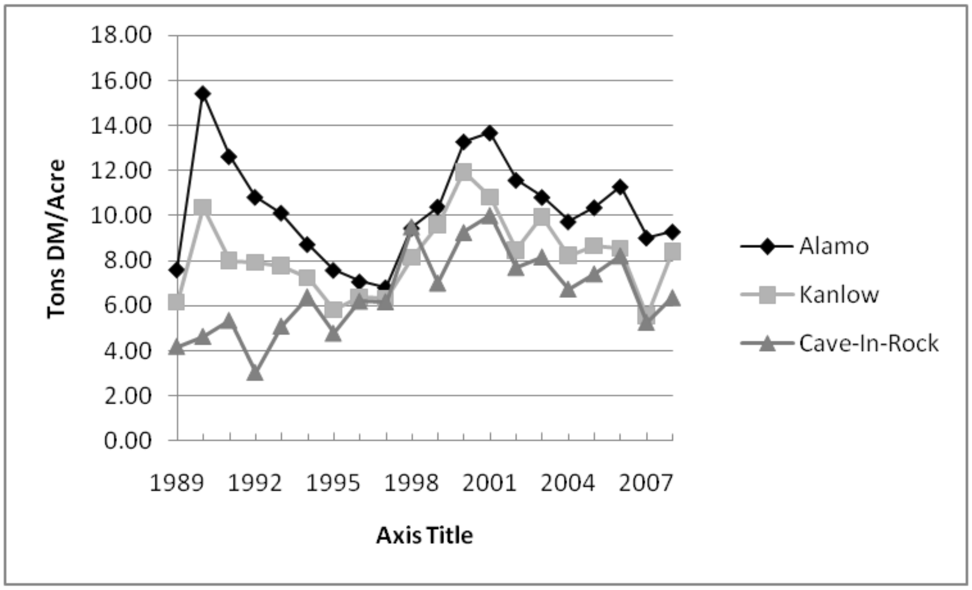


Figure 2. Ash (g kg⁻1) in eight switchgrass cultivars leaf and stem biomass

E.V. Smith Research Center: Shorter, Alabama

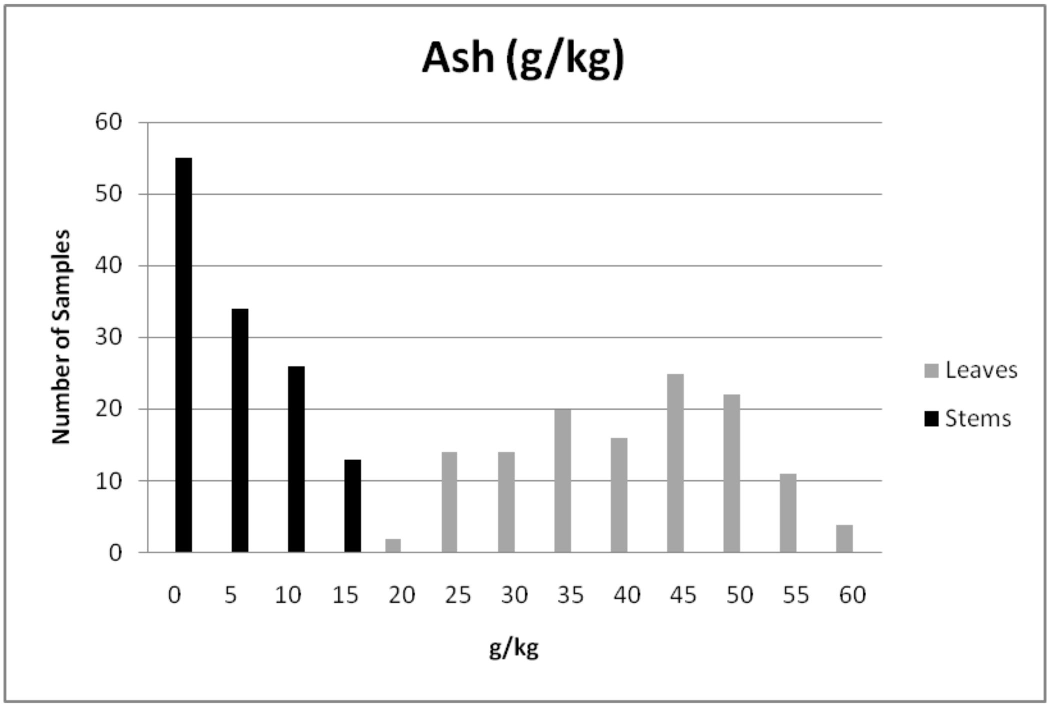


Figure 3. Protein (g kg⁻1) in eight switchgrass cultivars leaf and stem biomass

E.V. Smith Research Center: Shorter, Alabama

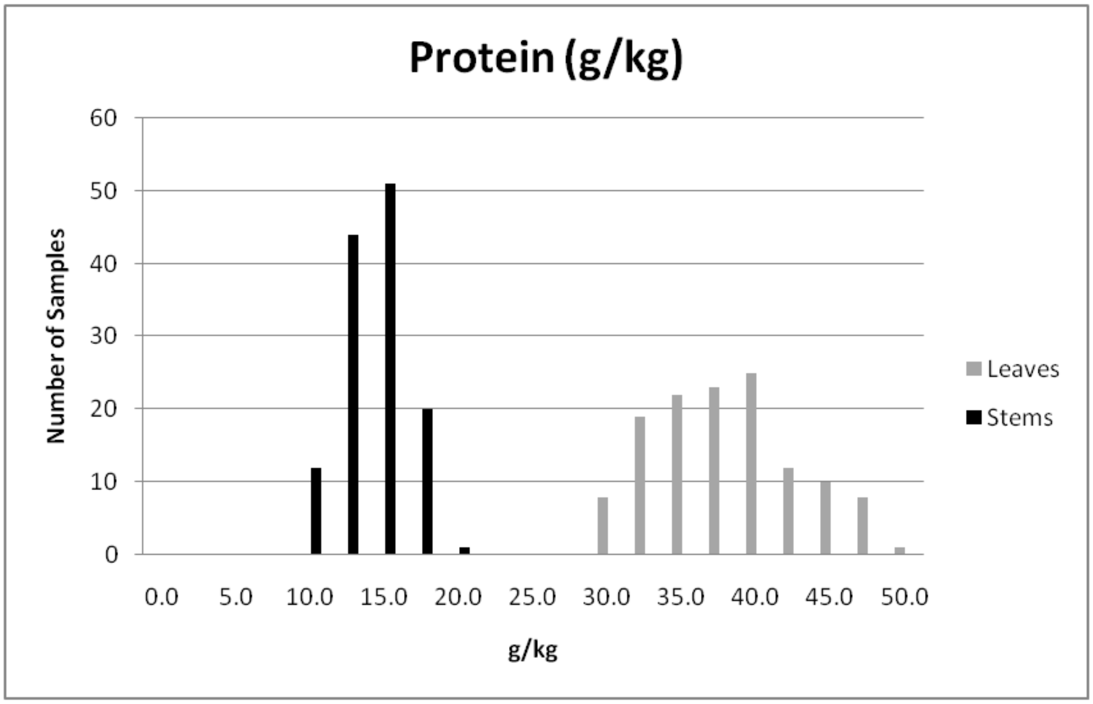


Figure 4. Glucan (g kg^{-1}) in eight switchgrass cultivars leaf and stem biomass

E.V. Smith Research Center: Shorter, Alabama

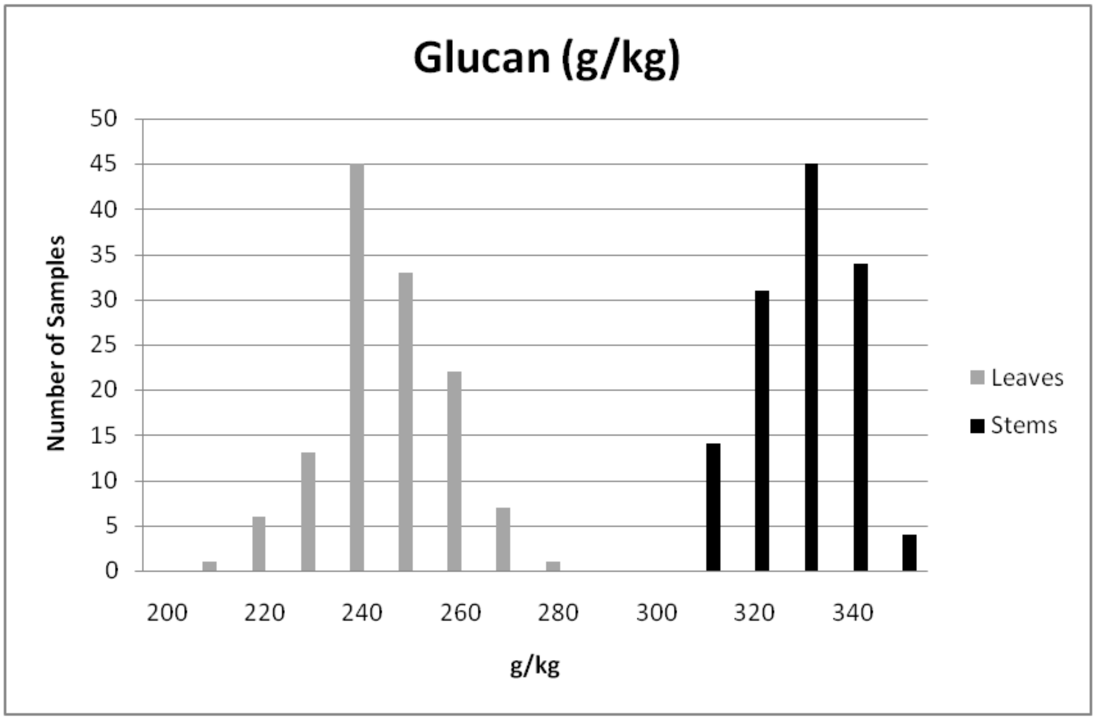


Figure 5. Lignin (g kg‾1) in eight switchgrass cultivars leaf and stem biomass

E.V. Smith Research Center: Shorter, Alabama

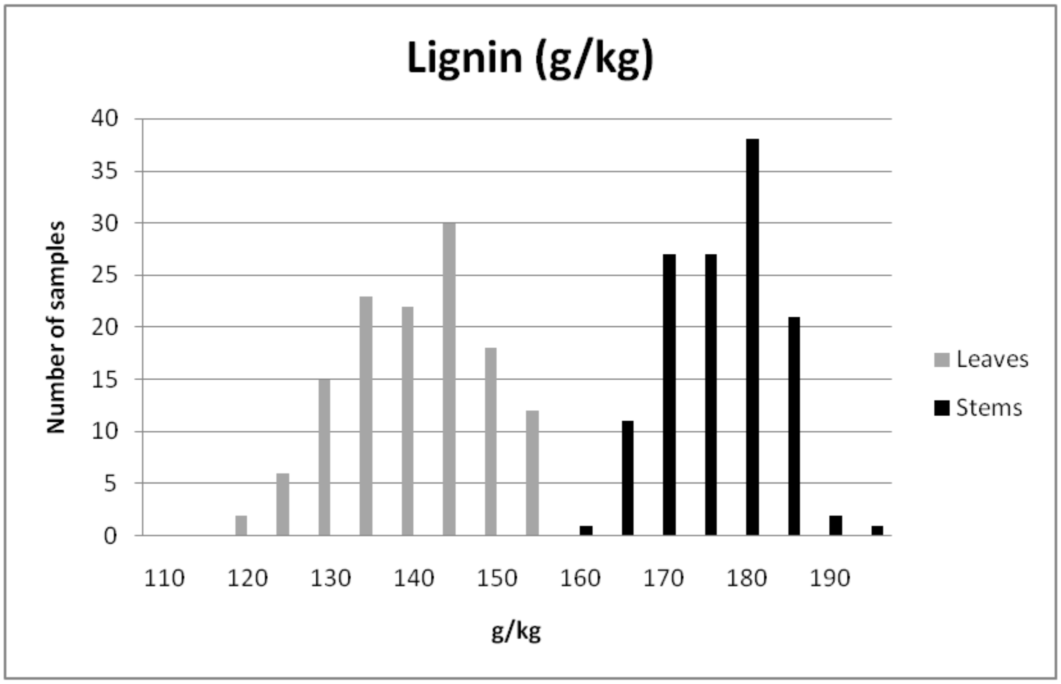


Figure 6. Acetyl (g kg⁻1) in eight switchgrass cultivars leaf and stem biomass
E.V. Smith Research Center: Shorter, Alabama

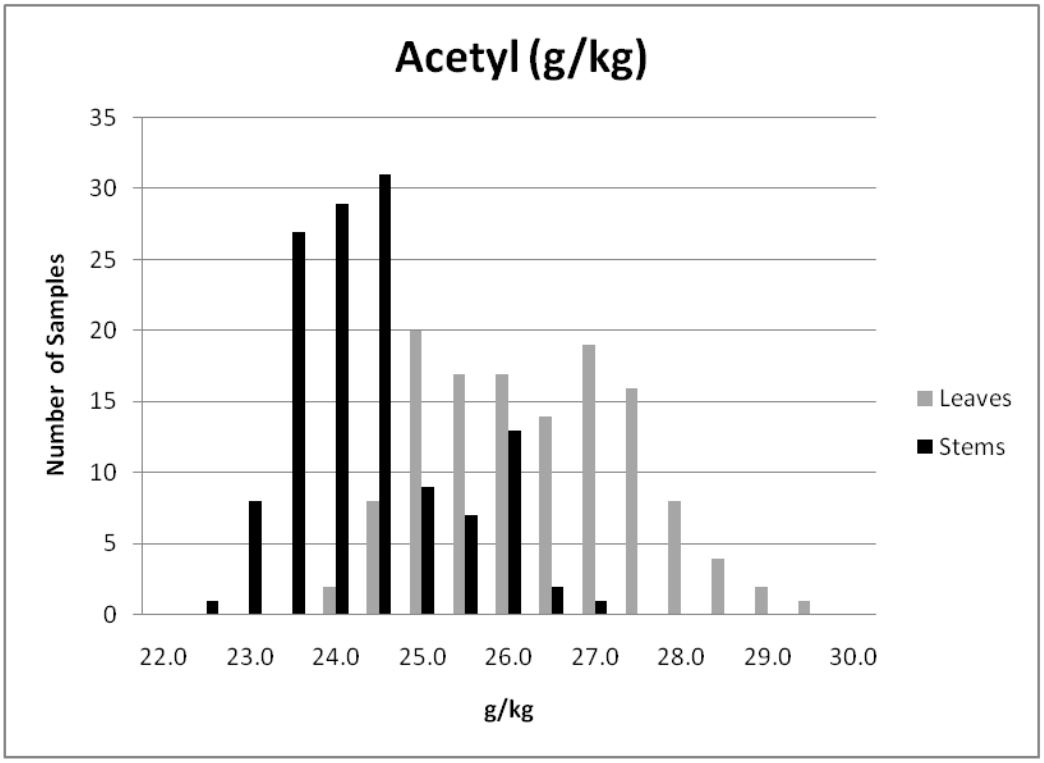


Figure 7. Arabinan (g kg⁻1) in eight switchgrass cultivars leaf and stem biomass

E.V. Smith Research Center: Shorter, Alabama

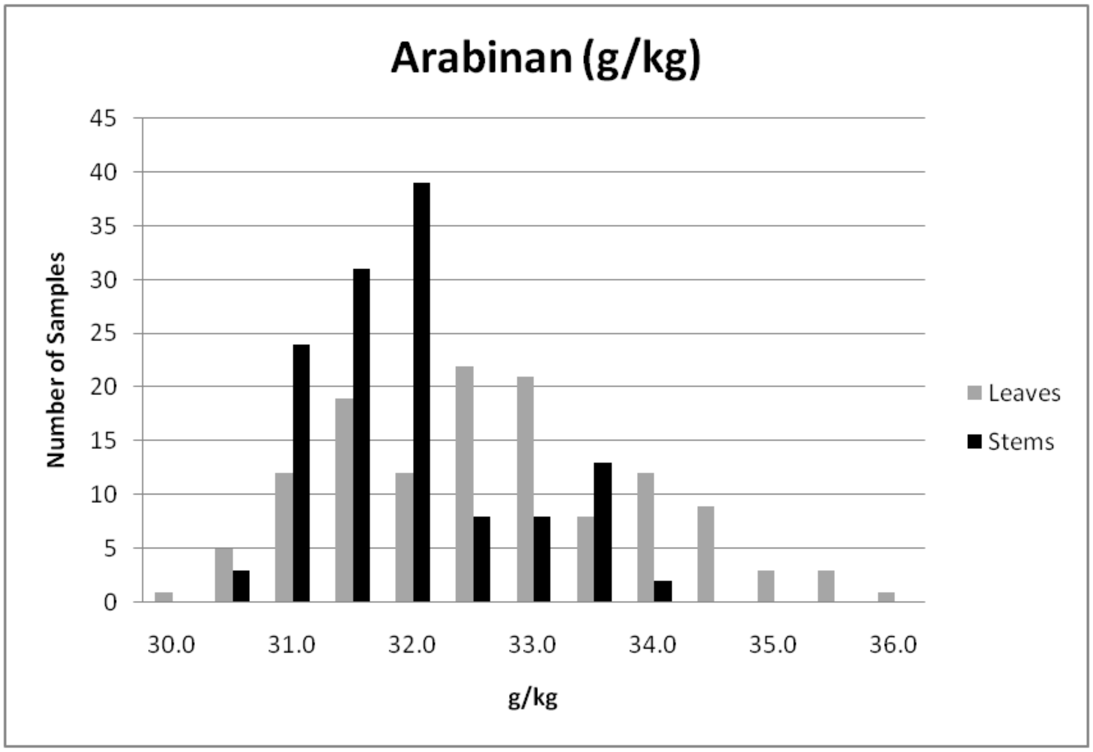


Figure 8. Xylan (g kg⁻1) in eight switchgrass cultivars leaf and stem biomass
E.V. Smith Research Center: Shorter, Alabama

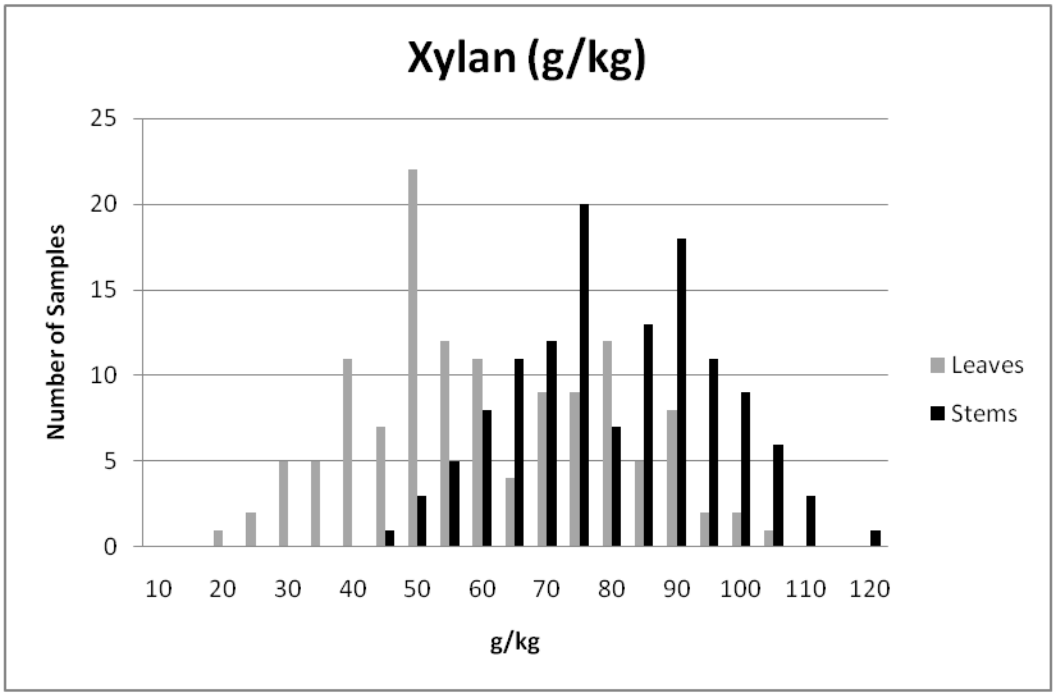
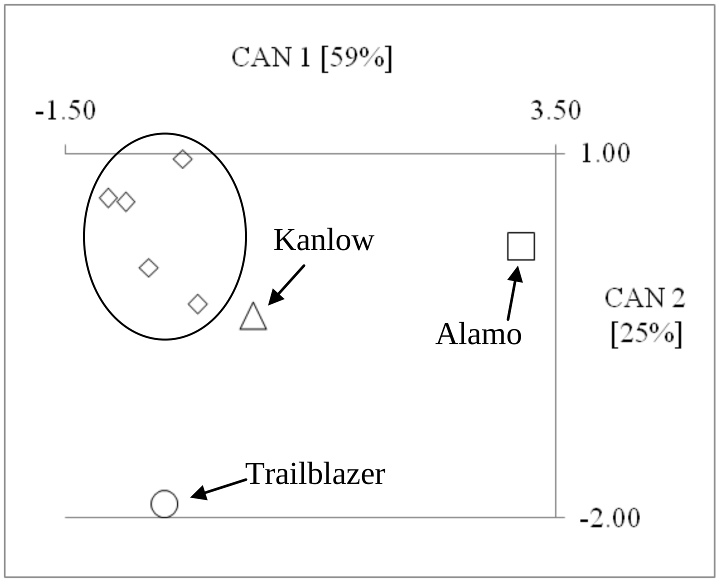


Figure 9. Canonical discriminant analysis; difference in total chemical composition among eight switchgrass cultivars
E.V. Smith Research Center: Shorter, Alabama



Variable	Can1	Can2	Part	Cut_date
S_E_Glucan	**0.95**	-0.24	Stems	Early
S_E_Xylan	**-0.64**	0.63	Stems	Early
L_L_Protein	**0.67**	0.64	Leaf	Late
L_E_EtOH	0.60	0.04	Leaf	Early
L_L_EtOH	0.31	**0.93**	Leaf	Late
L_L_Lignin	-0.04	**-0.83**	Leaf	Late
% of Variance	0.59	0.25		